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Calibration and use of a combination atmometer to estimate evapotranspiration and monitor soil moisture storage on farmland catchments in Western Australia

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Summary

Antecedent soil moisture affects runoff amount and peak flow rates (Australian Rainfall and Runoff, 1987; Townley and Bligh, 1989). A simple combination of shaded and unshaded atmometers was suggested to be capable of estimating cumulative areal evapotranspiration (Anon., 1973). Soil moisture storage was then to be estimated following the typical summer drought in the Mediterranean climate of South-Western Australia.

The readily-operated combination method of estimating evapotranspiration was applied using simple atmometers, calibrated against absolute evapotranspiration. While 76.6 per cent of the variance of estimates was accounted for by the regression in the first season under wheat, no significant results were achieved in a further four seasons. Combined data for two seasons under legume pastures enabled 30.1 per cent of the variance of estimates to be accounted for. Questions are raised concerning the validity of an assumed linear relationship between the transfer coefficients applicable to the path water vapour must take in going from the saturated surface of the atmometer to the ambient air in the vicinity, and from the vegetated surface to the ambient air.

Soil moisture storage was then estimated from a water balance on 11 farmland experimental catchments. The estimated soil moisture status revealed differences in typical soil moisture storages from the “break of season” to runoff initiation in the range of 25 to 70 mm.

The calibration of the combination atmometer against available lysimeter data at Merredin, Western Australia over seven growing seasons is described in Part I. Evapotranspiration was then estimated at the 11 farmland experimental catchments, and typical soil moisture storage at runoff initiation calculated in Part II.

It is concluded that estimating evaporation using the combination atmometer method is unreliable, negating its potential benefits for runoff prediction purposes.

Part I

Calibration of a Combination Atmometer for Estimating Evapotranspiration from Wheat Crops and Annual Sub.Clover Pastures

1.0 Introduction

Measurements of evaporation from an open water surface, such as that in a Class A evaporimeter pan, can give a reasonable estimate of evapotranspiration from a well-watered surface (McIlroy and Angus 1964). However estimates of actual evapotranspiration from a drying soil are required for use in estimating antecedent soil moisture using a water balance approach, for runoff prediction purposes.

Formulae of the combination type have proven an acceptably accurate means of estimating actual evapotranspiration from agricultural surfaces (McIlroy, 1966). They require measurements of net radiation, temperature, humidity and wind speed when soil water is not limiting evapotranspiration. An additional measurement of soil moisture status is necessary in order to estimate evapotranspiration when soil moisture is limiting evapotranspiration. Therefore estimating evapotranspiration using the combination approach requires complex equipment. Net radiometers, in particular, require constant maintenance, and are not usually included in meteorological stations.

Advantages of the combination atmometer are that it can be used to estimate moisture— limiting evapotranspiration (Anon. 1973), needs no power supply, and is simple to construct and easy to operate. A disadvantage is that it requires calibration against a direct measure of evapotranspiration, such as that obtained using a lysimeter. The aim of the work described in this paper is to develop and calibrate a combination atmometer, which is capable of operating unattended. Absolute evapotranspiration data were available from two lysimeters operated by the Agronomy Department of the University of Western Australia at Merredin Research Station (31'° 29°S, 118° 14'°E) approximately 250 km east of Perth. Average annual rainfall at the site is 329 mm, approximately 70% of which characteristically occurs during the months of May to October, inclusive.

2.0 Theory of the combination atmometer

Actual evaporation from a crop, E_c, can be expressed in terms of a combination formula as:

$$E_c = \frac{s}{s + {}_c} \frac{R_c}{L} - \frac{G_c}{L} - \frac{h_c}{L} (D_1 - D_2) \qquad \text{-(1)}$$

$\frac{S}{s +}$ Where is a slowly varying function of temperature at the mid—point of the height interval over which the wet—bulb depression measurements are made (s is the slope of the specific humidity curve versus temperature and is a constant C_p/L where C_p is the specific heat of air at constant pressure.

L is the latent heat of vaporization of water;

R is the incident net radiation flux;

G is the ground heat flux;

h is a transfer coefficient applicable to the height interval over which the wet—bulb depression measurements are made;

D_1 is the wet—bulb depression at the lower measuring height;

D_2 is the wet—bulb depression at the upper measuring height.

Summing (1) over the day:

$$E_c = \frac{s}{s + {}_c} \frac{R_c}{L} - \frac{s}{s + {}_c} \frac{G_c}{L} - \frac{h_c}{L} (D_1 - D_2) \qquad \text{-(1a)}$$

$$= \frac{s}{s + {}_c} \frac{R_c}{L} - \frac{h_c}{L} (D_1 - D_2) \qquad \text{-(1b)}$$

The following theory due to A.C. Dilley (unpublished) relates to three atmometers, one unshaded placed at the lower measuring height (U1), one shaded placed at the lower measuring height (S1) and one shaded placed at the upper measuring height (S2). Evaporation from the three atmometers may be expressed as:

$$E_{U1} = \frac{s}{s+} \; U1 \; \frac{R_{U1}}{L} - \frac{G^*_{U1}}{L} + \frac{h^*_{U1}}{L} \quad D1 \qquad -(2)$$

$$E_{U1} = \frac{S}{s+} \; S1 \; \frac{R_{S1}}{L} - \frac{G^*_{S1}}{L} + \frac{h^*_{S1}}{L} \quad D1 \qquad -(3)$$

$$E_{U1} = \frac{s}{s+} \; S2 \; \frac{R_{S2}}{L} - \frac{G^*_{S2}}{L} + \frac{h^*_{S2}}{L} \quad D2 \qquad -(3)$$

where G^* is the sum of the energy flux out of the sides and base of the atmometer and the change in energy stored within the atmometer and

h^* is a transfer coefficient applicable to the path water vapour must take in going from the saturated surface of the atmometer to the ambient air in the vicinity of the atmometer.

If the shading device is uniform and efficient at shading then,

$$R_{S1} = R_{S2} = pR_{U1} \qquad -(5)$$

Where p is a small fraction.

If the atmometers have identical geometeries,

$$h^*_{S1} = h^*_{S2} = h^*_{U1} = h^*_{A} \qquad -(6)$$

where h^*A is a transfer coefficient applicable to all 3 atmometers.

Subtracting Eq. 3 from Eq. 2 eliminates the second (aerodynamic) term.

$$E_{U1} - E_{S1} = \frac{s}{s+} \; U1 \; \frac{R_{U1}}{L} - \frac{G^*_{U1}}{L}$$

$$- S_{SU} = \frac{s}{s+} \; U1 \; \frac{pR_{U1}}{L} - \frac{G^*_{S1}}{L} \qquad -(7)$$

where,

$$S_{SU} = \frac{s}{s +} \quad S1 \quad \frac{s}{s +} \quad U1 \qquad \text{-(7a)}$$

Grouping terms,

$$E_{U1} - E_{S1} = \frac{s}{s +} \quad U1 \quad \frac{R_{U1}}{L} \quad (1 - S_{SU}P)$$

$$- \frac{s}{s +} \quad U1 \quad \frac{G^*_{U1}}{L} - S_{SU} \quad \frac{G^*SI}{L} \qquad \text{-(8)}$$

It may be supposed that the net radiation incident on the unshaded atmometer will be approximately proportional to the net radiation incident on the crop (R_c. Assuming an exact relationship,

$$R_{U1} = a R_c \qquad \text{-(8a)}$$

and substituting for R_{U1} in Eq. 8 we get

$$E_{U1} - E_{S1} = aS_{cu}(1- S_{SU}p) \quad \frac{s}{s +_{c}} \quad \frac{R_c}{L}$$

$$- \frac{s}{s +} \quad U1 \quad \frac{G^*_{U1}}{L} - S_{SU} \quad \frac{G_{S1}}{L} \qquad \text{-(9)}$$

where,

$$S_{cu} = \frac{s}{s +_{c}} \quad \frac{s}{s +} \quad U1 \qquad \text{-(9a)}$$

Transposing,.

$$\frac{S}{S +_{c}} \quad \frac{R_c}{L} = \frac{E_{U1} - E_{S1}}{aS_{cu}(1 - S_{su}P)} + \frac{\frac{s}{s +_{U1}} \frac{G^*_{U1}}{L} - S_{SU} \frac{G^*_{S1}}{L}}{aS_{cu}(1 - S_{SU}p)}$$

Now if the atmometers are well insulated and if the evaporation loss is measured over an integral number of days, G^*_{U1} and G^*_{S1} will be relatively small, and the difference between them will also be relatively small. Moreover, the difference in the temperatures at which S/S+ should be calculated for the three surfaces considered here will be small, and since S/S+ is a slowly varying function of temperature, S_{CU} and S_{SU} will be approximately constant. Thus, Eq. 10, suggests an approximately linear relationship between the first term of Eq. 1b and the difference in evaporation between the shaded and unshaded atmometers at the lower measuring height, i.e.

$$\frac{s}{s + {}_{c}} \quad \frac{R_c}{L} = A \quad (E_{U1} - E_{S1}) + B \qquad \text{-(11)}$$

$$= A \quad (E_{U1} - E_{S1}) + B \qquad \text{-(11a)}$$

Subtracting Eq. 4 from Eq. 3,

$$E_{S1} - E_{S2} = \frac{h^*_A}{L} \quad (D_1 - D_2) - \frac{s}{s + \quad {}_{S1}} \quad \frac{G^*_{S1}}{L} \quad - S_{21} \quad \frac{G^*_{S2}}{L} \qquad \text{-(12)}$$

where,

$$S_{21} = \quad \frac{s}{s + {}_{S2}} \quad \frac{s}{s + {}_{S1}} \qquad \text{-(12a)}$$

