DEPARTMENT OF TRANSPORT AND POWER
METEOROLOGICAL SERVICE

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GLOBAL SOLAR RADIATION, POTENTIAL EVAPOTRANSPIRATION AND POTENTIAL WATER DEFICIT IN IRELAND

BY

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Global Solar Radiation, Potential Evapotranspiration and Potential Water Deficit in Ireland

Summary

Section 1. From records of global solar radiation and of sunshine duration at Valentia Observatory for the period August 1954 to July 1965, a regression equation is obtained between the two elements. This regression equation is used to derive monthly mean daily values of global solar radiation at twenty three Irish stations at which sunshine duration is recorded; maps of mean daily global solar radiation for each month are presented.

Section 2. Monthly values of potential evapotranspiration (P.E.) are computed for Valentia Observatory for the years 1953 to 1965, using the regression equation, established in Section 1 between global solar radiation and sunshine duration, to calculate the short-wave radiation factor in the Penman formula. These computed values of P.E. are compared with measured values of P.E and it is found that there are significant differences between the two sets of values in almost all months of the year. However, significant correlations are obtained between computed and measured values of P.E. in the months May to October and regression equations are established between computed and measured values of P.E. during these months. These regression equations are used to compute sixteen-year mean monthly values of P.E. for twelve Irish stations; the data are presented in map form.

Section 3. Using monthly values of rainfall and P.E., the accumulated potential water deficit over the months May to October was calculated for thirteen stations and maps of its mean distribution over the months May to August and also of its distribution in the unusually dry Summer of 1959 are presented.

Section 1. Global Solar Radiation

Introduction:- Total solar radiation has been measured at Valentia Observatory since 1954, using a Moll-Gorczynski solarimeter; details of the exposure and calibration of the instrument are given in reference (1). The radiation data have been combined with records of the duration of bright sunshine at the station, as measured with a Campbell-Stokes sunshine recorder, to establish an Ångström-type relationship of the form

$$Q = Q_A (a + b\ ^n/N) \qquad \text{.......... Equation 1}$$

where Q = global solar radiation

Q_A = global solar radiation received through a transparent atmosphere

n = duration of bright sunshine

N = length of day

a, b = constants.

This type of relationship between Q and n has been widely used to estimate global solar radiation from records of sunshine duration and is a modified form of the equation given by Ångström (2).

The values of the constants a and b having been determined for Valentia Observatory, Equation 1 was used to estimate global solar radiation at twenty-three Irish stations, for which sunshine records are available. Maps of the distribution of mean daily global solar radiation for each month, based on these estimates, are presented and discussed.

Global Solar Radiation and Sunshine Duration at Valentia Observatory:- In the investigation of a relationship of the form of Equation 1 for Valentia Observatory, Q was taken as the monthly mean daily value of global solar radiation as measured at the station with a Moll-Gorczynski solarimeter, Q_A as the monthly mean daily value of the hypothetical global solar radiation which would be received, through a transparent atmosphere, on a horizontal surface at the station, n as the monthly mean daily duration of bright sunshine as measured at the station with a Campbell-Stokes sunshine recorder, and N as the monthly mean length of day at the station. The values of Q_A used were those derived by Angot and quoted by Brunt (3).

Over the eleven-year period (September 1954 - August 1965), it was found that the value of n/N ranged from 0.11 to 0.61 and that of Q/Q_A from 0.28 to 0.63, the mean values being 0.29 and 0.42 respectively. The correlation coefficient between n/N and Q/Q_A was 0.90 and when equation 1 was solved for a and b, using 132 monthly values of n/N and Q/Q_A, a was found to be 0.25 and b. 0.58. Thus the regression equation

$$Q = Q_A (0.25 + 0.58\, n/N) \quad \ldots\ldots\ldots \quad \text{Equation 2}$$

was obtained. The regression line and values of n/N and Q/Q_A are shown in Fig. 1.

An Estimate of the Distribution of Monthly Mean Daily Global Solar Radiation over Ireland:- Since global solar radiation is of interest to workers in many fields e.g. biologists, agriculturists, hydrologists and heating engineeers, it was considered desirable, in the absence of regular standardized measurements of this element on a country-wide scale, to estimate its seasonal and areal distribution. To this end, regression equation 2 has been used to calculate global solar radiation at Irish stations for which reliable records of sunshine duration are available.

Mean daily values of sunshine from each of twenty-three stations were used to estimate the mean daily values of global solar radiation for each month of the eight years 1958 to 1965. Although sunshine duration was recorded at some stations for many years before 1958, it was found that by considering a period commencing in that year, continuous records from a representative network of stations were available. The estimates of global solar radiation are presented, in the form of monthly maps, in Figs. 2 to 13.

Discussion:- As global solar radiation is not measured on a regular basis at any place in Ireland other than at Valentia Observatory, it is not possible to confirm the accuracy of the maps in Figs. 2 to 13 but it is encouraging to note that there is substantial agreement between them and those given by Day (4). When measurements of global solar radiation become available from other Irish stations. it may become necessary to modify equation 2 to allow for (a) latitudinal variation and (b) variation in turbidity. Black et al. (5), in their study of data from thirty-two widely-spaced stations, found that, although the constants of equation 1 could be grouped according to latitude ranges, there was no regular latitudinal variation. Glover and McCulloch (6) suggest that the value of the constant a is proportional to Cos ϕ, where ϕ is the latitude of the station. With regard to turbidity, it is felt that, apart from small limited areas near cities, atmospheric pollution does not cause any significant variation of solar radiation intensity in Ireland. It is possible, however, that lower atmospheric humidities in the Midlands and in the East might involve some modification of Equation 2 in these areas.

