Short communication

A method for discriminating between evaporation and seepage losses from open water canals

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Abstract

A method to discriminate between evaporation and seepage losses from open water canals was developed under controlled conditions and applied to standing water in two blocked-off concrete-lined canal compartments having sealed and unsealed joint treatments respectively.

Evaporation loss from both compartments averaged 11% monthly. Seepage loss ranged from 1% to 30%, on average, for sealed and unsealed compartments respectively.

Introduction

Water losses from irrigation canals have adverse economic and environmental consequences. The former include not only curtailed crop production but loss of revenue needed to operate and maintain irrigation schemes. Environmental consequences such as water-logging adjacent to earth canals, and seepage further afield are unacceptable in a country such as South Africa where both water and irrigable land are scarce.

Efficient management of a canal system depends on knowledge of losses *en route*, notably by evaporation, leakage and wetting of the concrete lining of the canals. Only on such information can a soundly-based decision to line or reline a canal be reached - a decision which has financial implications for both the supplier of water and the irrigation farmer.

Of the two main water loss components, leakage cannot easily be measured unless it is possible to get a reasonable estimate of evaporation. One option would be to measure evaporation from an evaporimeter such as an American Class A-pan or a Symon's tank, and convert it to evaporation from a canal, but it would take at least a year to derive a reasonably accurate conversion factor, during which time the calibration canal would be out of commission. Moreover, the conversion factor could contain an unknown seepage component, and thus would not be accurate and applicable to other canals.

As an alternative to using evaporimeters to gauge evaporation loss from canals, meteorological or thermodynamic models are unsatisfactory in that they require input data which are difficult to measure, and time-consuming and expensive to collect if the number of input variables is large. Moreover, calculated gross evaporation is seldom accurate for periods of less than 7 d (Gray, 1973). Uncertainties and errors inherent in empirical formulae make it difficult, if not impossible, to ascertain whether water loss from impoundments is due to evaporation or seepage, or a combination of the two.

A third alternative recommended by the author was used by Reid et al. (1987). It is an inexpensive technique for differentiating between leakage and evaporation from standing water in canals. This paper describes the technique and its practical implementation. However, it must be stressed that the main purpose of this paper is to describe the principle rather than the details of the technique. When applying the principle to specific projects, modifications may be required to suit particular circumstances.

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Materials and methods

Study area

Evaporation determination as used by Reid et al. (1987), was tested under controlled experimental conditions in a fully equipped meteorologial station at Roodeplaat Dam (25°37'S and 28°22'E) 20 km north-east of Pretoria.

Prior to its commissioning in 1987, seepage tests were run (March to November 1986) on the then newly constructed Sarel Hayward Canal (downstream of PK le Roux Dam) with a carrying capacity of 16 m^3/s which supplies irrigation water to 17 600 ha *en route* and supplements Kalkfontein Dam water to the Riet River Government Water Scheme at Jacobsdal (29°08'S and 24°46'E).

The canal passes through a region with a mean annual rainfall of 370 mm (Weather Bureau, 1972) and conforms to W Köppen's climate classification Type BShw which represents semi-arid, hot and dry conditions with mean monthly air temperatures exceeding 0°C (Weather Bureau, 1984) and with the driest season in the winter (Trewartha, 1954).

Hypothesis

It is hypothesised that water inside the evaporimeter cylinders, installed in water-tight evaporation tanks will, due to the restriction of air movement, evaporate less than the larger water surface of the evaporation tank surrounding it.