It may be supposed that the transfer coefficient for the atmometers will be approximately proportional to the transfer coefficient for the crop since both are strongly influenced by the same turbulent air stream. Assuming an exact relationship

$$h^*A = mh_c \qquad \text{-(12b)}$$

and substituting for h^*_A in Eq. 12 we get

$$E_{S1} - E_{S2} = m \frac{h^*_c}{L} \quad (D_1 - D_2) - \frac{s}{s + {}_{S1}} \quad \frac{G^*_{S1}}{L} \quad - S_{21} \quad \frac{G^*_{S2}}{L} \quad (13) \qquad -$$

Transposing,

$$\frac{h_c}{L} \quad (D_1 - D_2) = \frac{E_{S1} - E_{S2}}{m} + \frac{1}{m} \quad \frac{s}{s + {}_{S1}} \quad \frac{G^*_{S1}}{L} \quad - S_{21} \frac{G^*_{S2}}{L} \qquad \text{-(14)}$$

For similar reasons to those outlined above the second term will be relatively small. Thus Eq. 14 suggests an approximately linear relationship between the second term of Eq. 1b and the difference in evaporation between the lower and upper shaded atmometers, i.e.

$$\frac{h_c}{L}(D_1 - D_2) = M \quad (E_{S1} - E_{S2}) \quad + \quad N \qquad \text{-(15)}$$

$$= M \quad (E_{S1} - E_{S2}) \quad + \quad N \qquad \text{-(15a)}$$

Subtracting Eq. 15a from Eq. 11a

$$E_c = \frac{s}{S + {}_c} \quad \frac{R_c}{L} - \frac{h_c}{L} \quad (D_1 - D_2)$$

$$= A \quad (E_{U1} - E_{S1}) - M \quad (E_{S1} - E_{S2}) + B - N \qquad \text{-(16)}$$

$$E_c = A \quad E_{U1} - (M + A) \quad E_{S1} + M \quad E_{S2} + B - N \qquad \text{-(16a)}$$

In order to calibrate the Combination Atmometer measurements of E_c,

$\frac{s}{s +} \quad \frac{R_c}{L}$, E_{U1} , E_{S1} and E_{S2} are required.

The constants A and B may be determined by regressing $\frac{s}{s +} \quad \frac{R_c}{L}$ against E_{U1} - E_{S1}.

The constants M and N likewise may be determined by regressing $\frac{h_c}{L}(D_1 - D_2) = \frac{s}{s + {}_c} \quad \frac{R_c}{L} - E_C$ (from Eq. 1) against $E_{S1} - E_{S2}$. When calibrated E_c may be calculated from E_{U1}, E_{S1} and E_{S2} using Eq. 16a.

3.0 Materials and methods

A combination atmometer was required to be capable of operating unattended for periods during which up to 100 mm of evapotranspiration may occur. A simple wick evaporating surface was selected after considering alternative methods such as a Mariotte-tube or float valve arrangements for maintaining a free water surface at a constant elevation. These were considered less suitable for unattended operations because of a greater likelihood of blockages, and therefore, failure in operation.

Two 82 mm wide kerosene-fridge wicks of robust cotton fabric were selected for use in each atmometer. One end of each wick was suspended in distilled water, with the other end rising through a slot in a perspex sheet, over which both were turned into the horizontal plane though in opposing directions. These were cut to form a circular evaporating surface, to minimize any effect of wind direction on evaporation from the wicks.

An annular plastic cap of 80 mm internal diameter maintained the wicks in position over a 300 mm deep cylindrical reservoir. Transport of water up the wicks was adequate to ensure a saturated evaporating surface. Evaporation rates when the water level was 200 mm below the evaporating surface were observed to be approximately 98% of that when the water was 2 mm below.

Materials capable of withstanding direct sunlight for long periods were required for all external surfaces. Ultra-violet stabilized fibreglass was formed around plastic pipe fittings for all exposed plastic parts. Shading was provided where required by inverted minor—surfaced watchglasses of 150 mm diameter over each atmometer. Its perimeter was maintained at the same elevation as the evaporating surfaces by means of stainless steel spring—clips mounted on the atmometer housing. The outer housing on which the watchglass is mounted, can be lifted off the base in order to read the depth of water in the transparent perspex reservoir on an attached scale rule, graduated in millimetres. An identical geometry was maintained around unshaded atmometers by substituting transparent watchglasses.

Each atmometer was levelled and bolted to a galvanized pipe end-cap, which was welded to a 0.75 m length of galvanized pipe to minimize wind turbulence effects from a central mast support. The upper atmometer was mounted 1.0 m above the two lower atmometers on each instrument. The three atmometers can be adjusted to a pre-determined height as a unit, by raising or lowering their concentric mounting on a central mast set in an auger hole in the ground.

A 0.1 g mixture of Merthiolate (Thiomersol NF) per litre of distilled water prevented fungal growth on the wick surfaces. In order to minimize drying and crystal formation in hot weather, wicks were treated with petroleum ether and boiled in distilled water to remove organic fats. Wicks, which were thoroughly washed at intervals of from two to five weeks during a sixteen-week period, gave similar evaporation rates as unwashed wicks.

The atmometers were placed in position as close to the opening rains of the growing season as possible.

The six atmometers were read at least twice weekly, usually on Tuesday and Fridays. Wheat crops (cv. Gamenya) were grown on both soil types during the 1978, 1979, 1980, 1983 and 1984 growing seasons. Subterranean clover (cv. Nungarin) was sown on the clayey sand and barrel medic (cv. Cyprus) on the sandy clay loam pasture in 1981, and regenerated in the i982 growing season. The height of the lower atmometers was maintained at 0.5 m above the evaporating surface, taken as 0.85 times the maximum height of the vegetation.

Evaporation from similar vegetative surfaces as the surrounding paddocks was measured in 1.22 m diameter, 1.22 deep weighing lysimeters for each soil. Net radiation was measured over each surface in the i980 growing season, and over the clayey sand soil in all years. It for the sandy clay loam by correlation for 1979—1983, and measured in 1984. Wet-bulb temperatures were also measured in order to calculate “s”. The constant ( ) was taken as 0.8 for use in calculating

The constants A, B, M and N in Equations 14a and 15a were determined first by separate regressions, and by multiple regression in Equation 16.

Data later than a date in September were discarded after calculation for all data, in order to maximize the percentage of variance accounted for.

Correlations were obtained between evaporation from a Class A pan and the unshaded lower atmometer. Correlations were also opportunistically obtained between rainfall recorded on the lysimeters and in standard 208 mm diameter raingauges set at 0.75 m and 0.30 m above, and at ground level.

4.0 Results of calibrations

Percentages of variance accounted for in separate regressions of Equations ha and 15a are shown on Table 1.

4.1 Calibration for wheat

Six combination atmometers were grouped 15 m apart in a semi-circle around the light land lysimeter which is situated on a yellowish-grey Norpa clayey sand soil (Bettenay and Hingston; 1961, 1964) from June 16, until mid-November 1978. The wheat crop was sown on June 12. Evapotranspiration calculated using e.g. 16a was not significantly different ($p < 0.05$) for three of these sites up until October 6, beyond which regressions to determine M and N of 15(a) were not significant. Four data points were lost at the fourth site because of drying of the extremities of some wicks during September, and M and N could not be significantly determined.

The atmometer elevations were altered on the remaining two instruments, in order to test for sensitivity to variations from a standard setting. At the fifth site the upper atmometer was set only *0.5* m above the lower two, compared with 1.0 m for all other sites and seasons. The regression of M and N were insignificant at this setting. At the sixth site, all atmometers were set 0.1 m lower from mid-August. Calculated evapotranspiration at this site was not significantly different from those at the first three sites. However, when calculated evapotranspiration was regressed against lysimeter evapotranspiration, the slope and intercept were significantly different (p 0.05) from 1 and 0, respectively.

Three combination atmometers were placed 15 m away from each of the clayey sand and the reddish-brown Merredin sandy clay loam (Bettenay and Hingston; 1961, 1964) lysimeter sites from the break of the season in each of the years 1979, 1980, 1983 and 1984.

No significant determination of the constants M and N of 15a was obtained in the 1979, 1980 or 1983 growing seasons, with the exception of one sandy—clay loam site which accounted for 11.2per cent of the variance in 1979. Variance accounted for in the 1984 season ranged from 0.3 to 1.1 per cent on the sandy clay loam, with clayey sand lysimeter data unavailable.

Percentages of variance accounted for in multiple regressions are shown on Table 2.

Regressing combined data for Sites 1 to 3 for 1978 alone accounted for 76.6 per cent of the variance. Values of coefficients were

A = 0.886 (s.e. 0.134), $p = 0.001$;

M = 0.406 (s.e. 0.150), $p = 0.01$;

B-N = 1.141 (s.e. 0.614), N.S.

When data for all four years of wheat were combined, each of sites 1, 2 and 3 explained less than 9% of the variance.

Monthly rainfall at Merredin Research Station (CBM, 1984) are shown on Table 3 for April to October, 1978-84, together with average evaporation from a Class A pan (Luke *et al.,* 1987).