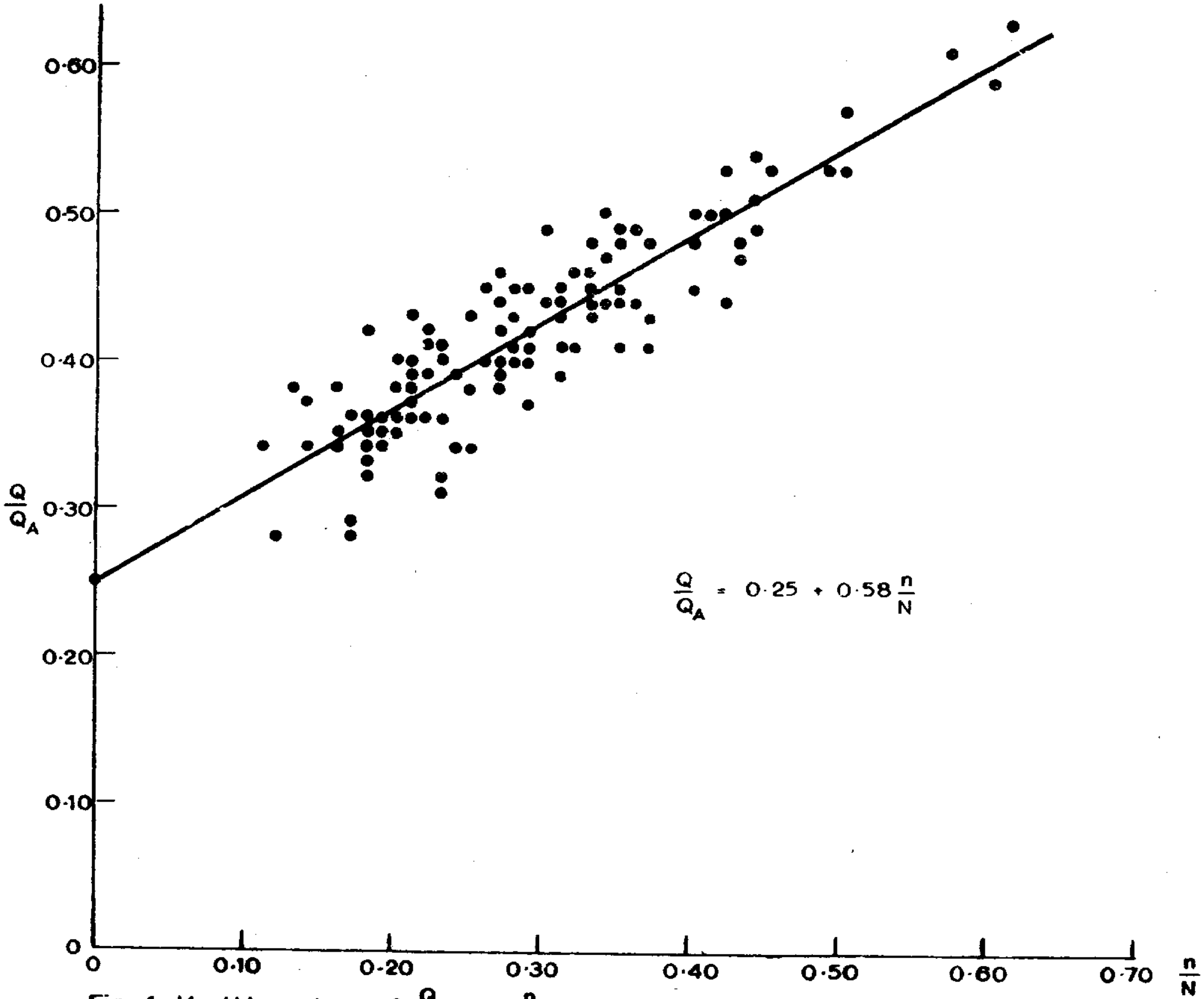

Fig. 1 Monthly values of $\frac{Q}{Q_A}$ and $\frac{n}{N}$ at Valentia Observatory (Sept. 1954 – Aug. 1965) and regression line $\frac{Q}{Q_A} = 0{\cdot}25 + 0{\cdot}58\frac{n}{N}$

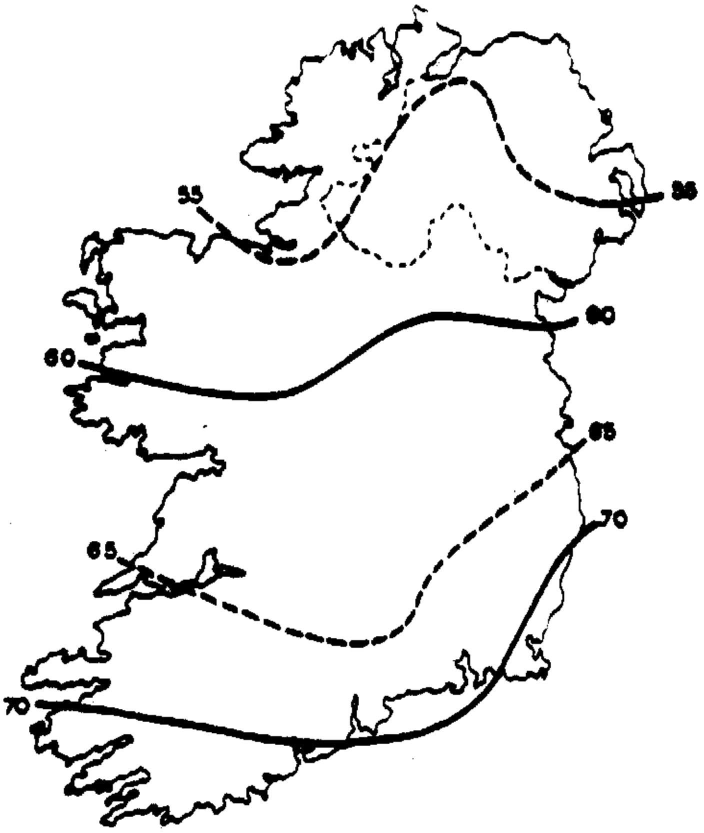

Fig. 2 Isopleths of Mean Daily Global Solar Radiation (cals/cm²) for January.

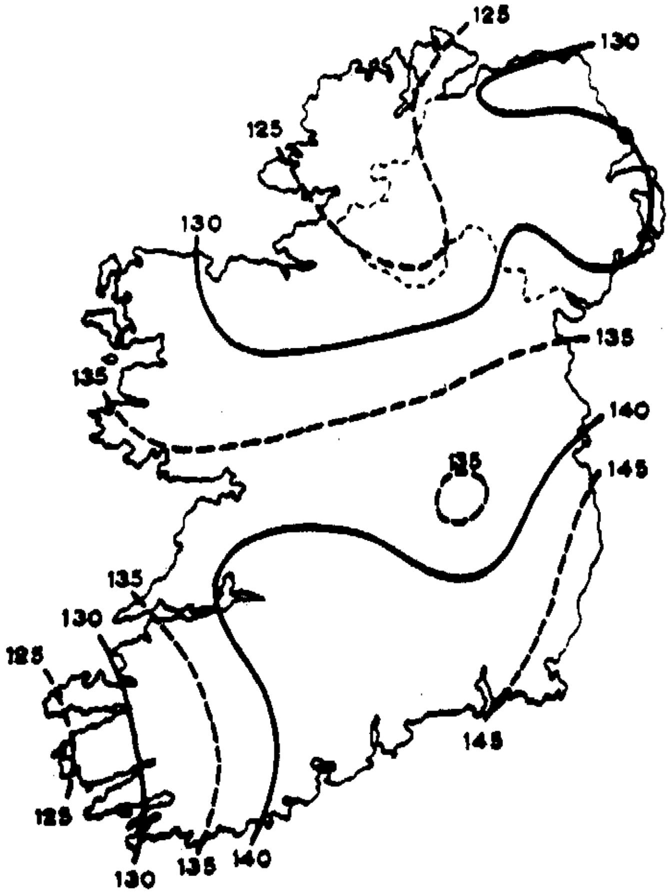

Fig. 3 Isopleths of Mean Daily Global Solar Radiation (cals/cm²) for February.

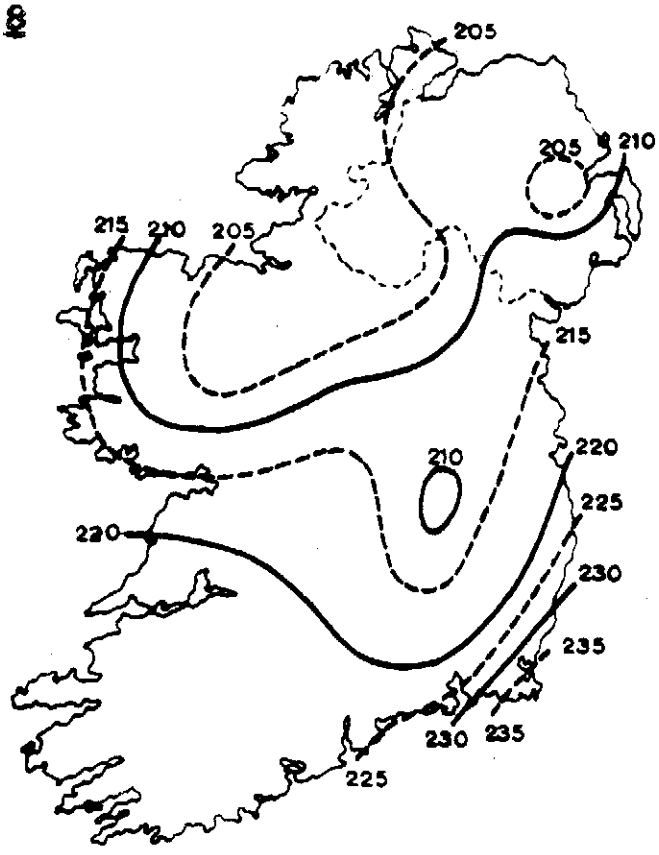

Fig. 4 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for March.

