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SOME ASPECTS OF THE RAINFALL OF PLYNLIMON, MID-WALES

by

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ABSTRACT

This Report sets on record the principal climatic characteristics of rainfall at Plynlimon from 1968-1975 with particular attention to 'water-years' October 1973 to September 1975. On average, 64% of days in the year have measurable rain. The relationship between rainfall and altitude is investigated. The seasonal distribution of precipitation shows a clear autumn and winter maximum, with November and January being the wettest months and June the driest. A study of wet and dry spells shows that rainfall of two hours' duration is more frequent than of one hour's duration, but that there are twice as many single dry hours as periods of two consecutive dry hours. Long wet spells occur throughout the year but are most frequent in winter; the implications for agriculture and forestry are discussed. The period from April to September has most long dry spells. The synoptic origins of rainfall are investigated; the average daily rainfall for each weather type is given. Westerly and cyclonic type days provide 85% of Plynlimon precipitation for 1973-75. The Report also examines the time distribution of storm rainfall and synoptic criteria associated with it.

So lay down your umbrellas
Strip off your plastic macs.
You've never felt the rain my friend,
Til you've felt it running down your back.

From 'Mamunia' in 'Band on the run'

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1. INTRODUCTION

The Institute of Hydrology is currently investigating the hydrological differences between coniferous forest and upland sheep pasture in the headwaters of the Rivers Wye and Severn on the eastern slopes of Plynlimon, Powys (Mid-Wales). To provide background information to the more detailed studies of data from the catchment experiments a description of some of the chief rainfall characteristics of this remote part of upland Wales has been assembled.

The two raingauges whose records form the basis of this report are located in the centre of the Upper Severn basin in a large clearing in Hafren Forest at Tanllwyth (or more correctly Moel Cynnedd) meteorological station at an altitude of 358 m above mean sea level. This site, for which monthly returns are made to the Meteorological Office, is the second highest in Wales and the seventh highest in Great Britain. Although 20% of Britain and 28% of Wales is land of over 300 m, a study of *British Rainfall* shows that there are only 39 daily standard gauges in England and 23 in Wales (7% of all Welsh daily gauges) at altitudes above that of Tanllwyth. Since only two of the 23 are located in Mid-Wales (Upper Severn and Elan), Tanllwyth is an important site in such a large, sparsely-gauged upland area.

The altitude of the Severn catchment ranges from 320-740 m with an aspect predominantly east and south-east; the western watershed is about 18.5 km from Cardigan Bay (see map in Clarke *et al.*, 1975 p2) and the prevailing rain-bearing winds, south-westerly. Manley (1952) has described the climatic characteristics of western marginal upland climates as cool temperate with a foreshortened growing season, low temperatures and a high annual rainfall, with rain occurring with great frequency; rainfall is often of longer duration and greater intensity than in the lowlands. Ratcliffe (1968, p388) has produced a map showing a mean annual number of wet days (defined as 1 mm or over in 24 hours) based on *British rainfall* data 1951-60; Plynlimon appears an an isolated spot in the 200-220 wet days a year class together with Snowdonia and the Lake District. Western Scotland and Ireland alone have higher totals of over 220 days. Presumably the Plynlimon figure was extrapolated by the Meteorological Office on the basis of rainfall/altitude relationships, as no daily gauge existed even at Tanllwyth's altitude in 1951-60; the eight-year average of wet days of 1 mm and over for Tanllwyth is in fact rather smaller, namely 193 days.