4.2 Calibration for sub.clover-based pastures

Statistically significant co-efficients in equation 16a were obtained at two of the three sites on each soil type under pastures in 1981, with from 31.0 to 60.9 per cent of the variance accounted for. Only the clayey sand soil returned statistically insignificant co-efficients in 1982, with 1.8 to 9.9 per cent of variance accounted for. Mass loss rather than depth of water evaporated was weighed to the nearest 0.01 g from July 16 to September 24, 1982, in order to test for depth-reading errors; significant co-efficients were not obtained from this sub-set of data at any site. Combined data for both 1981 and 1982 are shown on Table 4.

Table 1. Percentages of variance accounted for in separate regressions

Site	Cover	Wheat 1978		Wheat 1979		Wheat 1980	Pasture 1981	
		June 30-Nov 15	July 5-Oct 23	May 25-Oct 23	May 25-Sept 28	May 8-Oct 7	May 26-Sept 29	May 26-Sept 11
1	11a	86.9	89.2	44.8	31.7	71.9	49.4	38.6
1	15a	4.3	62.0	4.0	-	6.2	-	-
2	11a	87.5	82.2	36.5	13.3	661	57.5	50.2
2	15a	-	55.2	2.2	-	-	-	31.0
3	11a	89.5	88.1	54.5	23.6	32.3	16.6	19.2
3	15a	-	56.7	11.4	-	24.1	-	31.3
4	11a	83.2	86.2	30.5	29.7	24.0	31.9	32.7
4	15a	-	9.0	-	-	-	-	60.9
5	11a	59.5	54.9	65.4	35.5	23.9	21.7	15.7
5	15a	4.7	2.5	41.6	-	-	-	-
6	11a	65.9	64.8	7.0	26.8	8.6	40.4	23.5
6	15a	-	64.6	33.6	11.2	0.1	-	22.3
No. of points		27	18	43	36	40	34	29
1	11a	7.4	86.1	43.0	46.4	61.3	65.2	
1	15a	1.8	-	2.44	5.6	-	-	
2	11a	5.9	80.9	2.7	-	73.9	75.0	
2	15a	9.4	-	-	-	-	-	
3	11a	2.0	87.5	-	-	72.9	63.9	
3	15a	9.9	-	-	-	-	-	
4	11a	9.4	84.0	2.0	-	75.5	75.5	
4	15a	-	-	-	-	0.7	0.7	
5	11a	4.2	81.7	2.4	-	56.3	70.6	
5	15a	-	-	-	-	0.3	0.3	
6	11a	3.8	79.1	5.2	-	61.1	51.5	
6	15a	-	-	-	-	1.1	1.1	
No. of points		54	28	21	19	34	30	

Table 2. Percentages of variance accounted for and significance of multiple regressions of Lysimeter Evaporation = Constant + $A(E_{U1}-E_{S1}) - M(E_{S1}-E_{S2})$

	Site	Crop 1978	Pasture 1981	Pasture 1982	Crop 1983	Crop 1984
Clayey-sand	1	75.9 *** (17) 77.7	2.6 N.S. (23) 35.2	36.0 * (24) 36.1	4.8 N.S. (13) 26.0	
Clayey-sand	2	*** (17) 80.9	* (24) 37.6	* (25) 39.5	N.S. (16) 2.4	
Clayey-sand	3	(17)	* (24) 95.2	(25) 23.8	N.S. (15) -	28.4
Sandy clay-loam	4		* (5) 11.7	* (27) 23.2	N.S. (15) 20.0	* (30) 27.2
Sandy clay-loam	5		N.S. (16) 18.3	* (27) 35.6	N.S. (15) -	* (30) 12.2
Sandy clay-loam	6		N.S. (16)	* (23)	N.S. (15)	N.S. (30)

Figures in brackets are the number of data points

*** significant at p = 0.001;

** significant at p = 0.01;

* significant at p = 0.05.

The co-efficients A and M were not significantly different, though the constant (B-N) was significantly different between soil types at the p = 0.05 level, when the data were combined for the three sites on each soil type for both seasons, with 31.1 per cent of the variance accounted for. Combining both soil types for both seasons accounted for 30.1 per cent of the variance, with values of:

A = 0.4210 (s.e. 0.0858), p = 0.001;

M = 0.4931 (s.e. 0.0935), p = 0.001;

B-N = 1.9920, (s.e. 0.282), p = 0.001.

Table 3. Monthly rainfall at Merredin Research Station, and average Class A pan evaporation

Year	Month						
	April (mm)	**May (mm)**	**June (mm)**	**July (mm)**	**Aug (mm)**	**Sept (mm)**	**May-Sept (mm)**
1978	37.6	17.8	29.8	76.7	13.3	27.7	**165.3**
1979	21.4	38.6	46.4	22.1	62.4	8.4	**177.9**
1980	25.2	32.1	29.6	24.0	24.0	1.1	**105.8**
1981	18.8	73.6	44.5	39.0	36.9	8.9	**202.9**
1982	0.3	17.8	49.5	16.5	56.3	38.8	**178.9**
1983	2.2	5.4	55.1	45.5	36.0	38.2	**180.2**
1984	53.1	91.7	21.2	35.8	30.4	21.4	**200.5**
Av.evap.	184	110	70	74	90	129	473

Table 4. Significance levels and percentages of the variance accounted for in multiple regressions for each site for both pasture years' data combined

Variance accounted for %	Significant co-efficients at P = 0.05	Number of data points	Significance of regression
11.4	(B-N)	46	p = 0.050
31.2	(B-N), A, M	48	p = 0.001
41.6	(B-N)	48	p = 0.001
44.6	M	48	p = 0.001
23.0	(B-N)	42	p = 0.010
34.5	(B-N)	38	p = 0.001

5.0 Discussion

5.1 Calibration for wheat

Regressions for the second, transfer coefficient term of Equation 1 in Equation 15a were generally considerably less significant than for the first term according to Equation 11a (Table 1). This suggests that the relationship between the transfer coefficient applicable to the path water vapour must take in going from the saturated surface of the atmometer to the air in the vicinity, may not apply as assumed in Equation 12b. The increase in the percentage of variance accounted for as late September and October values are discarded (Table 3) - when rainfall is low and evaporative demand is increasing - also suggests that the theory is less valid under drier conditions.

The significant regressions which accounted for 76.6 per cent of the variance in 1978 may have been associated with the 76.7 mm of rainfall received at the beginning of the calibration period in July (Table 3). A similar result might have been expected during 1983, when combined June and July rainfall was comparable, though regressions of Equation ha were generally insignificant, and Equation 14a generally accounted for only a few percent of the variance. Relatively high average evaporation in April and May followed by low rainfall in June may cause moisture to be sufficiently limiting to invalidate the assumption concerning the transfer coefficient for the atmometer. High June and July rainfall, when average evaporation is minimal, (as in 1978 and 1984) may then validate the application of the theory until late September.

The objective of the calibration is to estimate evapotranspiration from the “break of season” rains until runoff becomes unlikely because of higher evaporation and vegetative cover in September. Use of the atmometers to estimate evapo-transpiration from wheat crops prior to June therefore results in the likelihood of considerable error in this environment. Their use in higher-rainfall areas with more humid growing season microclimates may however, result in acceptable accuracy in estimating evapotranspiration, in order to obtain an index of soil moisture storage.

5.2 *Calibration for sub.clover-based pasture*

The insignificance of regressions for Equation 15a despite the weighing atmometers to an accuracy of 0.01 g between July 15 and September 24, 1982 (Table 1) indicates that the accuracy of readings were not responsible. Therefore either other instrument errors or the invalidity of assumptions in the theory must have been responsible. The experimental evidence is insufficient to enable a conclusion to be reached on which factor resulted in a mere 30.1 percent of the variance being accounted for in combined data for the two pasture years.

In view of similarly low percentages of the variance being accounted for in most seasons under wheat, it is considered more likely that a breakdown of the theory is responsible.

The assumption concerning the proportionality of transfer coefficient applicable to the path water vapour must take in going from the saturated surface of the atmometer to the ambient air in the vicinity, and that of direct soil evaporation and evapo-transpiration combined, is considered suspect. Changes in the proportion of direct soil evaporation to evapotranspiration changing with time after rainfall, may explain at least part of a breakdown in theory set out above.

The future prospects of the combination atmometer as a practical tool for monitoring evaporative water use therefore appear unpromising. Though an attractive prospect theoretically, its validation was successful only in the first of the seven seasons tested in this 329 mm average annual rainfall zone. Its calibration for higher rainfall areas, if assumptions in the theory are more valid in these more humid growing-season microclimates, may result in acceptable accuracy in estimating evapotranspiration.

6.0 Conclusion

The combination atmometer theory shown in Section 2 appears not to be verified by the experimental data except in one of seven growing seasons tested. The simple and practical technique is therefore unreliable.

PART II

Estimating Soil Moisture Storage from Rainfall Measured Runoff and Estimated Evapotranspiration on Farmland Catchments

1.0 Introduction

Antecedent soil moisture is a prime determinant of runoff (Australian Rainfall and Runoff, 1987; Townley and Bligh, 1989), and particularly of saturation-excess runoff, which occurs when the soil profile becomes saturated (McFarlane and Bligh, 1986). Rainfall in excess of the saturated hydraulic conductivity of the profile is then available to runoff. The amount of rainfall minus evapotranspiration and runoff, which a profile stores prior to saturation, is therefore a measure of the likelihood of saturation-excess runoff.