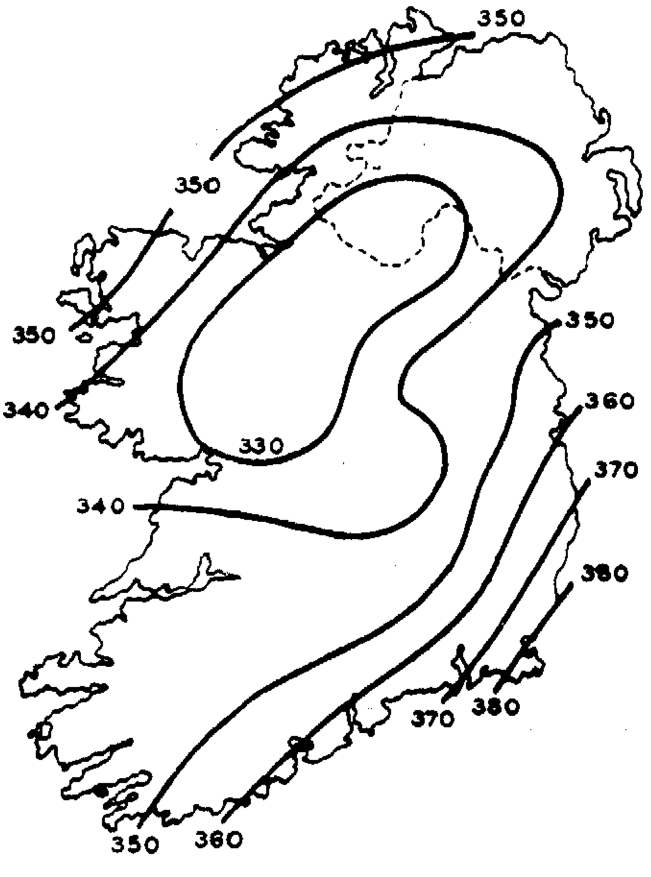

Fig. 5 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for April.

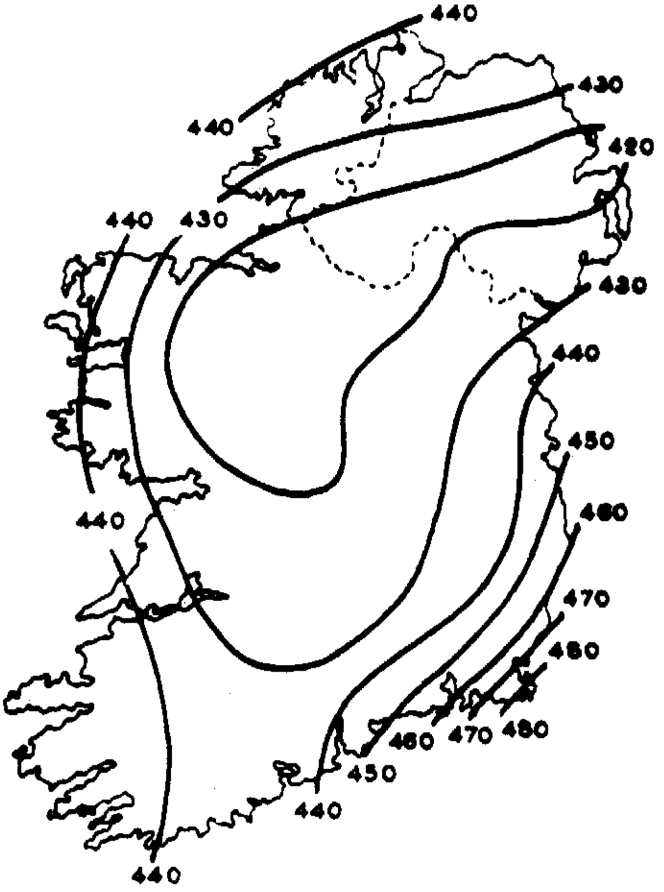

Fig. 6 Isopleths of Mean Daily Global Solar **Radiation** (cals/cm^2) for May.

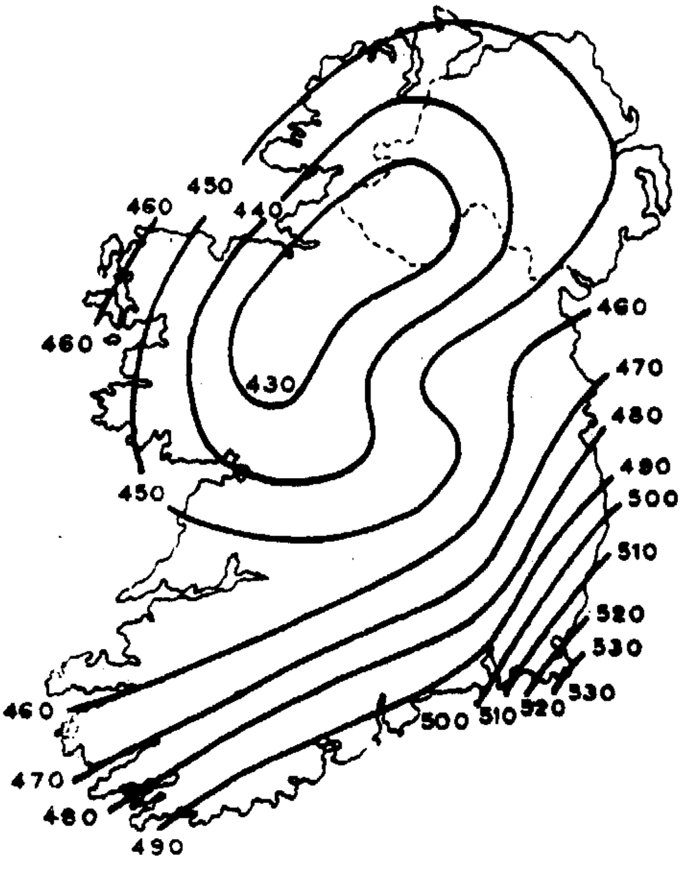

Fig. 7 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for June.

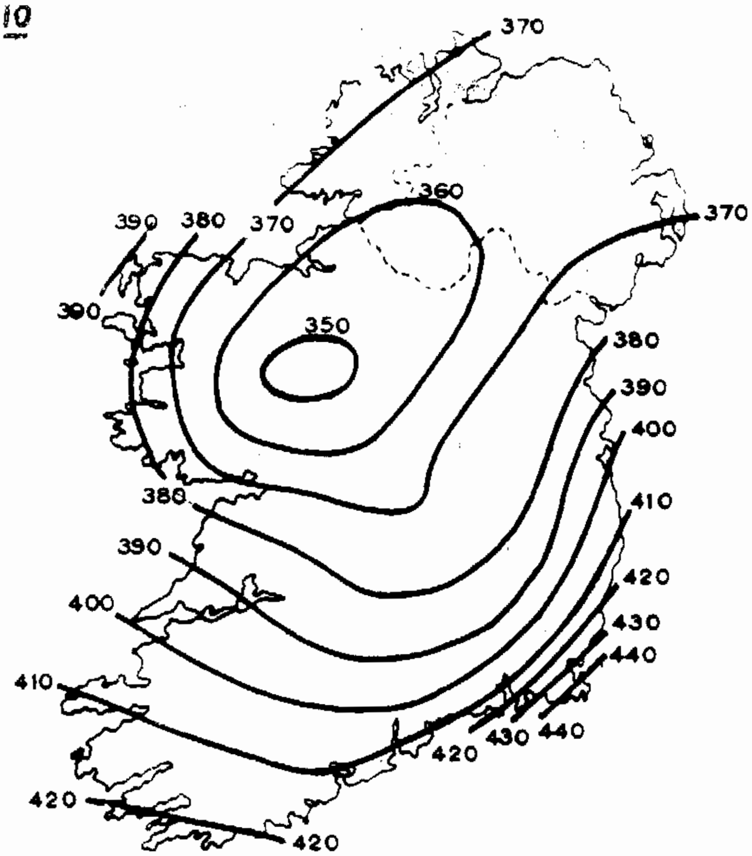

Fig. 8 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for July.