Heavy steady falls in the Welsh Uplands are caused by frontal rain accentuated by orographic influences, often giving large totals for periods of a few days; however the frequency of days of shrouding damp mist and persistent wetting drizzle, the latter often associated with low cloud and strong winds, does not emerge from a study of the records. Thunderstorms and convectional rain are less common than in the south and east of England. Holgate (1973) and Pedgley (1971) have both investigated orographic rainfall and 'rain shadow' effects in the Lake District and Snowdonia respectively, with comments relevant to the Plynlimon situation. Holgate attempted to assess the 'orographic contribution' to the rainfall pattern and found that the added rainfall was not spread evenly throughout the rainfall event at a low rate but rather was concentrated in short periods at rates of around 6 mm per hour, generally coinciding with the approach of warm and cold fronts. Although the mechanism which frequently gives high rainfall rates on the approach of cold fronts (in particular) is not yet fully understood, it has been stated (Holgate, 1973) that raindrops falling from high in the frontal zone scour out smaller cloud droplets released by forced uplift over the mountain. This appears to increase frontal rainfall on both windward and leeward sides of the mountain but 'the maximum rainfall, and presumably the maximum intensity, usually occurs over a limited distance immediately to the lee of the first mountain barrier' (Holgate), which in the case of the Plynlimon massif is the Upper Severn and Wye catchments. Holgate states further that in the lee the air achieves its maximum vertical velocity component and hence its minimum horizontal component; raindrops in a rising column of air have the maximum chance of collision with smaller droplets. If there is a reduction in horizontal flow because of the vertical motion then, in a given time, the raindrops fall onto a relatively smaller ground area. The rain shadow effect in the neighbourhood of Plynlimon, in an eastwards direction, can be illustrated using average annual rainfall totals which range from 2,217 mm at Tanllwyth, to 1,125 mm at nearby Trefeglwys (altitude 146 m), to less than 800 mm at Montgomery (altitude 155 m) which is approximately 56 km distant.

Snow

Snowfall has been ignored in this report; any snow in the funnel of the Tanllwyth daily gauge at the standard time of observation, 0900 hours GMT, is melted according to the Meteorological Office *Observer's Handbook* procedure and recorded in the normal way. Snow in the funnel of the Dines recording raingauge at Tanllwyth is not melted but the chart is marked accordingly and hence snow periods can be avoided in any Dines tabulation analysis. Considering the altitude of Moel Cynnedd, the number of days per year in which snow or sleet falls (but may not necessarily settle) is surprisingly small; in the calendar years 1969-1975 the highest number of such days is 56 and the lowest 23. Additionally, for the two years of detailed analysis in this report, snow was a particularly insignificant part of the total precipitation. This is borne out by Oliver (1958) who finds that although the Welsh uplands can experience very heavy snow falls, it appears that heavy continuous falls are not characteristic, suggesting that snowfall plays a less significant role in the precipitation of the uplands than might be suspected. Nevertheless, for a total calibration of the water balance, snow measurements are needed in detail and the Institute has performed these since early 1976.

Instrumentation

This report is based on the records from Tanllwyth daily standard raingauge (Meteorological Office, MK2). The orifice is 1 ft (300 mm) above the ground and the funnel 5 ins (127.0 mm) in diameter. The gauge is read at 0900 hrs GMT and the total 'thrown back' one calendar day. Rainfall measurements are also provided by a Dines tilting syphon recording gauge at Tanllwyth; it is at standard height (53 cms) above ground and the chart is changed daily. A battery-run heating element prevents the float chamber from freezing in winter. The tabulations from the Dines as they are used throughout this report are not corrected according to the Meteorological Office's recommended procedure by which the Dines catch is adjusted using the nearby daily standard gauge. In addition records from the monthly read period gauge (Octapent Mk2A) network in the Wye and Severn catchments are included whose site details are described by Clarke *et al*, (1975, pages 6 and 7).

Length of record analysed

The daily raingauge at Tanllwyth was operational from January 1968 and so averages are based on the eight-year record 1968-1975; it is appreciated however that a much longer record is essential for reliable averages. A more detailed investigation was made of the rainfall throughout the two water-years October 1973 to September 1975, a period which the author observed at first hand. These years appeared to provide two exceptionally wet winters, one wet summer and finally one unusually dry summer. As the Tanllwyth record is too short to assess the extent of rainfall deviation from the mean, the Meteorological Office Monthly Summary of the Daily Weather Report was used to obtain an indication of the representativity of the October 1973 to September 1975 period. This supported the original impression - rainfall for Wales was near average, average or above for the period October 1973 to January 1975, the sole exceptions being March and April 1974 which had well below average rainfall. The remaining part of the study period had below or well below average rainfall with the exception of April and September 1975 which had above average.

