WATER DEFICIT AND IRRIGATION NEEDS IN ONTARIO

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INTRODUCTION

Although the total annual precipitation in most parts of Ontario is sufficient to satisfy gross evaporative demands of vegetation the time distribution with respect to these demands is unsatisfactory. For perennial vegetation the April to October period is that in which practically all the evapotranspiration takes place. Potential evapotranspiration during this period is in the order of 20-22 inches in Southern Ontario, while rainfall averages about 18 inches. Furthermore rainfall in June and July frequently falls two to three inches below evaporative demands for each of these months. Irrigation can be used to supplement rainfall and ensure that moisture deficiencies resulting in decreased crop production do not occur. The number of irrigations will depend upon the moisture storage characteristics of the soil, and the magnitude and time distribution of seasonal rainfall.

A method will be presented for computing the magnitude of moisture deficiency and number of seasonal irrigations. This method will be applied to four levels of soil moisture storage at eleven locations in Southern Ontario for ten years of perennial crop.

LITERATURE REVIEW

Moisture Balance

The soil moisture balance is normally determined on a daily basis by the following equation:

$$SM = SMo + P - Ea$$

where SM = soil moisture storage on a given day
SMo = soil moisture storage on the preceding day
P = Precipitation for a given day
Ea = Evapotranspiration for a given day

Direct measurements of soil moisture and precipitation may be used to compute Ea, for current determination of moisture deficiency. However when past records of precipitation are to be used as a basis for computing the soil moisture balance, indirect methods of calculating the evapotranspiration based upon meteorological data must be adopted.

Potential Evapotranspiration

There are several empirical methods available for computing potential evapotranspiration. Among the better known are those attributed to Penman (6), Thornthwaite (10), Blaney and Criddle (1). Penman's equation although somewhat complex is rather rational in that a combined energy budget-sink strength approach is used. The equations of Thornthwaite and Blaney-Criddle express evapotranspiration as a function of mean monthly temperature and latitude. It is conclusively demonstrated by van Wijk and de Vries (12) that temperature based evapotranspiration formulae are seriously in error because of the time lag of temperature behind net radiation. The net energy supply must be considered the most important single item affecting potential evapotranspiration.

Actual Evapotranspiration

Under natural conditions potential evapotranspiration rates occur only when there is an ample supply of moisture to the plant roots. As the soil dries, moisture is less readily available and the rate of movement of moisture to the roots decreases and the evapotranspiration rate declines below the potential rate.

Veihmeyer and Hendrickson (11) maintain that evapotranspiration takes place at the potential rate over the full range of moisture from Field Capacity to Permanent Wilting Point. However these conclusions are not supported by the majority of workers.

Slatyer (7) in Australia, Smith (8) in the West Indies, Marlatt et al (5) in the United States found in experiments that the actual evapotranspiration varied linearly with the amount of available moisture in the plant root zone. Thornthwaite and Mather (10) applied this relationship in their studies. Other workers however, including Hartmann (2) and Makkink and Heemst (4) have shown that this simple linear relationship does not hold over the full range of potential evapotranspiration. The latter workers found that Ea was approximately equal to Et under low values of Et up to moisture tensions of seven metres, but actual evapotranspiration rates were much lower than potential rates when Et was high and soil moisture tension exceeded two meters.

TABLE I. MONTHLY COEFFICIENTS FOR POTENTIAL EVAPOTRANSPIRATION Et = a + bn (inches per month)

	Month						
	April	May	June	July	August	September	October
a	0.719	1.577	1.033	1.732	1.878	0.574	1.260
b	0.036	0.044	0.067	0.056	0.039	0.036	0.004

Holmes (3) presents data in which the actual evapotranspiration is modulated by zones. The moisture in the uppermost zone is lost at the potential rate while that in four lower zones is lost successively at decreasing proportions of the potential rate.

ANALYTICAL PROCEDURE

Potential Evapotranspiration

The Penman (6) method was used as a basis for computing the moisture budget. Data from London, Ontario were available for the period 1940-1961. Monthly values of evapotranspiration were computed for April to October inclusive for London. The monthly values of Et were plotted against the percentage of hours of possible sunshine for each month respectively, i.e. April, May, June, July, August, September and October. A simple linear relationship was determined for each month in the form

$$Et = a + bn$$

where n = monthly hours of sunshine as a percentage of the possible

The values of a and b are presented in table 1.

This relationship was utilized to determine daily values of potential evapotranspiration computed from half monthly totals of percentage of possible sunshine for the following sites in Southern Ontario; London, Ottawa, Port Dover, Vineland, St. Catharines, Delhi, Simcoe, Guelph, Ridgetown, Chatham, Harrow, for the months of April to October for the years 1953-1962.