Materials

To test the hypothesis i.e. whether or not water from the larger

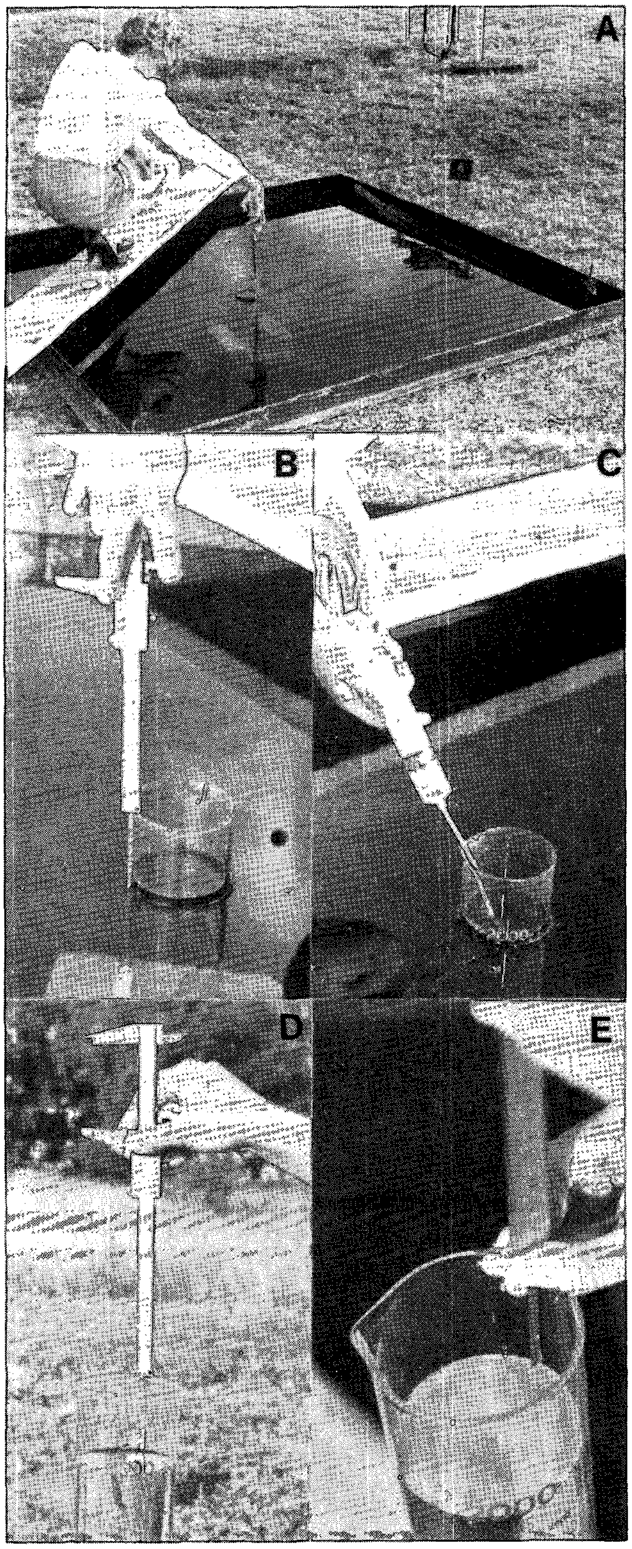

Figure 1
Experimental instrumentation and measuring technique
A) Symon's tanks were employed to determine cylinder: pan equation
B) Measuring outer-cylinder for initialising or drop in water level
C) Calibrating cylinder and Symon's tank water levels with the aid of a large syringe
D) & E) Measuring the inner-cylinder water level
NOTE: The bridge across tanks was used for weekly measurements and was removed after each operation

surface indeed evaporated more than that of the water inside the glass measuring cylinder installed inside a sunken evaporation tank, 2-ℓ glass measuring cylinders were placed in the centre of Symon's tanks (Roberts, 1960 ; Bosman, 1987), during the winter of 1987 and the summer of 1987/88 (Fig. 1A). The water levels inside the cylinders initially equalled those of the 3 tanks used.

Glass cylinders were employed to keep radiation and water temperature distribution inside and outside the cylinders as close to equilibrium as possible; glass cylinders have superior transparency (Bosman, 1983) and heat conductance qualities when compared to perspex cylinders used by Reid et al. (1987).

Seepage tests were run on two separated water-tight compartments 2 km upstream of the Scheiding Pump Station (29°55'S and 24°40'E) in the Sarel Hayward Canal . In one of the compartments the 16 mm joints between castings were sealed with "Viaseal". The sealed and unsealed canal compartments were respectively 77,84 m and 66,53 m in length with a mean water-surface cross-section of 10 m at 2 m water depth. With a 4,267 m base and trapesoidal sides ratio 1,5 :1,0 the canal has a maximum depth of 2,330 m.

Methods

Evaporation measurements

The relationship between the determined evaporation rate from the larger tank surface and that of the measuring cylinder, was achieved by weekly observations of water levels outside (Fig. 1B) and inside (Fig. 1D and 1E) the cylinders with vernier ruler calipers. The water levels inside and outside the cylinder were found to lie between 65 mm and 143 mm. The mentioned range of evaporation was the depth of water lost by evaporation before the tank and cylinder were topped up with water; therefore, this range applies to the conditions upon which calculations were based. Symon's tank evaporation for the same period was determined from slanted scale measurements (Bosman, 1987) and checked against micrometer measurement on the outside of the measuring cylinder for controlling purposes. Analysis of variance showed no statistical difference between slanted scale and evaporimeter observations of evaporation (F (d.f. = 2;4) = 5,0 < F0,05 (d.f. 2;4) = 6,94).