The year 1974 has been described by Jovicic and Young (1975) as exceptional across Europe in terms of weather in general and precipitation and temperature in particular. Lamb (1972) summarises the weather experienced by the British Isles, which lie in the zone of prevailing westerlies, as depending on the frequency with which westerlies are blocked by anticyclones and 1974 exemplifies this: in brief, there was intense cyclonic activity early in the year with a stronger than usual westerly flow, giving mild air over the British Isles and Europe, with high rainfall especially in the West. In spring, blocking anticyclones over Northern Europe gave sunny and exceptionally dry weather over a wide area.The atmospheric pressure was lower than normal in autumn and higher than normal precipitation resulted; a notably very mild and wet December was followed by a very wet January. For the rest of the 1974-75 water-year, rainfall was below or well below average for every month except April and September.

To assess the precipitation for the water-years October 1973 - September 1975 in terms of the Tanllwyth record, four rainfall climatic characteristics for each water-year on record are ranked in ascending order for comparison.

TABLE 1 Comparison of rainfall characteristics in water-years

Ranking	Annual Rainfall, mm		Annual total rain days (0.2 mm & over)		Total number of consecutive wet days in blocks of 10 days and over		Total number of consecutive dry days in blocks of 5 days and over	
1	1968-69	(1888.9)	1970-71	(210)	1972-73	(67)	1971-72	(96)
2	1971-72	(2065.0)	1972-73	(223)	1970-71	(101)	1970-71	(93)
3	1970-71	(2145.0)	1971-72	(228)	1974-75	(112)	1974-75	(87)
4	1972-73	(2235.7)	1974-75	(232)	1973-74	(116)	1972-73	(80)
5	1969-70	(2376.5)	1968-69	(235)	1971-72	(125)	1968-69	(53)
6	1974-75	(2412.6)	1973-74	(243)	1968-69	(129)	1973-74	(43)
7	1973-74	(2501.2)	1969-70	(257)	1969-70	(134)	1969-70	(30)

The water-year 1973-74 is outstanding in its 'wetness' with the highest annual rainfall, second highest annual total number of rain days and second least number of dry periods of five days' duration or more. However it was not extreme in terms of the number of consecutive wet days of ten days and over. The high annual total of the water-year 1974-75 is associated with the very wet first half of the year, although it ranks rather low in terms of total rain days, runs of consecutive rain days and dry days (i.e. less rain days and more groups of dry ones).

2. VARIATION OF RAINFALL WITH ALTITUDE

The rainfall over much of upland Britain is estimated by extrapolating observations from gauges at lower altitudes. The Plynlimon network is of obvious importance since it occupies the very poorly sampled zone 320 m to 740 m, for although 20% of Britain and 28% of Wales is land over 300 m, only 8% of raingauges (daily and monthly) in Britain and 21% in Wales are at altitudes above that of Tanllwyth (358 m).

Clarke *et al.*, (1975) in an analysis of monthly catch by the period (monthly) gauges in the Wye and Severn catchments found that monthly rainfall increased significantly with altitude, but found no relation between gauge catch and aspect or slope. In addition Newson and Clarke (1976) found no consistent difference in catch between ground level and canopy level gauges. Since, therefore, there was no evidence to support any hypothesis of differential catch by gauges on different slopes, aspects or at different levels, data for all gauges in the network has been examined for the four water-years (October 1971 to September 1975) for which records exist.

For the first three sample years (the most recent year was analysed separately) a linear arithmetic relationship between catch and altitude appears:

$$P = 1.71\,h + 1530$$

where P is annual catch (mm) and h is altitude (m)

The correlation coefficient is + 0.80 so that altitude explains 64% of the rainfall variation. Using the regression the annual rainfall can be roughly estimated at any ungauged point on the catchment to ± 240 mm (twice the standard error) with 95% probability. In individual years the regression coefficient is approximately the same (1.50, 1.49, 1.55); the intercept, however, increased over the three years (1430 mm, 1624 mm, 1869 mm). The correlation coefficient (r) is similar for the three years (0.67, 0.70, 0.68) but is slightly greater if the data for all three years are combined (0.80). The most recent water-year gave the following regression:

$$P = 1.30\,h + 1868$$

with a correlation coefficient of 0.48, much lower than previously. The slope of the regression line shows the increase in gauge catch with altitude is rather less than for the previous years analysed. The greatest deviation from the regression line in every year is a canopylevel gauge and the reduced correlation coefficient and increased standard error in the 1974-75 analysis may in part be the result of altering the raingauge network precision by considerably raising the height of the Severn catchment canopy level raingauges in early summer 1974, despite the conclusion by analysis of variance that the effect of gauge level (canopy or ground) is not statistically significant. This demonstrates the main practical problem of operating a network of canopy gauges; it is awkward and time consuming to adjust their height more often than every two or three years, while the Sitka Spruce are growing at a rate of about 0.5 m per year.