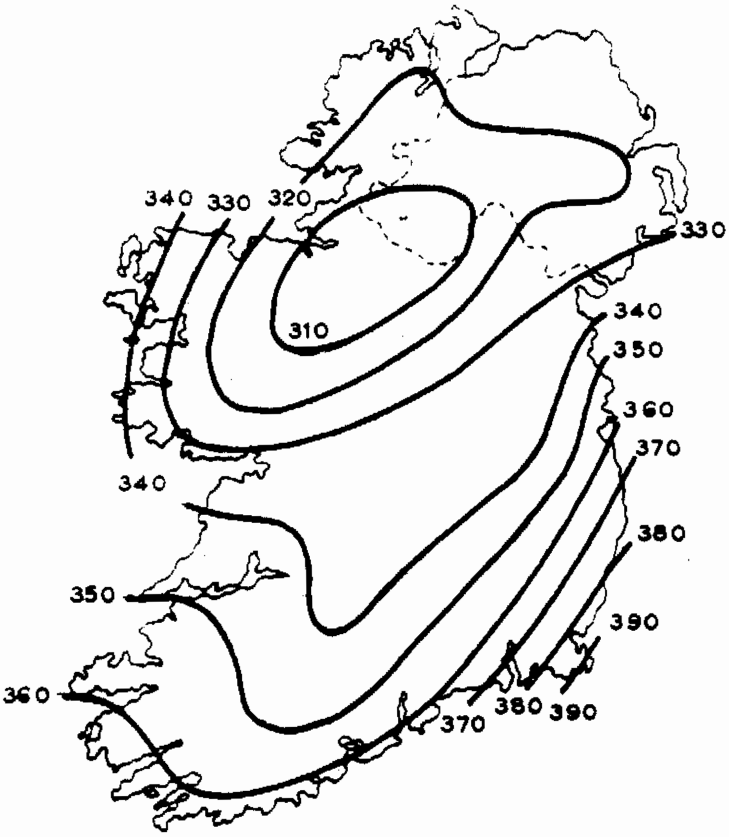

Fig. 9 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for August.

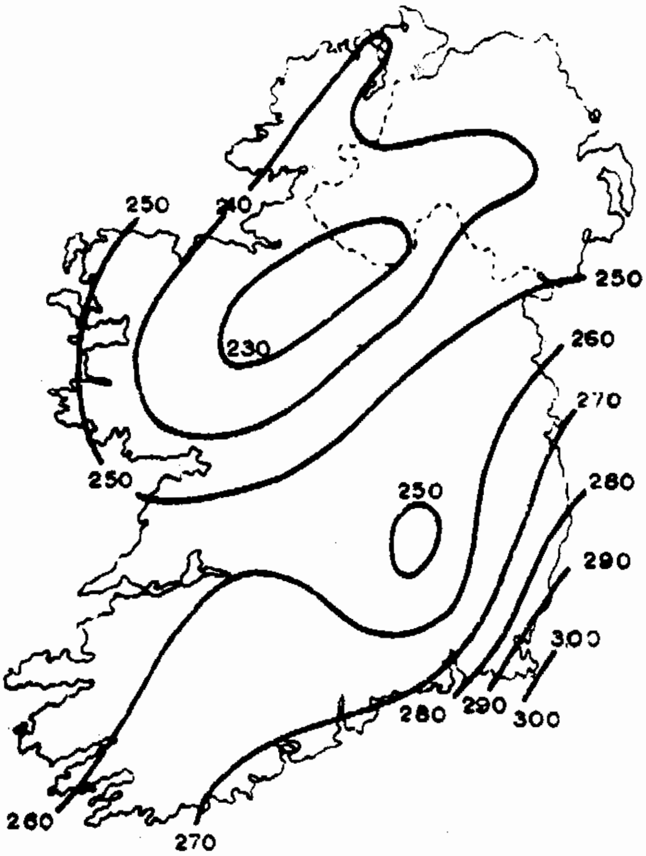

Fig. 10 Isopleths of Mean Daily Global Solar Radiation (cals/cm²) for September.

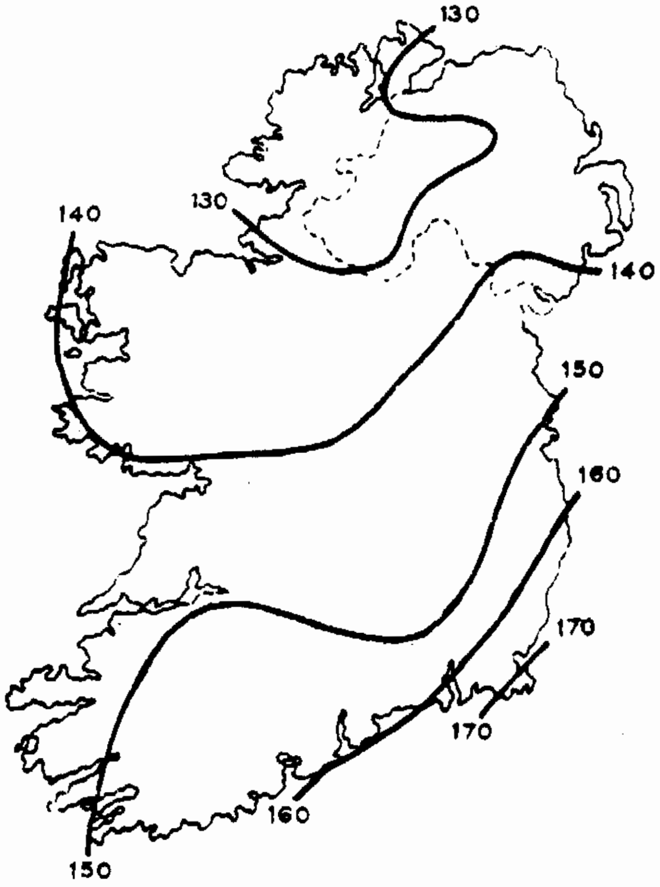

Fig. 11 Isopleths of Mean Daily Global Solar Radiation (cals/cm²) for October.

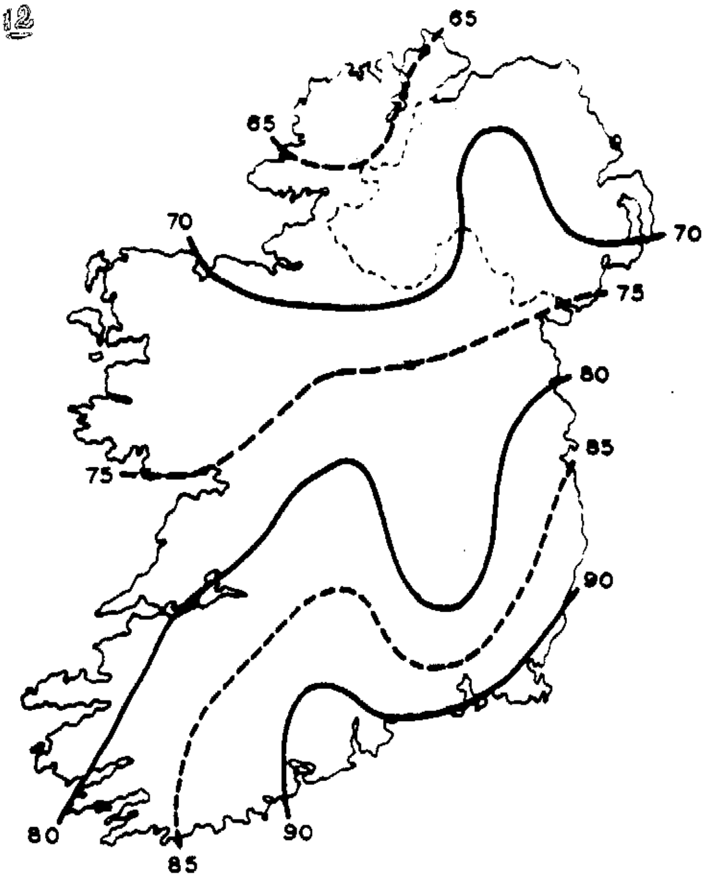

Fig. 12 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for November.