Soil moisture storage may be estimated on a seasonal basis in dry-summer regions as the difference between rainfall and the sum of measured runoff and estimated evapotranspiration, neglecting the usually small deep-drainage term on catchments with slowly-permeable clayey sub-soils.

A method of estimating evapotranspiration was therefore required which had low capital and operating costs. The combination atmometer method (Anon, 1973) appeared to be a low-cost method of estimating evapotranspiration under both potential and water-limiting evapotranspiration which required calibration against absolute evapotranspiration.

The equipment used by the originator of this combination atmometer theory, Mr A.C. Dilley, (Research Scientist of CSIRO Atmospheric Physics Division, Aspendale, Victoria) required daily weighing of the mass of water evaporated. An alternative depth measure was devised for convenient field application using wicks, and such new equipment manufactured. Instruments were first located at the Merredin lysimeter sites operated by Dr R.H. Sedgley (Senior Lecturer, Agronomy Department, University of Western Australia) for calibration, starting in the 1978 growing season, as described in Part I (above). Following indications of adequate calibration (Bligh, 1980), six further instruments were manufactured and located on farmland experimental catchments in each of the 1980 and 1982 growing seasons and operated until late 1985.

2.0 Estimated evapotranspiration from 11 farmland catchments

Combination atmometers were located on experimental catchments indicated on Table *5,* either just before or as soon as possible after the opening rains of the season. Wherever possible without inconvenience, landholders were requested to read water levels in the atmometers, and an adjacent rain gauge, following growing-season rains of greater than 12 mm. In many cases, landholders appreciated the opportunity to measure rainfall on a part of their property for which they previously did not have immediate recordings.

3.0 Estimated soil moisture storage

Runoff averaged over the areas of the experimental catchments was added sequentially throughout each growing season to the estimated evapotranspiration for the same interval, and the sum subtracted from the official Water Authority rainfall recording at each catchment, or a rain gauge at the atmometer, where unavailable. Estimated soil moisture storage together with rainfall at the atmometer sites and the other required variables are shown for each recording interval in Appendices 1 to 11. Rainfall in the seven-day period prior to the commencement of atmometer measurements is also shown, together with an estimate of evapotranspiration since the first rain based on average evapotranspiration in the subsequent interval.

Soil moisture storage is inferred as the difference between rainfall, and runoff and estimated evaporation for each recording interval. Deep drainage is considered negligible on loamy and clayey soil catchments which are most likely to yield winter runoff (Bligh 1989). Antecedent clayey soil catchments which are most likely to yield winter runoff (Bligh 1989). Antecedent soil moisture storage may be inferred from rainfall, runoff and estimated evapotranspiration as graphed from the break-of-season rains in Figure 1 for the 1981 growing season at the Berkshire Valley Experimental Catchment.

4.0 Discussion

Estimates of evapotranspiration from the first rains of the growing season allow a quantitative assessment of soil moisture storage and deep drainage during the period of likely winter runoff.

The calibration of the combination atmometer did not enable statistically significant estimates to be made when growing-season rainfall was less than approximately 180 mm (Bligh 1988b). Further, the calibration for sub.clover and barrel medic improved pasture accounted for only 30.1 per cent of the variance of estimates. Therefore estimates of evapotranspiration are considered reliable only for cereal crops in environments in the South-West of Western Australia receiving more than 180 mm of May-October rainfall.

The frequency of atmometer readings is important in increasing the accuracy of estimates of evapotranspiration. Calibration for wheat was carried out with maximum evapotranspiration between recordings of 17.3 mm. In order to avoid extrapolating outside the calibration data, thereby reducing the variance accounted for below the 76.6 per cent achieved in the calibration, a similar maximum should be used. Approximately weekly readings are considered desirable, as carried out at the North and South Nungarin catchments, and at Berkshire Valley in 1986. Operated in this manner, combination atmometers may be used to provide estimates of evapotranspiration for cereal crops on experimental catchments. Estimates of antecedent soil moisture storage may then be calculated for use in predicting the likelihood of runoff from further rains, and in estimating soil moisture storage.

Table 5. Vegetation and cultural techniques in each growing-season on experimental catchments, 1980-87 (inclusive), showing years of commencement of gauging and evapotranspiration estimation

Station no.	Name	1980	1981	1982	1983	1984	1985	Evapo-transpiration est'n started
602 600	Jackitup Creek, Hinkley's Farm	P	C	C	P	C	C	1981
615 600	Kunjin North	P	C	P	C	C(DD)	L(DD)	1980
615 601	Kunjin South	P	C	P	P	C	P	1986
615 602	Newdegate, Holland's Farm	P	C	C	P	C	C	1980
615 604	North Nungarin, Homestead	C	C	P	C	C(DD)	C(ZT)	1982
615 605	South Nungarin, Jolly's Farm	P	C	L	P	L	C	1982
617 600	Berkshire Valley	P	C	P	C	P	C	1980
618 601	Three Springs, Weir's Farm	P	C	C	P	C(DD)	C(DD)	1982
618 602	Three Springs, Minjin	P	C	C	P	C	C	1980
618 603	Three Springs, Moolanooka	C	C	P	C	P	C	1980
701 600	Nokanena Brook, Wearbe	P	C	P	P	C	P	1981

Legend: P = Pasture;
C = Cropped to cereals using traditional tillage;
L = Lupins.

Reduced tillage technique (in brackets).

RT = Reduced tillage;
DD = Sown direct using a combine or air seeder;
ZT = Zero tillage, sown using a disc seeder.

Soil moisture storage and deep drainage may be calculated as the difference between rainfall, and the sum of evapotranspiration and runoff. Deep drainage was neglected on catchments with relatively impermeable sub soils. Hence soil moisture storage may be inferred from a calculation. This water balance approach is unable to provide an indication of surface soil wetness, which influences the infiltration of rainfall and therefore runoff. However, saturation-excess runoff (Bligh and McFarlane, 1986) predominates on sandy-surfaced soils, with slowly permeable subsoils mid and late winter in the agricultural areas of Western Australia. An index of total soil moisture storage may therefore be a useful tool for characterising the runoff behaviour of agricultural soils during this period.

Figure 1. Inferred soil moisture storage at the Berkshire Valley Experimental Catchment during the 1981 growing season

160
Rain:
Runoff:
Evaporation:
140
120
Inferred soil moisture storage (mm) 100
80
60
40
20

23 1 10 20 1 10 20 1 10 20 1 10 20 28
June July August September

Perusal of the calculations of estimated soil moisture storage in Appendices 1 to 11 enables tabulation of characteristic levels at which more than one millimetre of runoff occurred in a recording interval, as shown on Table 6. Levels are not shown for the South Nungarin, Jolly's Farm and Three Springs (Minjin) catchments, where deep drainage is considered to occur (Bligh, 1988a).

Table 6. Estimated soil moisture storage when more than 1 millimetre of runoff occurred in a recording interval

Station number	Name	Soil moisture storage (mm)
602 600	Jackitup Creek, Hinkley's Farm	50
615 600	Kunjin North	70
615 601	Kunjin South	NA
615 602	Newdegate, Holland's Farm	25
615 604	North Nungarin, Homestead	> 70
615 605	South Nungarin, Jolly's Farm	**NA**
617 600	Berkshire Valley	50
618 601	Three Springs, Weir's Farm	60
618 602	Three Springs, Minjin	NA
618 603	Three Springs, Moolanooka	>60
701 600	Nokanena Brook, Wearbe	**50**

Consideration of data in this manner neglects effects of factors such as rainfall intensity, and surface sealing caused by raindrop energy on impacting the soil. The relatively low level of 25 mm of antecedent soil moisture storage suggests that such factors may be important at the Holland's Farm catchment at Newdegate, since the approximately 0.10 m of surface loamy sand (Bligh 1989) would store 40-50 mm at saturation. Unusually high intensity rainfall may also cause the infiltration-excess runoff mechanism to apply (Bligh and McFarlane 1986), thereby invalidating the assumption of saturation-excess runoff.

The implicit assumption of spatially uniform runoff within each catchment also imposes some limitations. Assessments of catchments which include more than a single soil type relate only to that soil type which generates runoff first. Thus the Kunjin North, Kunjin South, Berkshire Valley and Three Springs, (Moolanooka) catchments may not contribute runoff from the whole of their catchment areas (Bligh 1988a), when soil moisture storage reaches the levels shown.

5.0 Conclusion

Estimating average catchment soil moisture storage based on estimated evaporation and measured rainfall would provide a useful if crude estimate of runoff if the evaporation term could be reliably estimated. The lack of reliability in estimating evaporation, as concluded in Part I, precludes the achievement of such a water balance-based prediction.