The evaporation calculations from both the tanks and cylinders at the Roodeplaat Dam experimental site were done for weeks without storm precipitation, thus excluding any uncontrolled splash of water into or out of the measuring cylinders.

Weekly evaporation measurements from the evaporation installation sets were reduced to mean daily evaporation.

Seepage determination

Daily evaporation measurements from cable suspended perspex evaporimeters (125 mm diameter x 300 mm) of which 50 mm protruded above the canal water level were supplemented by mechanical water-level recorders in the blocked-off canal compartments.

Tank evaporation to evaporation tank diameter ratios discussed by Gangopadhyaya et al. (1966) were employed to convert evaporation from 125 mm diameter perspex evaporimeters to that measured in 74 mm diameter 2-ℓ glass measuring cylinders installed for calibration purposes in Symon's

TABLE 1
FORMULAE EMPLOYED IN CANAL EVAPORATION AND SEEPAGE STUDY

Conversion	Regression	Degrees of freedom d.f.=(n-2)	Statistics: Correlation coefficient Expected $r_{0,01}$[**]	Calculated r	Coefficient of determination r^2	Standard error of estimate SE:± mm
1. Daily evaporation from inside (x_1) to the outside (y_1) of 74 mm diam. glass measuring cylinder: $\bar{x}_1$ = 5,3 mm/d; $\bar{y}_1$ = 4,7 mm/d	$y_1=0,3124+0,8485x_1$	13	0,6410	0,9742[**]	0,9492	0,3518
2. Correcting evaporation for cylinder diameter differences: Tank diameter (x_2) to evaporation (y_2) ratio (366 cm diam. = 100[+]	$\log y_2=1,6029+0,1592 \log x_2$	3	0,9590	0,9665[**]	0,9342	-
3. Converting Symon's Tank screen (25 mm mesh) protected (x_3) to unprotected (y_3) monthly evaporation[++]	$y_3=-5,4586+1,1722x_3$	10	0,9080	0,9982[**]	0,9964	2,3

[+] Gangopadhyaya et al. (1966)
[++] Bosman (1990)
[**] Calculated r statistically significant at the 1% level (Snedecor and Cochran, 1967)

tanks at Roodeplaat Dam (Table 1).

Results

Formulae used for converting daily evaporation measurements to actual potential evaporation are summarised in Table 1. Evaporation from the canal water surface and water losses from the canal compartments are summarised in Table 2 and Table 3 respectively. Figure 1 illustrates the technique used to manage the experiment and Fig. 2 explains the principle of measurement discussed.

Discussion

Contrary to the set hypothesis, experimental results confirmed that evaporation inside ($\bar{x}$ = 5,3 mm/d) the measuring cylinder evaporimeter exceeded that measured on the outside ($\bar{y}$ = 4,7 mm/d) in the Symon's Tank. The conversion of inside (x_1) evaporation to that on the outside (y_1), can be effected with 95% statistical confidence (Table 1).

No statistically significant difference existed between mean monthly evaporation in unsealed (165 mm) and sealed (162 mm) canal compartments or that of the Symon's tank (171 mm) (t (d.f.16) < 1 < t 0,05 (d.f.16) = 2,120) (Table 2).

Table 3 illustrates the importance of accurate evaporation measurements in canal seepage studies. Not having had the inner-outer evaporimeter conversion formulae available, negative results were experienced by Reid et al. (1987) in the sealed canal compartment seepage. This, however, was changed