3. SEASONAL AND MONTHLY RAINFALL DISTRIBUTION

For the hydrologist, the seasonality of rainfall input is of key importance. It also has agricultural significance: average monthly rainfall data is used by the Meteorological Office together with the calculated monthly potential evapotranspiration to give an indication of excess water and moisture deficits throughout the year. The critical factors for plant growth are <u>summer</u> rainfall and the rate at which plants use up soil moisture by transpiration. However in western areas and on higher ground, summer input often exceeds output so that soils are leached both in summer and winter giving acid soils of low fertility. This is generally the situation over Plynlimon where

TABLE 2 Monthly rainfall (mm), Tanllwyth daily standard, in water-years

WATER - YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APL	MAY	JUNE	JULY	AUG	SEPT	WATER - YEAR TOTAL
1967-1968				*309.0	55.1	232.0	134.6	194.7	167.0	102.3	86.7	249.4	
1968-1969	195.5	126.0	134.2	268.2	146.0	144.1	188.6	222.5	137.0	66.6	155.6	104.6	1888.9
1969-1970	111.1	300.7	243.6	163.0	122.3	210.8	348.9	27.1	108.9	167.7	166.4	206.0	2376.5
1970-1971	353.0	425.8	160.1	248.4	186.8	132.7	68.8	64.7	165.2	63.0	203.6	72.9	2145.0
1971-1972	211.8	282.7	118.5	226.8	124.4	194.9	301.0	140.9	172.2	113.5	118.2	60.1	2065.0
1972-1973	66.5	322.7	269.7	158.8	257.5	112.2	185.0	182.2	51.5	176.6	230.4	222.1	2235.2
1973-1974	200.2	243.7	311.9	371.6	226.7	105.0	21.9	91.5	136.2	286.9	113.9	385.7	2501.2
1974-1975	222.5	314.6	452.4	442.4	72.8	117.4	191.8	69.6	42.0	149.9	79.1	258.1	2412.6
1975-	108.4	237.1	233.2										
Monthly average	183.6	281.7	240.5	273.6	174.0	156.1	180.0	124.2	122.5	140.8	145.0	194.9	

*Raingauge not reached for four days in snow, figure suspect.

For comparison with other areas, the calendar-year totals are as follows:

1968	1986.4*	1972	2110.9
1969	2088.6	1973	2332.1
1970	2660.0	1974	2234.9
1971	1819.1	1975	2001.8

TABLE 3 Number of rain days per month, Tanllwyth, January 1968 - December 1975

Number of rain days	January ≥0.2mm or >0.2	January ≥1.0mm or >1.0	January ≥5.0mm or >5.0	February 0.2	February 1.0	February 5.0	March 0.2	March 1.0	March 5.0	April 0.2	April 1.0	April 5.0	May 0.2	May 1.0	May 5.0	June 0.2	June 1.0	June 5.0
Year																		
1968	27*			13	9	6	17	15	11	17	11	8	19	15	13	17	15	8
1969	27	23	18	24	20	10	15	9	5	14	13	12	26	24	15	15	12	7
1970	26	23	16	22	20	17	28	22	13	27	24	14	13	7	2	15	14	8
1971	23	20	15	15	11	20	17	14	9	12	10	3	13	11	2	21	15	8
1972	27	22	13	27	21	9	18	15	9	17	16	14	21	19	12	27	22	9
1973	17	17	9	21	16	12	13	11	7	16	15	6	21	20	13	16	12	3
1974	27	25	19	24	20	[illegible]	14	11	6	7	5	2	18	13	7	18	15	10
1975	31	27	23	11	9	8	21	19	10	23	20	12	9	8	4	7	6	3
Monthly Av.	26	22	16	20	16	11	18	15	9	17	14	9	18	15	9	17	14	7