6.0 Acknowledgements

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Appendices

Estimated Soil Moisture Storage And Measurement Runoff From Experimental Catchments

Appendix 1. Station No. 602 600, Jackitup Creek, Hinkley's Farm

Date	Rain (mm)	WAWA (510601)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Estimated evapotrans-piration (mm)	Estimated soil moisture storage (mm)	Catchment runoff (mm)
1981	**Barley 1981**							
28/5		17.5	279	278	282	(9.6)*	7.9	
4/6	31.0	33.9	260	264	261	9.6	32.2	0.02
13/6	19.0	19.5	228	241	234	8.6	43.1	0
24/6	4.3	4.5	192	214	200	11.3	35.0	1.27
23/7	40.3	51.5	(96** (272	147 270	113 273	31.5	54.7	0.33
28/7	7.3	7.5	258	261	257	9.5	52.7	0.04
1/8	2.1	1.8	240	249	242	6.4	48.0	0.02
12/8	23.7	26.3	197	218	210	7.3	63.2	3.79
18/8	12.6	9.5	170	199	179	15.3	55.6	1.81
20/8	3.8	1.4	162	196	171	7.7	49.3	0.01
8/9	18.3	15.8	(90 (265	(138 (255	(90 (250	27.9	37.2	0.06
1982	**Wheat 1982**							
25/6	26.6	*5.4*	(108 (278	(137 (278	(108 (279		0	
10/8	45.87	43.1	(107 (287	(145 (287	(107 (282	52.8	0	0
27/8	25.8	30.3	228	236	220	14.7	15.6	0.42

Date	Rain (mm)	WAWA (510601)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Estimated evapotrans-piration (mm)	Estimated soil moisture storage (mm)	Catchment runoff (mm)
1983	**Pasture 1983**							
		0.6	278	283	276		0	
22/6	46.2	51.0	(190 (281	(222 (281	(193 (280	24.5	26.0	0.51
30/6	34.2	43.6	261	262	257	4.2	53.9	11.52
18/7	19.5	21.5	222	233	211	14.0	56.9	4.48
26/7	18.1	18.1	179	204	169	14.3	60.4	0.26
9/8	27.1	33.8	132	170	117	15.9	67.6	**10.73**
18/8	7.4	8.0	(94 (291	(140 (282	(75 (285	11.0	64.6	0.02
1984	**Barley 1984**							
22/5	37.5	17.3	274	272	275	(8.7)	8.6	0
7/6	29.6	36.0	214	225	214	19.8	25.7	0
28/6	21.5	23.1	(149 (270	(174 (269	(142 (270	26.1	22.7	0
6/7	6.1	6.3	238	242	238	27.2	1.8	0
15/8	41.2	51.8	(135 (276	(160 (272	(110 (273	51.5	0.3	0
28/9		75.1	166	178	103	76.3	0	

* Estimated evapotranspiration figures in brackets are from the break-of-season rains, based on average rates during the following recording interval.

* * Atmometer readings linked by double brackets were taken before and after refilling the containers.

Appendix 2. Station No. 615 600, Kunjin North (clayey soil, site)

Date	Rain (mm)	WAWA (510601)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Estimated evapotrans-piration (mm)	Estimated soil moisture storage (mm)	Catchment runoff (mm)
1980	**Pasture 1980**							
28/5		9.3	284	282	282	(4.3)	5.0	
3/7	24.2	40.3	(141 (284	(163 (281	(144 (287	22.2	23.1	0
13/8		55.7	(131 (283	(153 (280	(topoff (280			0
1981	**Wheat 1981**							
25/6	26.0	33.0	277	276	276	(18.5)	14.5	
2/6	39.6	41.0	353	260	253	21.6	33.9	0
11/6	0.5	35.2	222	236	221	11.4	57.7	0.08
23/6	0.5	3.3	188	208	184	11.9	49.1	0
1/7	8.7	8.8	164	191	158	12.2	45.7	0
21/7	**9.3**	17.2	(100 (283	(140 (274	(90 (283	22.1	40.8	0
20/8	*52.5*	66.4	(176 (281	(197 (270	(176 (282	40.9	66.3	0.17
1982	**Pasture 1982**							
10/5		2.8	291	284	286	(6.5)	0	
24/5	13.6	17.2	230	235	225	12.9	4.3	0
1/6	0	1.3	(205 (281	(214 (277	(197 (282	6.9	0	0
8/6	18.6	20.7	218	225	224	32.1	0	0
18/6	20.6	21.5	193	206	200	7.0	14.5	0
21/7	33.4	47.4	63	99	65	25.0	36.9	0
8/8	34.6	35.4	2	50	0			0.01
9/8	27.5	0	(NR (289	(44 (287	(NR (285			0
25/8	37.0	39.4	233	243	220	16.7		1.19
17/9	21.0	24.2	145	117	(top off)			0
1983	**Wheat 1983**							
30/5	—	0	281	276	285		0	
20/6	*55.2*	67.8	175	182	170	25.7	41.9	0.25
21/6	0	0.5	(160 (285	(177 (284	(168 (287	2.6	39.8	0
28/6	32.5	40.4	267	270	267	8.3	70.5	1.36
30/6	13.2	11.3	262	268	263	4.2	74.2	3.44
15/7	29.0	32.4	218	236	210	25.1	72.4	9.07
1/8	49.2	57.1	150	184	131	32.5	90.0	7.02
2/8		0.2	141	173	120	0.4	89.8	0
15/8		9.5	(83 (279	(123 (279	(50 (287	22.7	76.4	0.13
6/9	39.2	54.7	183	204	168	49.7	77.5	3.94
13/10	1.5	14.0	32	100	NR			0

Appendix 2. Station No. 615 600, Kunjin North (clayey soil, site) (continued)

Date	Rain (mm)	WAWA (510020)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Estimated evapotranspir-ation (mm)	Estimated soil moisture storage (mm)	Catchment runoff (mm)
1984	**Wheat 1984**							
23/5	—	21.7	272	276	277	(12.4)	13.3	
16/7	44.4	79.8	132	145	88	57.8	35.3	1.37
11/8	28.2	31.8	(70 (225	(103 (205	(46 (225	9.8	57.3	0
1985	**Lupins 1985**							
24/6	3.5	6.8	(217 (281	(216 (278	(208 (279			
817	17.4	19.3	207	215	202			0
14/7	21.0	22.0	177	194	170			0
26/7	13.8	15.2	146	167	133			0
20/8	30.6	38.0	64	111	38			0
1986	**Wheat 1986**							
3/6	—	0	280	282	282		0	0
9/6	4.5	9.1	252	255	254	2.7	6.4	0
20/6	32.8	28.2	227	228	228	24.3	10.3	0
10/9	59.7	41.3	40	130	10	45.4	0	3.45

Note: NR = No record

Appendix 3. Station No. 615 600, Kunjin North (loamy sand _ site)

Date	Rain (mm)	WAWA	Shaded upper (nun)	Shaded lower (mm)	Unshaded lower (mm)	Estimated Evapotransp-iration (mm)	Estimated soil moisture storage (mm)	Catchment runoff (mm)
1982	**Pasture 1982**							
10/5	—	2.8	285	278	284	(1.8)	1.0	
25/4	13.4	17.2	237	228	228	3.5	14.7	0
1/6	0	1.3	(210 (280	(218 (279	(203 (284	16.6	0	0
16/6	20.6	38.7	191	206	205	12.4	26.3	0
21/7	33.4	22.2	56	98	(top oft)			0
8/8	34.6	35.4	20	*55*	*50*			0.1
9/8	0	0	(dry (85	(dry (287	(44 (285			0
25/8	37.0	39.4	227	240	220			1.19
17/9	21.0	24.2	140	170	112	26.3	—	0
6/10	27.0		72	(top off)	(top off)			0
13/10	1.5	30.0	32	100	dry			0
1983	**Wheat 1983**							
30/5	—	0	283	282	292			
20/6	63.6	67.8	168	187	173	31.7	35.9	0.25
21/6	0	0.5	(166 (279	(175 (282	(158 (282			0
28/6	39.3	40.4	263	268	263	5.2	70.2	1.36
30/6	19.2	11.3	260	261	260			3.44
15(7	30.0	32.4	215	233	215	18.4	83.0	9.07
1/7	51.0	57.1	154	180	130	33.4	99.7	7.02
2/8		0.2	135	171	124	8.0	91.9	0
15/8		*9.5*	(72 (283	(123 (283	(56 (286	25.6	75.6	0.13
6/9	48.0		193	208	173	41.9	84.5	3.94
1984	**Wheat 1984**							
23/5	—	21.7	284	283	277	*(3.5)*	18.2	
29/5	11.2	21.7	268	269	262	3.0	36.9	0
1617	14.6	58.1	106	148	125	33.4	61.6	1.37
11/8	14.2	31.8	(53 (233	(110 (232	(60 (213	31.7	61.7	0
1985	**Lupins 1985**							
24/6	10.8		(216 (282	(233 (278	(199 (282			
817	17.4		218	220	216			0
1417	21.0		178	194	173			0
2617	14.0		145	170	141			0
20/8	31.2		61	105	50			0

Appendix 3. Station No. 615 600, Kunjin North (loamy sand – site) (continued)

Date	Rain (mm)	WAWA	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Estimated soil moisture storage (mm)	Catchment runoff (mm)
615 601 Kunjin South (loamy sand)								
1986	**Wheat 1986**							
9/6	4.3	11.0	283	278	282	(9.8)	1.2	0
20/6	15.0	23.8	253	254	245	15.4	9.6	0
26/6	**29.0**	**36.5**	235	235	229	5.2		0
1/7	12.4	13.4	230	234	222	68.4		0
10/9	26.4	77.7	54	95	26		54.3	0
							63.6	