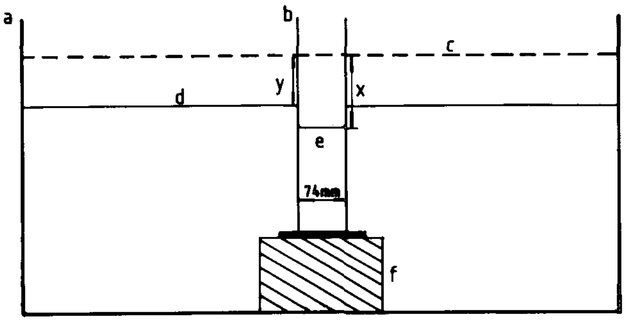

Figure 2
Estimating evaporation and seepage

a = *Evaporation tank*
b = *Glass measuring cylinder*
c = *Original water level in tank and cylinder*
d = *Water level in tank after n = number of days*
e = *Water level in measuring cylinder after n*
= *number of days*
f = *Pedestal for measuring cylinder*
x = $\frac{x}{n}$ = *mm/d corresponding to x_1 in Table 1*
y = *mm/d ± (Table 1) estimated water loss: Evaporation without or with seepage included*
y<x = *Only evaporation, no seepage*
y>x = *Evaporation including seepage*
Seepage = *Water loss in excess of estimated evaporation (y_1; Table 1)*

TABLE 2
EVAPORATION (mm) FROM IRRIGATION CANAL AND SYMON'S TANK

Month 1986	Evaporation (mm)				Symon's tank[*]
	Canal				
	Unsealed		Sealed		
	Inside[**]	Outside[+]	Inside[**]	Outside[+]	
March	247	213	247	213	250
April	185	158	185	158	173
May	151	142	143	128	137
June	118	106	111	99	90
July	112	106	112	100	96
August	147	128	147	131	119
September	190	166	190	166	178
October	249	214	249	214	221
November	297	252	297	252	272
TOTAL	1 696	1 485	1 681	1 461	1 536
MEAN	188	165	187	162	171

[*] PK le Roux Dam: 29° 59,25'S; 24° 44,0'E; Hydrology Sta. no. D3EO3 (Dept. of Water Affairs, 1990); Corrected for 25 mm mesh protective screen (Table 1).

[**] Evaporation measured inside perspex evaporimeter suspended into water in canal compartments.

[+] Evaporation in perspex evaporimeter corrected for canal evaporation i.e. regression equation as well as reduced evaporative surface influence of glass evaporimeter.

TABLE 3
EVAPORATION AND SEEPAGE LOSSES (m^3) FROM IRRIGATION CANAL

Month 1986	Canal									
	Unsealed					Sealed				
	Evaporation(E)		Seepage(S)		Mean daily volume	Evaporation(E)		Seepage(S)		Mean daily volume
	E_o	E_c	S_o	S_c	V_1	E_o	E_c	S_o	S_c	V_2
March	149	128	528	571	914	177	153	-20	5	1 125
April	110	96	391	405	871	128	112	-14	3	1 032
May	35	30	135	140	877	83	74	-1	8	1 003
June	69	62	226	233	843	78	72	4	13	1 075
July	66	61	240	244	860	79	72	5	13	1 080
August	87	77	182	192	871	103	93	-10	1	1 079
September	111	96	183	198	851	114	117	-15	2	1 070
October	134	116	224	243	824	163	141	11	34	1 069
November	176	150	86	112	851	209	177	-20	12	1 068
TOTAL	937	816	2 195	2 338	-	1 134	1 009	-60	90	-
MEAN	104	91	244	260	862	126	112	-7	10	1 066
Mean monthly canal loss (%)	-	11	-	30	-	-	11	-	1	-

E_o = Uncorrected canal evaporation
E_c = Corrected canal evaporation
S_o = Uncorrected seepage from canal
S_c = Corrected seepage from canal
V_1 = Mean daily impounded volume for canal with unsealed joints
V_2 = Mean daily impounded volume for canal with sealed joints

to positive seepage after the required correcting formulae were applied. The unsealed canal's evaporation influence was cancelled by its high seepage loss. An average 11% per month of the impounded volume was lost due to evaporation during the 9 months of study. During the same period an average 30% was lost monthly through seepage in the unsealed compartment and only a negligible 1% in the sealed compartment.

From Fig. 1 it is clear that measurements can be effected with little trouble.

As for the principle of measurement, by inspection of the water level differences it is possible to observe water loss due to evaporation or seepage (Fig. 2).

Conclusions

Because the water on average evaporated more from inside the measuring cylinder evaporimeter than from the outside, the hypothesis is rejected.

In practice the method of accurate evaporation measurement in seepage determinations in canals proved to be critical when quantification was required.

Evaporation from canals cannot be disregarded in water loss calculations because large volumes of water are lost in this way, which, when added to seepage losses, could have significant consequences in canal management and water distribution.

The evaporation principle which was described can also be applied to reservoirs, fish ponds, swimming pools and plastic-lined ponds to test their water-holding capabilities.

Acknowledgements

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