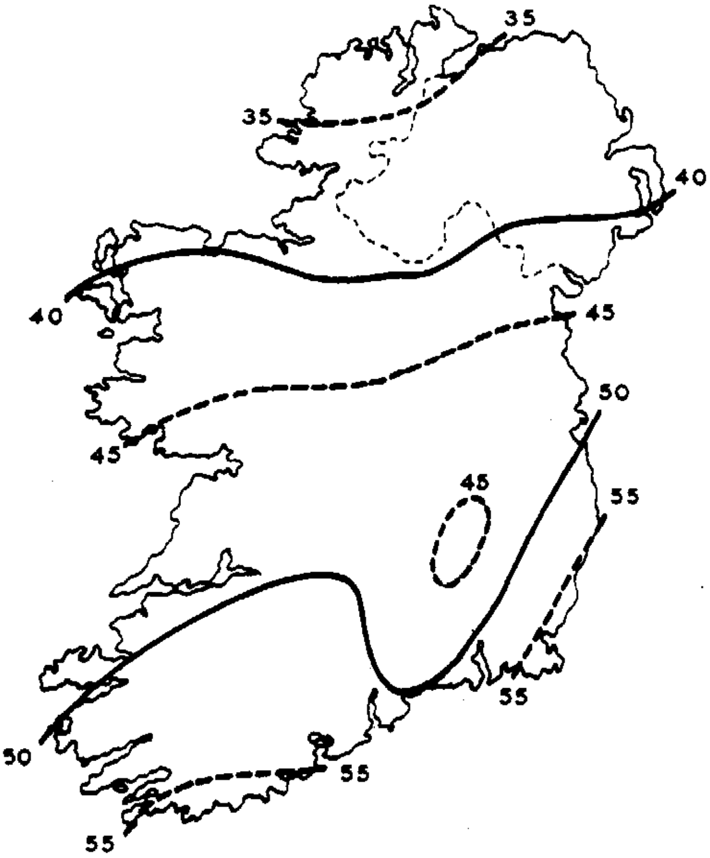

Fig. 13 Isopleths of Mean Daily Global Solar Radiation (cals/cm^2) for December.

Section 2. Potential Evapotranspiration

Introduction:- Penman's formula (7) has been widely used to compute potential evapotranspiration (P.E.). In Ireland, Guerrini (8) and Morgan (9) have applied it to compute P.E. at Valentia Observatory and have compared the computed values with values of P.E. as measured at that station, while Burke (10) has used it to estimate soil moisture deficits at Collinstown, Co. Dublin. In the present paper, the relationship, established in Section 1, between global solar radiation and sunshine duration at Valentia Observatory, has been incorporated into the Penman formula and the formula then used to compute P.E. for Valentia Observatory. These computed values are compared with measured values of P.E. and on the basis of these comparisons, maps of the mean monthly distribution of P.E. over Ireland during the months May to October have been constructed and are presented in Figs. 14 to 19.

Potential Evapotranspiration at Valentia Observatory:- Daily measurements of potential evapotranspiration (P.E.) have been made at Valentia Observatory since July 1952 from four sunken tanks, of the Thornthwaite type, described by Guerrini (11). In his comparison between these measured values and values of P.E. computed using the Penman formula, Morgan (9) found that, for most months, there was no significant difference between the two sets of mean monthly values. In view of the fact that the relationship, given by Equation 2, Section 1, between global solar radiation and sunshine duration differs from that used in the short-wave radiation term of the Penman formula, it was decided that

Equation 2 should be incorporated into the formula when used to compute P.E. for Valentia Observatory.

Smith (12) makes a similar adjustment to the formula to allow for global solar radiation records from British stations. In addition, in consultation with Penman, he makes the following further modifications:-

(i) the factor (1-r) originally 0.95 (corresponding to a water surface) is replaced by 0.75 (corresponding to a grass surface)

(ii) the humidity factor in the long-wave radiation term, originally $(0.56 - 0.09\sqrt{e_d})$ is replaced by $(0.47 - 0.075\sqrt{e_d})$

(iii) the sunshine factor in the long-wave radiation term, originally $(0.10 + 0.90\, n/N)$ is replaced by $(0.17 + 0.83\, n/N)$

(iv) the conversion factors from open water to grass are no longer used.

With the above changes and the introduction of vapour pressure and wind factors for use when these elements are expressed in millibars and knots, respectively, the terms of the Penman formula

$$P.E. = \frac{E_a + \Delta/\gamma\, H}{1 + \Delta/\gamma} \quad \ldots\ldots\ldots \text{ Equation 3}$$

are E_a = $0.26\,(e_a - e_d)(1 + 0.2\,u_{10})$

Δ = slope of the vapour pressure curve for water at mean air temperature, T.

γ = constant of the wet and dry bulb hygrometer equation.

e_a = saturation vapour pressure at mean temperature T.

e_d = actual vapour pressure of the air.

$H = 0.75\, R_a(0.25 + 0.58\, n/N) - \sigma T^4(0.47 - 0.065\sqrt{e_d})\,(0.17 + 0.83\, n/N)$

u_{10} = average wind speed in knots at 10 metres above the ground.

n/N = actual/possible hours of bright sunshine

σT^4 = theoretical black-body radiation at mean air temperature T.

R_A = Angot values of global solar radiation for a transparent atmosphere.

Monthly values of P.E. were computed, using the above formula, for Valentia Observatory for the years 1953 to 1965, inclusive. Computed and observed values are given in Tables 1 and 2. It is seen that the computed mean monthly values of P.E. exceed the measured mean monthly values in all months of the year. The mean differences are significant at the 5% level in all months, except November.

The correlation coefficients between the computed monthly values and the corresponding measured values are shown below, values indicated by S being significant at the 5% level.

Jan.	0.13	July	0.75 S
Feb.	0.00	Aug.	0.60 S
Mar.	-0.21	Sept.	0.75 S
Apr.	0.36	Oct.	0.70 S
May	0.74 S	Nov.	0.28
June	0.81 S	Dec.	0.35

It is apparent from the discrepancy between computed and observed values of P.E., that the Penman formula, with the modified factors, is not suitable for the direct calculation of P.E. at Valentia Observatory. However, the significantly high correlation coefficients between computed and observed values in the months May to October suggest that regression equations might be derived and used as estimating equations for these months. These equations would take the form: $T = cP + d$, where T equals the estimated P.E., P equals the Penman value of P.E. and c, d are constants. Using the data of Tables 1 and 2, values of c and d were determined for each of the six months and the following estimating equations obtained:-

$$\left.\begin{aligned} \text{May} &: T = 1.27P - 59.28 \\ \text{June} &: T = 0.88P - 22.30 \\ \text{July} &: T = 1.07P - 31.25 \\ \text{Aug.} &: T = 2.14P - 107.48 \\ \text{Sept.} &: T = 1.87P - 61.86 \\ \text{Oct.} &: T = 1.55P - 28.27 \end{aligned}\right\} \quad \text{.......... Equations 4}$$

<u>Estimation of P.E. in Ireland</u>:- Although the network of evaporimeters and evapotranspirometers in Ireland has been expanded in recent years, sufficient data are not yet available to give a country-wide picture of the distribution of evaporation or evapotranspiration. It was, therefore, considered that an estimate of the mean variation of P.E. over the country during the months May to October would be of interest.