Appendix 4. Station No. 615 602, Newdegate, Holland's Farm

Date	Rain (mm)	WAWA (510022)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1980	**Pasture 1980**							
29/5			282	280	282			
Mast heeled over-atmometers spilled								
2/7	30.7	37.5	283	288	287			0.116
7/8		26.3	168	183	139	25.0		0
4/9		18.6		Top off	Top off			0
1981	**Wheat (sown 11/6) 1981**							
27/5	12.3	12.8	276	276	277	(6.8)	6.0	
3/6	34.7	36.2	242	251	247	9.5	26.5	6.22
11/6	25.9	27.9	210	225	218	6.5	36.6	**11.30**
23/6		6.3	167	195	175	18.3	24.6	0.02
2/7	13.7	15.3	(133 (277	(172 (277	(145 (276	12.1	27.7	0.08
22/7	21.7	20.9	208	221	204	21.3	27.0	0.29
29/7	11.6	10.6	183	203	180	*9.5*	27.3	0.78
5/8	*5.7*	2.8	(154 (281	(184 (281	(152 (281	13.4	16.7	0.01
12/8	28.6	29.4	210	227	210	23.8	20.9	1.45
2/9	41.1	0	(162 (280	(190 (277	(151 (276	25.6	0	0
7/10	10.7	19.4	(57 (270	(112 (277	(34 (278			0
27/10	0.8	1.6	(96 (282	(146 (293	(88 (283			0
29/10	0	0.1	267	269	264			0
1982	**Wheat 1982**							
11/5			273	274	284		0	
25/5	*9.5*	9.8	232	238	233	16.9	0	0
1/6	10.0	0.8	(206 (277	(217 (274	(200 (271	14.1	0	0
14/6	14.5	22.6	208	216	198	19.6	3.0	0
24/6	7.0	7.7	(178 (277	(192 (277	(166 (278	11.0	0	0
8/7	8.7	8.2	229	234	222	15.2	0	0
21/7	10.8	*5.9*	161	207	150	58.3	0	0

Appendix 4. Station No. 615 602, Newdegate, Holland's Farm (continued)

Date	Rain (mm)	WAWA (510022)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1982	**Wheat 1982 (continued)**							
28/7	6.2		(131 (277	(186 (270	(118 (275	14.8	0	0
9/8	25.5	25.7	233	234	222	19.9	5.8	0
11/8	0	2.1	226	231	217	4.6	3.3	0
25/8	30.0	31.0	174	191	158	23.4	10.9	1.44
30/8	1.3	1.3	(164 (274	(180 (261	(140 (264	7.1	5.1	0.01
14/9	0	7.3	201	205	178	35.4	0	0
21/9	0.1	(12.0	(170 (279	(181 (275	138 (273	18.5	0	0
29/9	9.0	6.8	250	249	233	15.1	0	0
14/10	20.1	23.1	157	183	129	46.7	0	0.52
1983	**Pasture 1983**							
31/5		0	269	277	268			
23/6	28.2	*25.5*	(142 (286	(179 (283	(142 (287	28.0	0	0
29/6	26.6	26.0	261	264	262	7.5	17.6	0.89
1517	14.2	13.1	208	223	203	15.4	0	0.26
25/7	31.5	18.7	153	177	143	12.3	5.6	0.81
2/8	9.4	10.1	129	160	114	23.2	0	*0.55*
9/8	1.5	1.3	98	135	75	10.8		0
13/8	10.6	6.8	135	top off	top off			0
17/8	9.3	0.7	36	89	12			
1984	**Wheat 1984**							
22/5		(17.9)	278	287	276	(14.7)	3.2	
27/6	33.3	(36.7)	(139 (269	(169 (281	(109 (274	54.5	0	0.05
4/7	9.6	(15.0)	238	*255*	237	13.2	0	0.27
4/8	33.0	*(45.1)*	158	196	140	44.2	0	0.70
14/8	4.0	(3.8)	134	172	102	13.8	0	0.02
1985	**Wheat 1985**							
30/4	11.6	0	271	274	276			
26/5		(17.2)	75	86	63	28.6		0
25/6	19.3	(11.9)	NR	NR	NR			0

Appendix 5. Station No. 615 604, North Nungarin, Homestead

Date	Rain (mm)	WAWA (510023)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1982	**Pasture 1982**							
2/6		3.6	281	579	281			
5/6	28.2	0	(144	(164	top off (280			0
			(279	(277				
16/8	17.4	83.1	(90	(127	(78	42.9		0
1983	**Wheat 1983**							
9/6		0.6	270	270	274		0	
17/6	6.0	0	209	209	210	4.4	1.6	0
18/6	9.8	15.2	205	204	205	0.8	10.6	0
20/6	2.2	2.5	204	204	205	1.6	11.5	0
22/6	7.2	6.3	199	198	195	4.4	13.4	0
27/6	5.2	4.1	187	187	180	5.2	12.3	0
28/6	6.6	6.7	182	182	177			0
29/6	3.0	2.6	177	178	170	2.5	19.1	0
30/6	6.7	0.4	176	178	167	5.0	14.5	0
9/7	4.8	5.2	136	137	123	3.8	15.9	0
26/7	19.8	23.7	67	73	43	18.1	21.5	0
30/7	5.6	4.5	53	60	26	5.2	20.8	0
1/8	0.3		(46 (275	(*55* (271	(NR (292			0
23/8	12.8	12.9	144	165	160	35.6		0
29/8	14.0	13.2	126	150	140	7.0		0
1/9	4.4	9.0	103	135	117	11.7		0
7/9	16.6	17.8	85	120	96	7.9		0
12/9	3.2	4.4	(63	(104	(72	10.9		0
20/9			(279	(273	(290			0
	0	*0.5*	219	227	220	28.7		0
12/10	0	1.5	12	NR	NR			0
1984	**Wheat 1984**							
29/5		21.0	283	269	279	(7.6)	13.4	0
6/6	3.6	3.0	248	236	240	7.6	8.8	0
13/6	0	0.2	(209 (281	(207 (270	(202 (284	13.5	0	0
15/6	5.8	4.9	279	266	278	2.1	2.8	0
22/6	5.0	*5.2*	239	233	235	13.2	0	0
417	18.9	17.6	191	193	191	8.4	9.2	0
8/7	5.0	5.1	180	185	178	5.9	8.4	0

Appendix 5. Station No. 615 604, North Nungarin, Homestead (continued)

Date	Rain (mm)	WAWA (510023)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1982	**Pasture 1982**							
20/7	12.8	10.4	152	161	143	12.8	6.0	0
2/8	4.2	5.4	114	130	95	19.5	0	0
13/8	2.4	2.8	(82 (283	(106 (280	(*56* (285	18.0	0	0
22/8	2.0	2.1	258	260	250	16.7	0	0
10/9	10.4	10.9	183	190	137	42.2	0	0
17/9	8.0	8.3	134	150	70	29.3	0	0
21/9	0.1	0	(125 (284	(141 (280	(61 (286			0
1985	**Wheat 1985**							
28/6 1/7	14.5 4.4	3.6 4.3	(193 (272 238	(299 (280 255	(174 (270 242	(4.0) 4.0 7.8	13.9 17.1 0	0
617	6.3	6.2	222	242	221	9.6	0	0
1617	7.4	10.8	165	197	160	20.8	0	0
2017	**5.2**	**11.4**	158	190	150	3.9	*7.5*	0
13/8	24.8	29.8	93	144	69	40.5	0	0
20/8	8.8	7.9	60	115	58			0
28/8	12.6	10.5	45	97	30			0
1986	**Pasture 1986**							
9/6	—	17.9	282	280	284	(4.0)	13.9	0
16/6	5.6	7.2	268	265	263	4.0	17.1	0
23/6	1.8	1.5	243	240	235	3.3	15.3	0
25/6	16.2	17.0	240	239	233	3.4	28.9	0
27/6	6.2	5.2	236	236	229	2.9	31.2	0
1/7	12.2	13.0	230	230	222	2.4	41.8	0
5/7	7.6	7.0	224	225	214	3.7	45.1	.0
1617	8.2	8.3	195	200	182	6.9	46.5	0
30/7	8.4	8.1	153	160	135	5.9	48.7	0
13/8	(Tipped over)	18.7	115	132	109	**6.1**	**61.3**	**0**
18/8	*5.0*	6.2	96	110	86	0.9	66.6	0
16/9	0	19.6	NR	40	NR			0

Appendix 6. Station No. 615 605, South Nungarin, Jolly's Farm

Date	Rain (mm)	WAWA (510023)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1982	**Lupins 1982**							
5/7	5.5		277	278	276			
16/8		30.9	86	131	82			0
1983	**Pasture 1983**							
9/6	—	0.9	285	277	287	(10.7)	0	
17/6	6.4	19.2	210	217	220	12.3	6.9	0
18/6	10.8	0.1	207	214	215	2.8	4.2	0
20/6	3.0	2.5	205	212	211	2.8	3.9	0
22/6	8.4	7.4	201	208	208	1.6	9.7	0
27/6	6.2	5.5	189	1988	190	6.3	8.9	0
28/6	8.4	9.2	182	192	184	2.5	15.6	0
29/6	2.4	2.1	177	188	180	2.5	15.2	0
30/6	1.0	0.6	175	186	178	2.0	13.8	0
9/7	4.4	6.1	125	148	127	13.3	6.6	0
26/7	17.5	26.6	54	82	35	15.4	17.8	0
30/7	5.6	5.8	35	69	16	7.5	16.1	0
1/8	0	1.0	(25 (294	(61 (283	(7 (296	3.4	13.7	0
23/8	12.6	13.9	138	165	129	41.2	0	0
29/8	17.0	17.0	120	149	102	7.6	9.4	0
1/9	4.4	5.3	90	125	73	7.0	7.7	0
7/9	22.2	23.9	66	107	40	11.2	20.4	1.3
12/9	2.6	2.4	(43 (282	(84 (279	(top off) (282			0 0
20/9	0	1.1	215	(top off)	(top off)			0
12/10	1.4	1.9	46	100	44			0
1984	**Lupins 1984**							
29/5		25.5	285	284	289			0
6/6	3.6	3.7	245	256	245			0
13/6	0	4.9	(206 (281	*(225* (279	*(225* (283			0
15/6	5.0	*0.5*	279	276	280			0
22/6	5.2	6.2	237	243	238			0