Actual Evapotranspiration

A modulated moisture budget based on an Upper Zone and a Lower Zone for a perennial grass and legume crop was assumed. In the model system (figure 1) evapotranspiration from place to place rather than differences

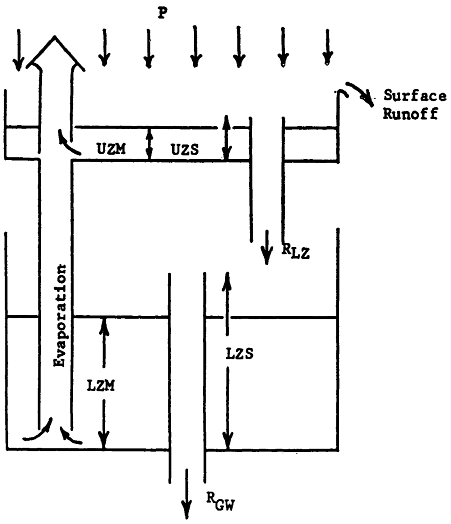

Figure 1: Soil Moisture Model.

the Upper Zone occurred at potential rate until available storage was depleted. Evapotranspiration from the Lower Zone occurred when the Upper Zone storage was depleted. The rate was proportional to the available storage in the Lower Zone.

Moisture Budget Model

The moisture budget was carried out on a daily basis at all sites indicated above for four moisture storage models.

Moisture Model	A	B	C	D
UZS (Upper Zone Storage) (in)	0.50	1.00	1.00	1.00
LZS (Lower Zone Storage) (in)	1.50	2.00	3.00	4.00

The budget was carried out according to the following equations:

$$UZM = UZMo + P - Et \quad \ldots\ldots\ldots\ldots 1$$

when $UZMo > 0.0$ inches, $P > Et$,
Maximum value of $UZM = UZS$,
minimum value of $UZM = 0.0$ inches

UZM is the available moisture storage in the Upper Zone at the end of a given day (inches)

UZMo is the available moisture storage in the Upper Zone at the end of the preceding day (inches)

P is precipitation (inches)

Et is potential evapotranspiration (inches)

$$\text{and } LZM = LZMo \quad \ldots\ldots\ldots\ldots 2$$

when $UZM > 0.0$ inches

$$\text{and } LZM = LZMo - \frac{Et\,(LZMo)}{(LZS)} \quad \ldots\ldots\ldots 3$$

when $UZM = 0.0$

where LZM and LZMo are the available moisture storage in the Lower Zone on a given day and preceding day respectively.

Soil moisture recharge will occur first in the Upper Zone when $P > Et$ until $UZM = UZS$, at which time recharge of the Lower Zone takes place until $LZM = LZS$. This is not in exact agreement with physical processes but is satisfactory as a mathematical concept. A surplus occurs at this time which may recharge groundwater or run off the surface. That this model is a reasonable one is illustrated by figures 2, 3 and 4. No adjustment was made to rainfall for runoff losses since experience indicates that this is extremely rare on sod areas.

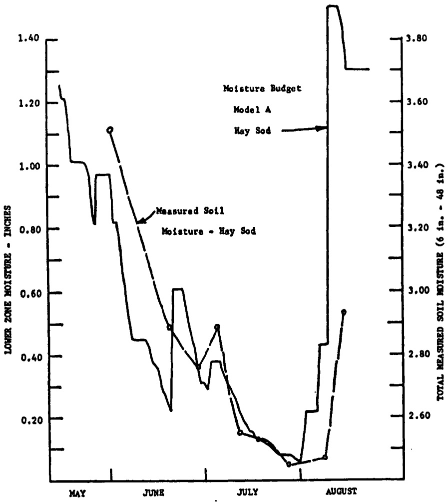

Figure 2: Moisture Depletion Model - Hespeler - 1961.

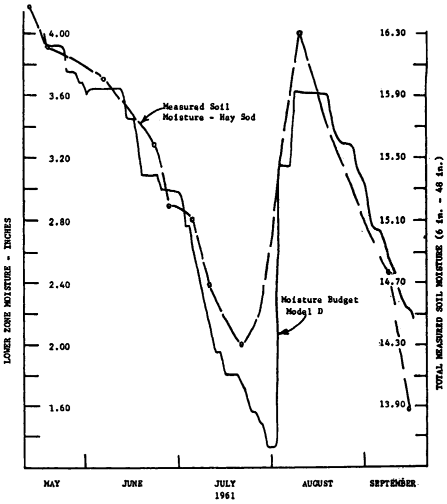

Figure 3: Moisture Depletion Model - Cayuga.

Irrigation Schedule

Irrigation was superimposed on the natural moisture budget model when certain moisture conditions occurred as follows:

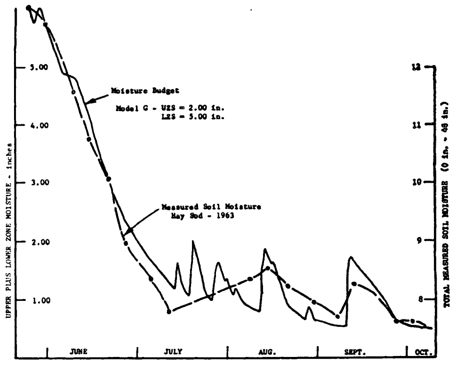

Figure 4. Moisture Depletion Model - Guelph - 1963.