Monthly values of P.E. were computed, according to the modified Penman formula (Equation 3), for twelve synoptic stations and sixteen-year (1950-1965) means of P.E. were derived for each of the months May to October. Where a station's records were available for only a portion of the period, its short-term values were weighted to the full period by reference to nearby sixteen-year stations. The regression equations derived from the data from Valentia Observatory (Equations 4) were then used to obtain estimates of mean P.E. for each of the six months for each station. These estimates were used to construct the maps shown in Figs. 14 to 19.

Discussion:- It is apparent from the above comparison between computed and measured P.E. at Valentia Observatory that the modified Penman formula, as given in Equation 3, is not satisfactory for the computation of P.E. at that station. From examination of the limited records available from evapotranspirometers at Johnstown Castle, Co. Wexford, Ballinamore, Co. Leitrim and Glenamoy, Co. Mayo, it is seen that at these stations, too, the modified Penman formula gives values of P.E. which are generally in excess of measured values. It is concluded, therefore, that the modified formula is not suitable for the computation of P.E. in Irish climatic conditions although it may provide a basis for the estimation of P.E. during the months May to October.

Table 1 Values of potential evapotranspiration (mm.) measured at Valentia Observatory

Month	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Mean
Jan.	11	13	5	6	4	6	5	7	22	2	13	10	16	9.2
Feb.	6	20	26	10	3	17	21	28	15	18	23	18	21	17.4
Mar.	37	37	13	19	22	41	16	18	40	44	34	21	37	29.2
Apr.	52	49	46	53	35	22	32	49	43	45	38	40	49	42.5
May	39	84	65	73	86	68	70	60	78	69	46	55	54	65.1
June	63	74	48	73	86	60	88	74	64	75	64	59	59	68.2
July	91	69	100	72	55	54	78	66	52	66	72	55	67	69.0
Aug.	60	100	93	64	65	48	66	65	63	58	41	48	55	63.5
Sept.	50	44	73	32	50	56	55	35	49	44	31	39	33	45.5
Oct.	25	13	32	24	25	3	52	23	23	20	19	13	34	23.5
Nov.	5	4	26	19	8	5	20	27	24	8	8	13	17	14.1
Dec.	5	-7	9	10	5	10	19	4	20	16	19	3	5	9.1

Table 2 Values of potential evapotranspiration (mm.) at Valentia Observatory as computed using the modified Penman formula.

Month	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Mean
Jan.	11	12	15	13	17	11	15	11	14	16	18	16	20	14.5
Feb.	24	27	24	24	30	25	30	28	33	30	29	33	24	27.8
Mar.	45	52	52	52	43	47	52	52	42	46	48	47	60	49.2
Apr.	76	75	75	72	77	70	73	78	69	75	65	69	72	72.8
May	88	106	102	97	103	89	100	91	113	105	90	99	87	97.7
June	104	95	87	100	117	97	118	113	89	114	103	93	101	102.4
July	96	85	123	90	87	83	99	93	95	91	91	88	99	93.8
Aug.	72	82	88	78	77	77	86	85	82	82	75	78	77	79.9
Sept.	55	59	67	51	54	61	65	56	56	56	57	60	51	57.5
Oct.	30	30	32	32	33	31	48	26	35	30	34	35	38	33.4
Nov.	19	18	18	20	17	13	15	23	17	15	23	19	24	18.5
Dec.	11	15	16	18	13	12	16	14	16	16	15	14	15	14.7

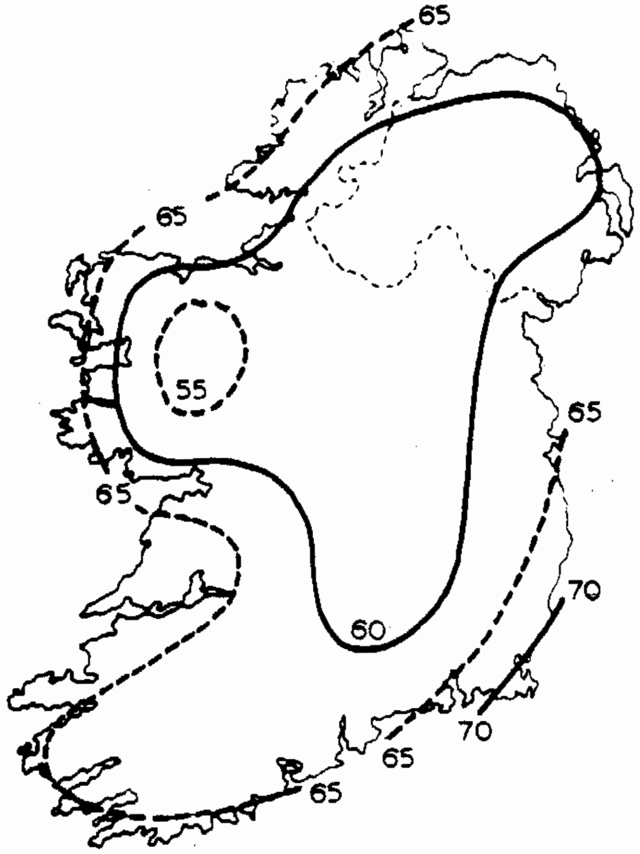

Fig. 14. Isopleths of Mean Monthly Potential Evapotranspiration (millimetres) for May.

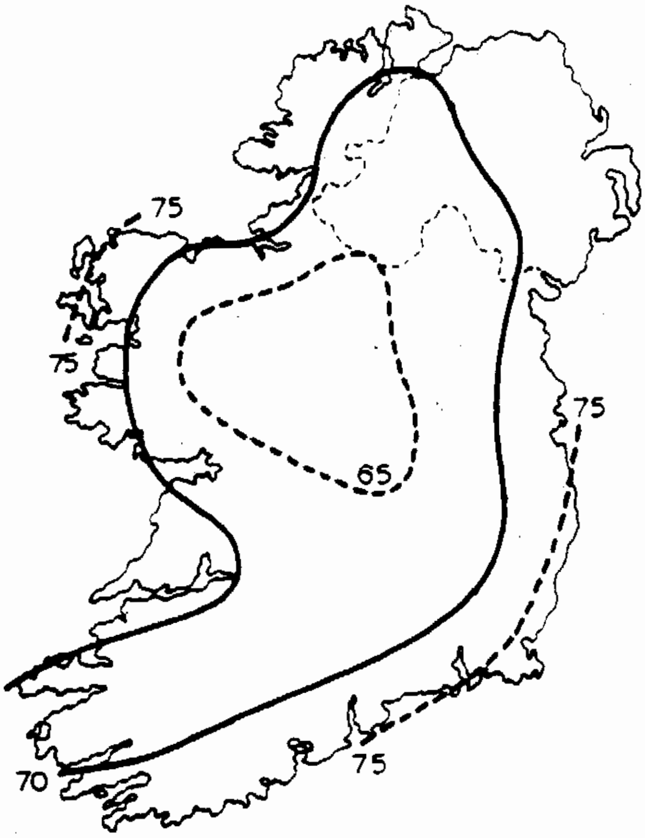

Fig. 15. Isopleths of Mean Monthly Potential Evapotranspiration (millimetres) for June.