Appendix 6. Station No. 615 605, South Nungarin, Jolly's Farm (continued)

Date	Rain (mm)	WAWA (510023)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
4/7	18.8	18.9	187	203	184			0
8/7	4.2	*5.5*	172	194	168			0
20/7	9.6	10.6	145	179	133			0
2/8	3.4	4.3	109	153	85			0
13/8	2.4	4.2	(78 (282	(139 (281	(45 (282			0
22/8	3.8	3.7	257	260	250			0
10/9	10.8	11.9	178	201	140			0
17/9	6.2	6.7	130	162	77			0
21/9	0.4	0	(121 (282	(157 (280	(69 (281			0
1985	Wheat 1985							
29/5	—	10.4	285	284	289	(4.1)	6.3	
13/6	0	17.4	(206 (281	(225 (279	(225 (283	14.4	9.3	0
28/6	1.7	1.6	(189 (270	(202 (276	(184 (274	27.6	0	0
1i7	16.4	6.2	236	242	244			0
6/7	6.6	6.4	220	226	225	0.8	11.8	0
16/7	8.8	10.9	173	187	176	13.7	9.0	0
18/7	7.6	6.8	160	176	164	3.0	12.8	0
20/7	4.4	15.7	156	169	157	(9.6)	6.1	0
13/8	22.2	34.8	78	106	66	32.8	8.1	0
20/8	6.6	9.2	40	73	30	6.2	11.1	0
28/8	6.8	11.3	30	50	25			0
1986	**Pasture 1986**							
9/6	—	17.5	282	282	282	(0.3)	17.2	
16/6	3.8	5.8	270	263	265			0
23/6	1.3	0.8	245	243	236	4.0	19.8	0
25/6	13.4	20.7	243	240	234	1.1	39.4	0
27/6	9.2	10.2	239	240	231	*5.2*	44.4	0
117	9.8	14.2	233	235	223	3.7	54.9	0
517	6.2	7.9	220	227	217	3.6	59.2	0
16/7	(tipped over)	8.8	198	202	179	6.0	62.0	0
30/7	7.2	9.4	157	165	123	11.9	*59.5*	0
13/8	15.0	18.9	120	125	73	4.7	73.7	0
18/8	5.2	7.3	103	109	52	4.6	76.4	0
16/9	16.6	22.8	NR	70	NR			0

Appendix 7. Station No. 617 600, Berkshire Valley

Date	Rain (mm)	WAWA (508001)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1980	**Pasture 1980**							
3/6		NR	282	282	282			
15/7	79.0	79.0	153	177	NR			0.5
16/7		0.5	284	279	287		NR	
25/8	**49.5**	30.5	(188	(200	**(170** (281	26.3	NR	
			(280	*(275*				
5/9	22.8	NR	(249 (278	(254 (278	(241 (280	14.9	NR	
24/10	28.7	40.8	35	73	NR			0
1981	(see Figure 1)	**Wheat 1981**						
1982	**Pasture 1982**							
19/5		0	280	279	283			
14/6	69.5	75.7	(165 (284	(180 (274	(128 (277	33.4	42.1	0.22
17/6	8.7	8.0	278	270	269	4.7	45.3	0.06
2717	45.6	50.6	160	170	136	24.7	69.8	1.42
30/7	0	0.3	(152 (282	(165 (278	(127 (284	5.1	64.8	0.20
25/10	112.3	129.4	NR	NR	NR			4.84
1983	**Wheat 1983**							
14/6	(37.5)	0	272	267	271			0
20/6	40.6	42.7	233	243	242	12.0	30.7	0
25/6	13.6	13.5	224	237	228	9.6	34.3	0.28
29/6	23.8	23.7	210	225	214	3.9	53.5	0.63
817	41.4	42.4	178	201	182	11.8	78.4	5.67
19/7	117.5	1.0	(151 (290	(183 (277	(146 (292	21.0	57.2	1.24
1/8	62.0	67.2	248	246	244	21.1	86.7	16.63
18/8	28.5	26.3	190	206	175	34.7	76.5	1.79
24/8	22.5	21.5	173	195	152	14.4	82.1	1.08
29/8	22.0	22.4	162	187	135	10.5	90.6	3.39
2/9	10.8	11.3	146	177	116	50.4	49.9	1.62
1984	**Pasture 1984**							
20/5	33.7	32.1	274	277	274	(6.9)	25.2	1.15
18/6	52.1	54.9	169	206	179	28.7	51.4	5.70
11/9	116.5	126.5	56	89	MR			

Appendix 7. Station No. 617 600, Berkshire Valley (continued)

Date	Rain (mm)	WAWA (508001)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1985	**Wheat 1985**							
13/6	—		276	281	282	(10.3)	1.0	
6/8	87.8	98.2	95	130	*55*	82.6	16.6	1.16
1986	**Wheat 1986**							
20/5		39.7				(13.4)	26.3	
27/5		9.3	34	22	30	13.4	22.1	0.11
4/6		0	44	33	45	16.7	5.4	0.01
10/6		4.0	24	23	27	*5.3*	4.1	0
17/6		7.4	18	14	24	11.8	0	0
24/6		11.7	26	21	29	10.5	1.1	0.08
1/7		79.0	15	15	17	3.1	71.9	5.13
11/7		5.5	25	16	35	21.9	54.7	0.77
15/7		16.3	13	11	15	5.6	65.1	0.36
22/7		37.8	19	15	22	9.2	90.0	3.63
25/7		0.1	*5*	*5*	9	4.8	84.1	1.24
30/7		13.4	21	18	25	8.8	88.3	0.40
6/8		25.3	20	11	26	18.3	90.3	4.96
12/8		14.0	14	15	23	8.0	94.7	1.68
15/8		6.0	10	13	16	2.7	97.5	0.45
19/8		6.8	14	11	16	6.9	97.0	0.40
22/8		10.2	6	4	10	7.3	99.3	0.56
27/8		*5.0*	14	11	26	15.8	88.0	0.53
1/9		0.6	11	6	17	13.0	75.4	0.18
9/9		0.4	37	30	50	22.1	53.6	0.12
16/9		12.2	20	14	32	19.8	45.9	0.14
3/9		2.1	22	17	49	31.8	16.1	0.07
1/10		5.1	28	24	33	11.0	10.1	0.07
8/10		19.7	20	13	30	19.3	10.3	0.22

Appendix 8. Station No. 618 601, Three Springs, Weir's farm

Date	Rain (mm)	WAWA (508001)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1982	**Wheat 1982**							
19/5	—	0	280	278	281			
17/6	68.7	79.1	(140 (276	(191 (275	(127 (274	83.4		0
22/7	16.0	17.4	143	164	122	47.8		0
27/7	3.6	3.4	(132 (283	(153 (277	(107 (279	4.8		0
24/8	20.3	22.7	155	170	118	58.9		0
16/9	22.8	21.7	85	100	10	35.7		0
21/9	18.0	17.6	75	90	0			0.01
23/9		1.4	70	83	0			0
25/10	9.9	10.8						0
1983	**Pasture 1983**							
14/6	—	MR	290	268	286			
18/6	32.1	NR	258	247	262	8.6	23.5	MR
25/6	21.0	NR	240	230	238	5.4	39.1	NR
30/6	11.7	MR	224	216	220	4.7	46.1	NR
15/7	20.3	28.1	172	167	160	8.1	66.1	0.20
21/7	0	0.3	(153 (285	(147 (282	(134 (294	4.0	62.4	0
2517	33.8	37.8	260	252	272			0.35
23/8	32.5	35.3	155	163	146	37.6	97.4	0.14
8/9	22.8	25.9	100	118	75	17.8	105.4	0.08
13/9	8.9	7.1	85	105	*55*	*5.9*	106.6	0
20/9	1.6	1.1	(64	(94	(20	17.0	90.7	0
1984	**Wheat 1984**							
18/5	—	2.6	271	270	277	(1.5)	1.1	
14/6	38.8	51.3	190	197	187	20.3	31.5	0.61
19/6	1.0	0	(171 (273	(180 (270	(166 (281	5.7	25.8	0
10/7	24.1	39.1	213	217	215	16.1	22.9	0.15
3/8	15.3	14.5	152	163	143	20.6	16.8	0
11/9	15.0	14.5	56	83	16	50.3	0	0

Appendix 8. Station No. 618 601, Three Springs, Weir's Farm (continued)