	UZM (in)	LZM (in)	Irrigation (in)
Model A	0.00	1.00	1.00
Model B	0.00	1.00	1.50
Model C	0.00	2.00	1.50
Model D	0.00	2.00	2.50

With the exception of Model A, the amount of irrigation applied was 0.50 inches less than that required to cause the value of UZM + LZM to equal UZS + LZS. This was done to take advantage of additional storage capacity in the event of rains. In Model A the amount of irrigation was just sufficient to bring the soil to its full storage capacity. The Model G illustrated in Figure 4 was not used in this study, although it appears appropriate for Guelph loam soil.

RESULTS

The total number of irrigations for each of eleven stations over the ten years is indicated in table II. As would be expected storage Model A would require the greatest number of irrigations varying on the average from 8 to 10 per year. Ottawa, Delhi and Simcoe require the lowest number of irrigations while St. Catherines and Vineland in the Niagara region require the greatest number. The differences are largely attributable to evaporative demands varying from

TABLE II. TOTAL IRRIGATIONS
1953-1962

	Model A	Model B	Model C	Model D
Ottawa	85	34	42	18
London	91	40	46	19
Port Dover	94	40	46	19
Vineland	99	45	52	23
St. Catherines	104	44	51	19
Delhi	80	29	37	15
Simcoe	83	33	37	12
Guelph	92	37	42	18
Ridgetown	96	42	47	22
Chatham*	99	41	48	20
Harrow	94	41	45	18

*Estimated from 9 years of observations.

in precipitation pattern. The random nature of rainfall in a given year however may create substantial differences between the irrigation needs by region for that year. Over a longer period of time these differences are less important.

The differences between Models with respect to number of irrigations is about as expected. About one-half as many irrigations would be required on Models B and C as in the case of Model A. Similarly the number of irrigations for storage Model D is about one-fifth that required in the case of Model A. The fact that Model C requires more irrigations than Model B may be explained by reference to the equations 1, 2, 3. The storage conditions at which irrigation is required will be reached at an earlier date in the case of Model C.

Keeping in mind that the amounts of irrigation water applied were 1.00 in, 1.50 in, 1.50 in, and 2.50 in respectively for Models A, B, C, D, the average yearly irrigation water applied was as follows.

Model A	8 - 10 inches
Model B	4.5 - 6.5 inches
Model C	5.5 - 7.5 inches
Model D	3.0 - 5.5 inches

The difference between Models in terms of amounts of water are thus rather small and it would appear that the four models give a reasonable representation of the range of moisture storage conditions.

The monthly distribution of irrigations is indicated in table III for London only for the period 1953-1962.

TABLE III. TOTAL IRRIGATIONS BY MONTHS AT LONDON, ONTARIO 1953 - 1962

	Apr.	May	June	July	Aug.	Sept.	Oct.
Model A	2	18	20	28	16	5	2
Model B	0	5	10	13	8	4	0
Model C	0	5	14	13	12	2	0
Model D	0	2	4	7	6	0	0

The June and July periods are those in which irrigation is scheduled most frequently regardless of Model. It is common to delay irrigation until signs of drought are obvious. This would mean waiting until July. The synthesized schedule indicates a need to start irrigation in June in nearly every year, even though peak temperatures do not occur until July.

Moisture surpluses as a result of random rainfall events are to be expected in humid regions. The magnitude of the moisture surpluses were calculated in terms of the excess over what would have occurred without irrigation. The results are presented for London only by years in table IV. As would be expected surpluses are greatest for storage Model A. However, this is not true for every year. The random nature of rainfall occurrences causes deviations from the general pattern. Late season rains, as for example in 1954 result in greater surpluses for Models C and D, because the final irrigation is also likely to occur at a later date.

TABLE IV. MOISTURE SURPLUS IRRIGATED OVER NON-IRRIGATED AT LONDON, ONTARIO, 1953-1962 (inches)

	Model			
Year	A	B	C	D
1953	3.05	1.82	1.86	1.10
1954	1.32	1.75	3.46	3.77
1955	1.41	2.59	2.35	1.87
1956	2.19	2.23	2.38	0.00
1957	5.34	2.96	4.33	3.06
1958	1.83	1.42	3.00	2.87
1959	4.57	2.69	2.62	3.05
1960	2.81	2.01	1.33	0.00
1961	4.03	0.45	3.16	2.23
1962	2.83	1.27	2.07	1.35
Total	29.42	19.19	26.56	19.29

CONCLUSIONS

Although the period of computation is limited it is obvious that the pattern of irrigation demands is not greatly different by geographic region within Southern Ontario. It is felt that the number of stations could be decreased and use made of a longer period of record and possibly more storage models for a probability study. It is necessary that field verification of the storage models be carried out on a more extensive basis and related to Soil Associations or Series.

ACKNOWLEDGEMENTS

The author is indebted to personnel of the Departments of Soil Science and Horticulture for providing data on soil moisture observations and rainfall. Professor W. N. Stammers of the Department of Engineering Science developed the computer program for the determination of the synthetic irrigation schedule.

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