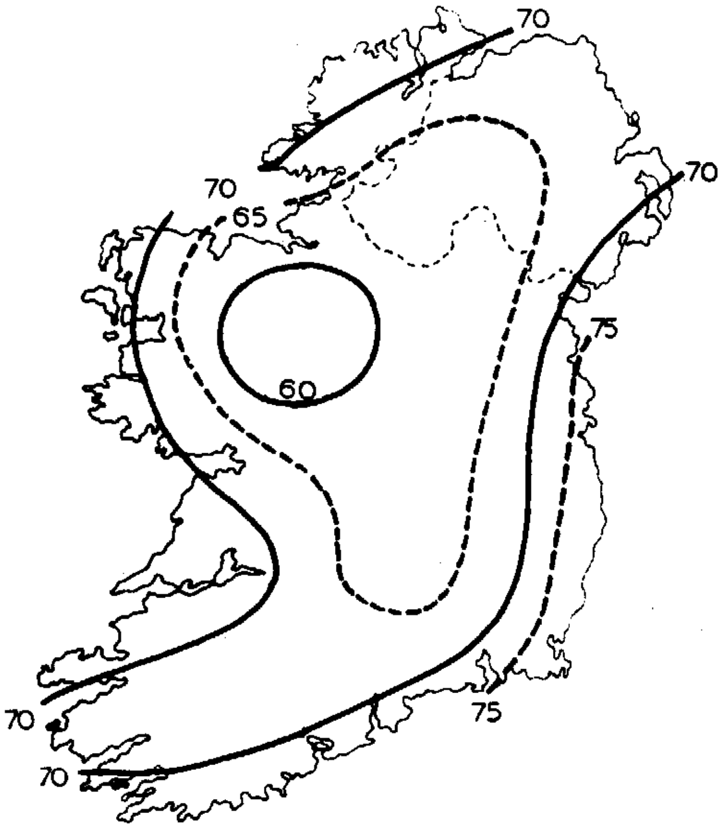

Fig. 16. Isopleths of Mean Monthly Potential Evapotranspiration (millimetres) for July.

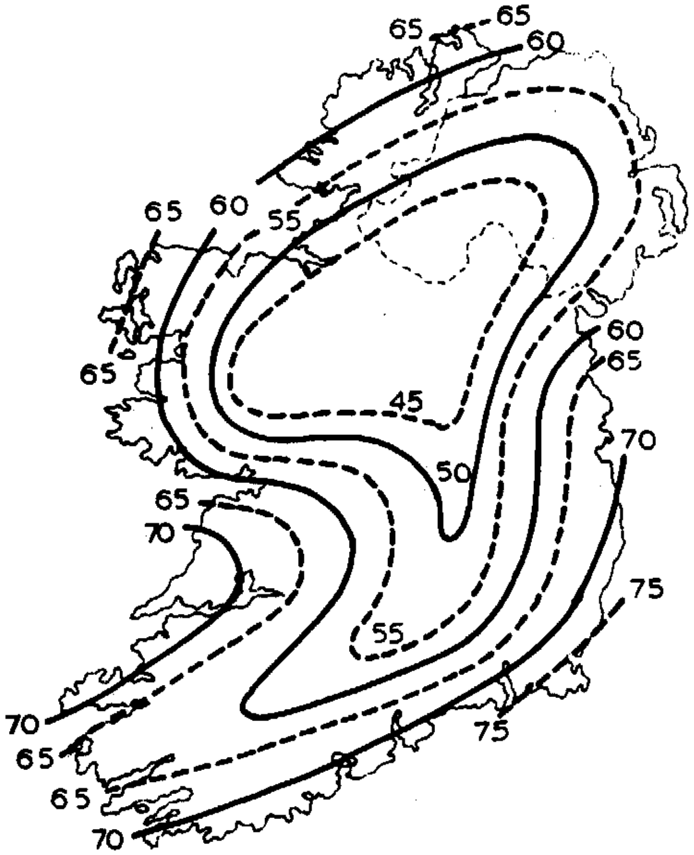

Fig. 17. Isopleths of Mean Monthly Potential Evapotranspiration (millimetres) for August.

Section 3. Potential Water Deficit

Introduction:- Agriculturists, hydrologists and engineers are interested in the moisture content of the soil. While the instantaneous value, at a given site, can be measured with a reasonable degree of accuracy by various methods, as outlined, for example, by Cope and Trickett (13), it is often desirable to have a mean value and an estimate of its fluctuations in time and space. The difference between potential evapotranspiration (P.E.) and rainfall (R) is used to provide such an estimate. This difference, (P.E.-R), termed "potential water deficit" by Greene (14), has been used to calculate irrigation need in England and Wales (15) and is a basic factor in the method of forecasting liver fluke disease, described by Ollerenshaw and Rowlands (16).

Estimation of Potential Water Deficit in Ireland:- Estimates of P.E. were obtained for twelve Irish synoptic stations for the months May to October in the years 1958-1965 on the basis of Equations 4 of Section 2 of this paper. These estimates, together with monthly rainfall values, were then used to calculate the potential water deficit (or, simply, the deficit) for each of the six months at each of the twelve stations; similar calculations for Valentia Observatory were based on actual P.E. values for that station.

It was found that (P.E.-R) was negative for all stations in September and October in all eight years, except in the year 1959 when some stations had deficits in September. In that dry year, the September deficits ranged in value from 6 millimetres at Shannon Airport to 55 millimetres at Roches Point. In the other months,

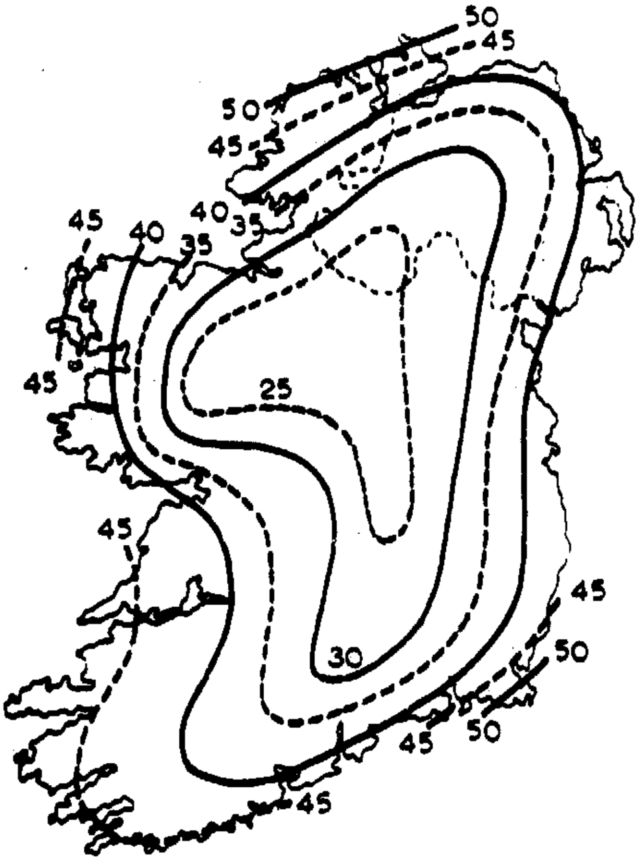

Fig. 18. Isopleths of Mean Monthly Potential Evapotranspiration (millimetres) for September.

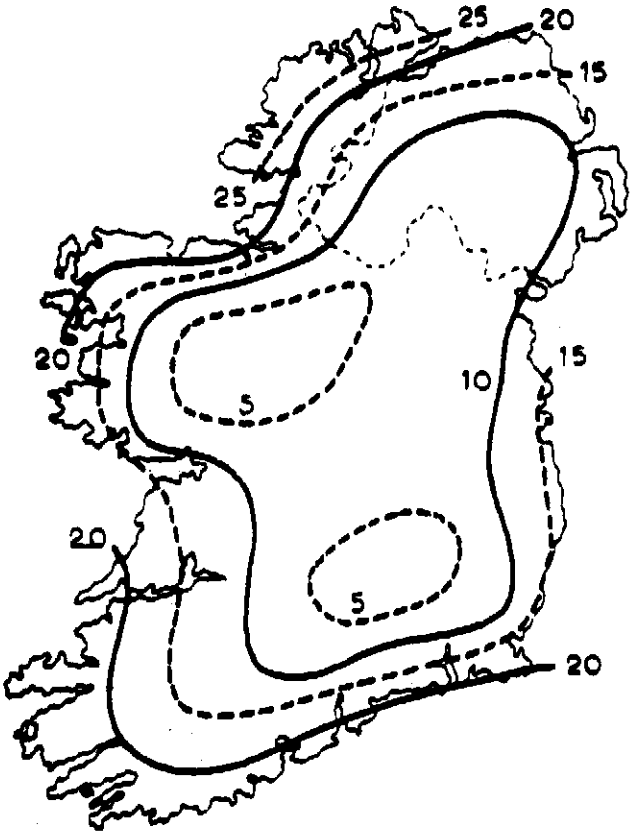

Fig. 19. Isopleths of Mean Monthly Potential Evapotranspiration (millimetres) for October.