Date	Rain (mm)	WAWA (508001)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1985	**Wheat 1985**							
21/5		0	281	272	268			0
26/5	10.0	6.1						0
8/6	26.9	26.4						0.08
5/7	11.5	*15.5*						
1517	**13.5**	**15.8**	25	53	5	57.7		0.12
19/7	13.9	15.0	10	50	0	7.9		0.18
28/7	14.2	13.8						0.02
5/8	14.2	13.5						0.02
1986	**Pasture 1986**							
26/5		21.0	285	272	281	(6.0)	15.0	0.41
19/6	20.3	23.5	155	160	145	20.9	17.2	1.39
30/6	52.8	61.7	135	145	118	*9.5*	68.0	5.87
2317	39.4	*57.5*	260	260	260	19.5		0.18
10/8	33.1	29.8	200	210	180	23.7	129.8	0.40
1/9	24.1	33.3	150	170	100		139.0	

Appendix 9. Station No. 618 602, Three Springs, Minjin

Date	Rain (mm)	WAWA (508003)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1980	**Pasture 1980**							
16/7	72.6		169	(leaked)	142			
25/8	34.1	31.8	(173 (284	(206 (277	(154 (282			0
26/8	10.2	9.3	273	268	273	3.0		0
29/8	0	2.0	268	264	262.5	5.2		0
3/9	0	1.5	249	249	237			0
5/9	0	0	(NR	(MR	MR			0
1982	**Wheat 1982**							
19/5	—	0	271	268	267			0
11/6	29.1	27.9	134	137	117	21.8	6.1	0
17/6	41.7	43.1	(125 (266	(130 (228	(108 (274	3.8	45.4	0
22/6	1.0	0.5	248	209	255	0.9	45.0	0
18/7	9.5	8.9	137	100	123	23.5	30.4	0
2717	11.7	10.2	(116 (279	(84 (279	(94 (279	14.9	25.7	0
2/8	4.0	13.6	247	245	240	5.1	34.2	0
19/8	5.8	5.6	168	175	146	26.9	32.9	0
23/8	4.8	6.2	156	160	126	*4.5*	34.6	0
14/9	11.8	12.9	60	66	0	31.4	16.1	0
23/9	22.5	40.6	34	39	0			3.0
25/10	12.2	15.6						0
1983	**Pasture 1983**							
14/6	21.8		268	274	266			0
12/7	74.4	88.7	154	(top off)	150			0
21/7	0	0.3	(112 (290	(181 (280	(106 (290	*5.6*		0
3117	35.2	38.9	234	234	228	13.6		0
22/8	19.8	29.8	153	(top off)	(top off)			0
14/9	41.8	47.3	75	(top off)	(top off)			0

Appendix 9. Station No. 618 602, Three Springs, Minjin continued

Date	Rain (mm)	WAWA (508003)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1984	**Wheat 1984**							
20/5		28.3	274	277	274	(5.6)	22.7	0
28/5	22.9	25.8	242	249	237	11.1	37.4	0
19/6	5.7	5.8	(150 (276	(177 (274	(148 (274	25.2	18.0	0
8/7	35.1	44.4	208	224	204	26.8	35.6	0
8/8	25.4	23.5	142	178	130	34.7	24.4	0
11/9		13.4	67	115	10	57.4	0	0
1985	**Crop 1985**							
23/5	—	0	292	292	292			0
28/5	7.9	7.2	247	253	255	2.2	5.0	0
5/6	12.2	14.3	194	200	198	5.2	14.1	0
1317	18.3	33.9	8	18	32			0
27/8	55.0	69.2						0

Appendix 10. Station No. 618 603, Three Springs, Moolanooka

Date	Rain (mm)	WAWA (508004)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1980	**Wheat 1980**							
4/6	—	13.3	281	277	277	(7.5)	*5.8*	
11/6	0	0.7	248	248	243	7.5	0	0
13/6	7.0	6.1	238	240	233	3.8	1.3	0
16/6	1.6	1.1	232	236	228	2.9	0	0
20/6	12.3	33.8	221	225	212	5.7	27.6	0
23/6	12.6	19.6	217	223	208	3.8	43.4	0.01
24/6	*5.1*	10.3	212	219	202	3.4	50.3	0
2/7	6.0	10.7	194	206	181	10.4	50.6	0
10/7	8.8	10.2	171	188	156	9.6	51.2	0
16/7	31.4	3.7	(158 (279	(179 (279	(140 (281	9.1	45.6	0.18
28/7	23.4	6.4	258	266	250	20.6	31.3	0.11
5/8	11.0	0.7	240	254	230	10.8	21.2	0
13/8	1.8	0.2	221	242	207	13.9	7.5	0
18/8	5.4	0.2	196	228	181	16.5	0	0
25/8	2.4	0	(173 (270	(213 (278	(156 (282	13.5		0
29/8	11.4	16.9	*255*	266	259	22.6		0
5/9	1.0	1.6	(230 (279	(241 (278	(225 (280	9.4		0
10/9	0	0.4	240	247	239	13.6		0
17/9	1.0	0.9	206	217	192	18.2		0
23/9	3.5	2.1	169	186	146	17.3		0
1981	**Wheat 1981**							
21/5	—	3.9	272	280	276	(0.6)	3.3	0
25/5	21.0	35.6	253	259	253	2.3	36.6	0
30/5	21.5	12.5	235	244	233	7.0	42.1	0
7/6	11.4	15.0	207	218	198	10.2	46.9	0
13/6	9.8	11.9	178	198	165	16.6	42.2	0
23/6	0.2	8.4	156	178	139	7.5	43.1	0
29/6	26.4	22.1	143	166	120	7.9	57.3	0
217	3.6	0.7	139	164	115	4.7	53.3	0
14/7	1.2	2.7	(107 (278	(135 (279	(74 (278	13.3	42.7	0
2117	1.8	9.7	265	267	257	9.7	42.7	0
25/7	13.6	9.0	251	257	242	7.3	44.4	0
3017	*5.5*	8.1	240	246	222	9.3	43.2	0

Appendix 10. Station No. 618 603, Three Springs, Moolanooka (continued)

Date	Rain (mm)	WAWA (508004)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
5/8	48.6	44.4	230	241	209	10.4	77.2	0
7/8	3.6	2.1	225	237	207			0
1982	**Pasture 1982**							
17/6	—		(125 (282	(149 (277	(108 (278			
2917			123	93	84			0
25/10	2.2		MR	MR	NR			0
1983	**Wheat 1983**							
29/6 21/7 20/9	0	92.1 90.8	254 MR (272 (*5* (270	266 (145 (272 (116 (275	275 (107 (276 MR (273			0.10 0.11

Appendix 11. Station No. 701 600, Nokanena Brook, Wearbe

Date	Rain (mm)	WAWA (508018)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1981	**Wheat 1981**							
22/5	31.0	28.0	271	272	274	(1.5)	26.5	
3/6		88.3	200	212	181	35.6	79.2	MR
117		119.3	(82 (280	(121 (280	(74 (280	27.4	159.9	11.25
27/7		44.1	215	231	209	27.8	174.4	1.77
6/8		56.9	(158 (279	(191 (282	(172 (283	5.8	223.5	2.03
28/8		34.5	(203 (282	(235 (280	(199 (280	46.4	211.6	0.60
17/9		12.1	(165 (282	(191 (280	(148 (280	51.8	171.9	0
28/9		12.6	223	236	189	49.6	134.9	0
1982	**Pasture 1982**							
18/5	—	0	283	281	280			
16/6	172.4	204.0	(83 (283	(108 (281	(74 (280	29.1	174.9	17.81
15/7	36.1	31.2	(135 (281	(170 (281	(162 (282	23.1	183.0	NR
28/7	31.6	42.6	238	250	233	15.4	208.2	2.02
8/8	20.1	17.7	205	184	170			0.34
1/9	38.8	38.0	117	147	84	30.1	232.9	*0.55*
15/9	23.6	36.5	(114	(109	(10			0.42
1983	**Pasture 1983**							
16/6		0	265	264	269			
2017		156.4	(70 (268	(161 (269	(72 (271	86.6	64.4	5.42
8/8	9.9	41.9	105	184	170	46.9	59.0	0.4
19/8	7.2	20.4	138	164	117	38.9	40.4	0.1
1/9	39.8	95.2	117	147	84	10.7	113.5	11.4
15/9	21.0	38.1	(NR (280	(109 280	(10 280			2.6
19/9		0.6	263	266	268	2.6		14.53
17/10		3.0	98	(top off)	(top off)			0

Appendix 11. Station No. 701 600, Nokanena Brook, Wearbe (continued)

Date	Rain (mm)	WAWA (508018)	Shaded upper (mm)	Shaded lower (mm)	Unshaded lower (mm)	Est. evapo-transpiration (mm)	Est. soil moisture storage (mm)	Catchment runoff (mm)
1984	**Wheat 1984**							
19/5	—	32.3	279	266	266	2.0	30.3	
17/6		58.4	133	133	120	19.4	58.9	10.36
28/7		*95.5*	(10 (270	(20 (270	NR (270			7.68
25/8		93.0	186	242	179	80.5		2.18
12/9		25.6	124	216	118	47.3		
1985	**Pasture 1985**							
22/5 14/7 28/8	—	0 106.8 119.3	283 (S (270 (115 (280	272 (65 (270 (163 (270	270 (10 (270 (160 (270	59.0 26.8	47.8 140.3	0 0.02
1986	**Pasture 1986**							
27/5 26/6 25/7 31/7		4.6 33.9 177.2 21.9	275 (50 (270 (86 (240 198	268 (100 (270 (105 (240 198	272 (95 (270 (50 (240 185	(3.4) 33.7 34.4 7.5	1.2 1.4 137.3 150.5	0 6.9 1.2