(P.E.-R) varied from -116 millimetres to +91 millimetres, the higher positive values being found, predictably, at stations in the eastern half of the country.

The accumulated deficits over the months May to August were then calculated for each station for each of the eight years. In these calculations, when the cumulative sum of monthly deficits, Σ(P.E.-R), was negative, the value was replaced by zero on the assumption that surplus water above that required to bring the soil to saturation level was lost through surface run-off and drainage. The mean values of accumulated deficits are presented in map form in Fig. 20. The greatest variations from the mean occurred in 1958 (abnormally rainy) when the accumulated deficit was zero at all stations and in 1959 (very dry) when it exceeded 200 millimetres in the South-East. The distribution of Σ(P.E.-R) in 1959 is shown in Fig. 21.

<u>Discussion</u>:- It may be seen from Fig. 20 that, in an average year, plant growth is unlikely to be seriously restricted by lack of soil moisture, except, perhaps, in the case of shallow-rooted grasses and garden crops in the East and South-East. Fig. 21 suggests that, in a dry Summer like that of 1959, even deep-rooted crops may suffer from appreciable soil moisture deficits over a large part of country. These deficits, however, are not likely to be quite as great as those shown in Fig. 21 since, during lengthy dry spells, such as were experienced in 1959, actual evapotranspiration is considerably less than P.E. because of the reduced availability of water to plant roots.

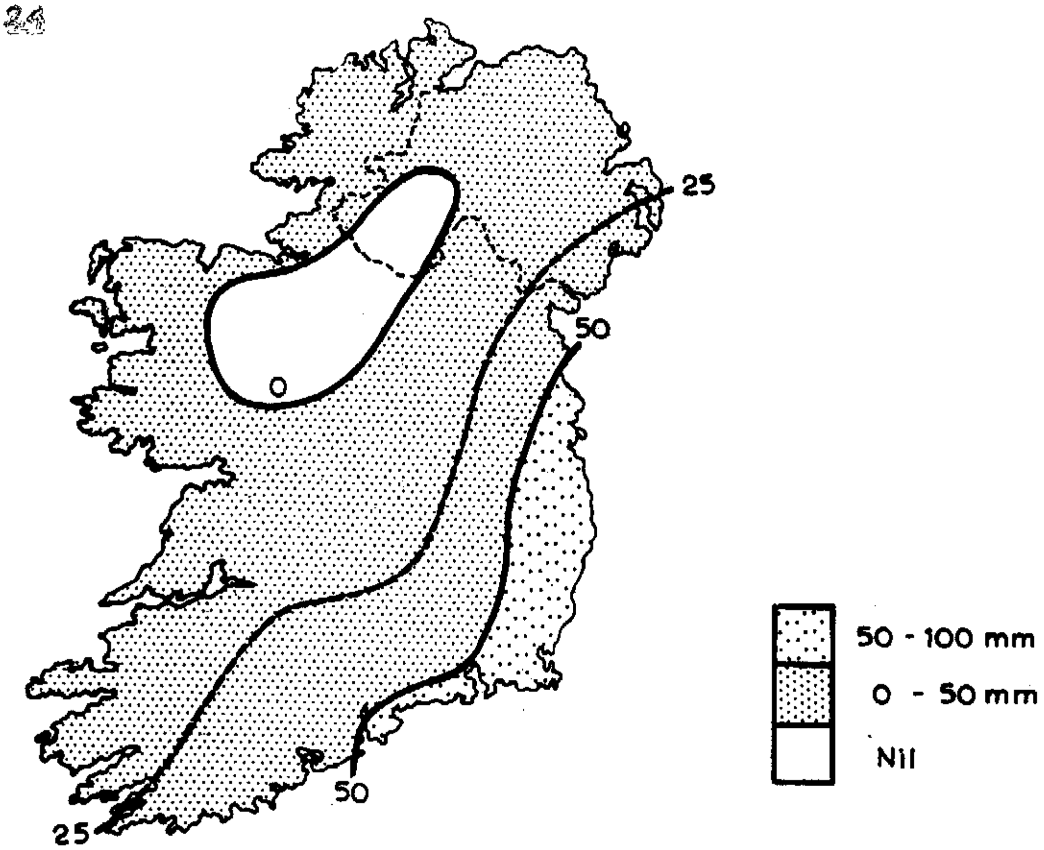

Fig. 20. Mean distribution of Accumulated Potential Water Deficits (May to August) 1958 - 1965.

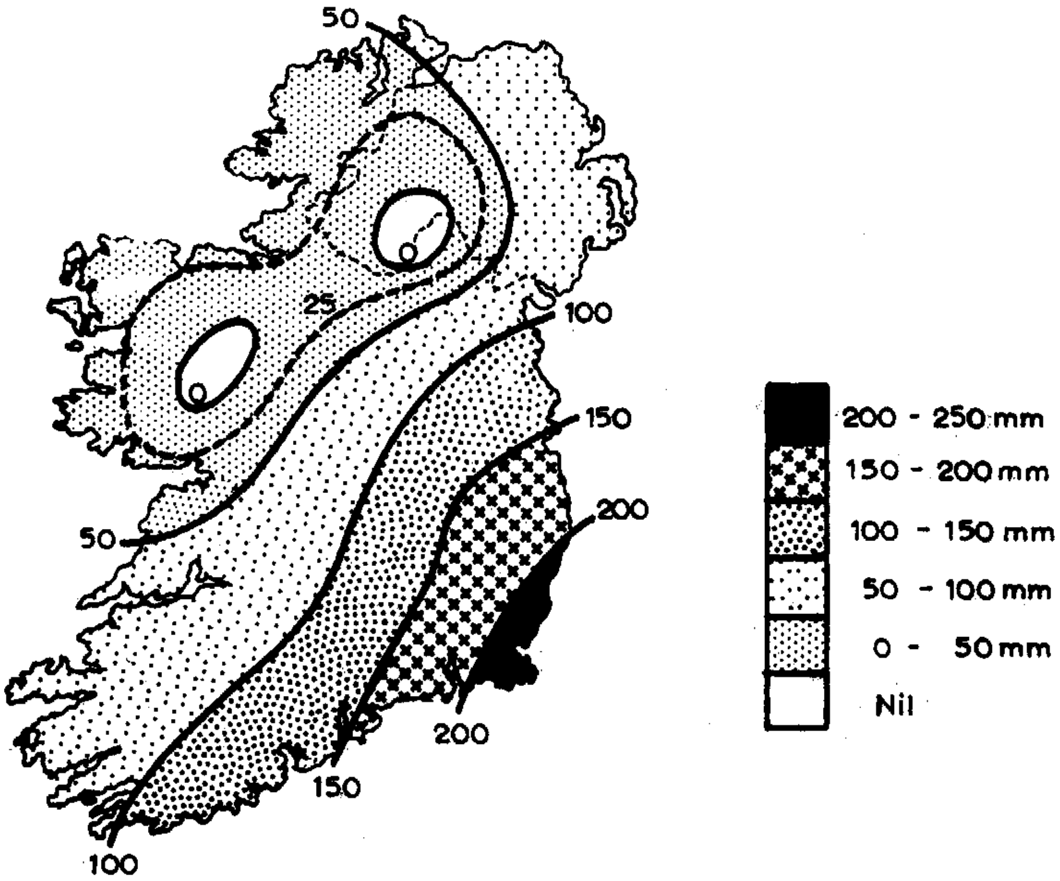

Fig. 21. Distribution of Accumulated Potential Water Deficits (May to August) 1959.

Acknowledgment

Data from meteorological stations in some northern counties were kindly supplied by the British Meteorological Office.

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