Number of rain days	July 0.2	July 1.0	July 5.0	August 0.2	August 1.0	August 5.0	September 0.2	September 1.0	September 5.0	October 0.2	October 1.0	October 5.0	November 0.2	November 1.0	November 5.0	December 0.2	December 1.0	December 5.0	Annual total rain days
Year																			
1968	11	10	6	16	14	3	25	19	14	23	17	13	19	13	8	22	14	7	226
1969	14	8	4	20	14	8	16	11	7	17	11	5	26	26	15	22	20	12	236
1970	22	20	12	18	12	9	21	14	9	22	21	16	27	26	21	20	15	9	261
1971	8	7	5	23	22	10	9	9	5	15	15	10	24	18	12	19	15	7	199
1972	12	9	6	13	11	7	8	6	3	15	11	5	26	22	14	21	19	12	232
1973	21	14	9	18	15	6	18	14	9	18	15	8	22	16	11	25	23	17	226
1974	24	20	14	20	16	9	26	26	20	26	22	12	25	25	19	29	28	24	256
1975	17	13	8	12	11	5	21	19	14	17	14	7	19	18	14	22	13	6	210
Monthly Av.	16	13	8	18	14	7	18	15	10	19	16	10	24	21	14	23	18	12	

* Raingauge not reached for 4 days in snow, figure suspect.

Mean annual total rain days
0.2 mm and above = 231 days

Mean annual total rain days
1.0 mm and above = 193 days

Mean annual total rain days
5.0 mm and above = 122 days

soils rarely suffer from water stress except in times of nationwide drought. The survey of the *Soils in Powys* (Lea, 1975) shows that in this region as a whole there is usually more loss of water from the soil (by transpiration, evaporation and drainage) than rainfall from May to July and a moisture deficit can occur from April to September with a maximum theoretical cumulative deficit in July, which may become sufficient to stop plant growth. From July the transpiration rate of plants decreases and by October the soils normally return to field capacity as the onset of the winter rainfall exceeds the losses. Preliminary results based on Plynlimon data show that even in the dry summer of 1975 the period of soil moisture deficit was foreshortened by a month at each end of the season, commencing late April and ending early September.

The average (eight-year) monthly rainfall (from Table 2) at Tanllwyth, ranked in order of decreasing amount, shows the winter and autumn half of the year with the highest falls:

March)		November)		
August)		January)		
July)	Spring/Summer	December)		
May)		September)	Autumn/Winter	
June)		October)		
		April)		
		February		

The seasons are as defined by Manley (1952):

March - April - May = SPRING
June - July - August = SUMMER
September - October - November = AUTUMN
December - January - February = WINTER
and November - April = WINTER
May - October = SUMMER

A similar pattern appears using the average number of rain days per month from Table 3 for both total number of rain days (ie falls of > 0.2 mm per day), rain days of 1.0 mm and over, and the heavier rain days of 5.0 mm and over, and ranking them:

TABLE 4 <u>Average monthly rain days</u>

Rain days with ≥ 0.2 mm	Average Number of days	Rain days with ≥ 1.0 mm	Average Number of days	Rain days with ≥ 5.0 mm	Average Number of days
January	26	January	22	January	16
November	24	November	21	November	14
December	23	December	18	December	12
February	20	February	16	February	11
October	19	October	16	September	10
March	18	March	15	October	10
May	18	May	15	March	9
August	18	September	15	April	9
September	18	April	14	May	9
April	17	June	14	July	8
June	17	August	14	June	7
July	16	July	13	August	7

The order of wettest to driest broadly corresponds to that for average monthly totals. Although all months have a large number of rain days with comparatively little separation between months, the autumn/winter months of January, November, December, February (especially the first three) are outstanding in their high number of rain days, of which a high proportion are days with 1.0 mm and over. January, November, and December also have twice the number of heavy (5.0 mm and over) rainfall days than the summer months June, July and August. The three summer months correspond to their already low ranking in average monthly rainfall totals by having the least number of rain days over 1 mm. August has a slightly higher total of all rain days (ie 0.2 mm and over) than June and July, although its position in the other two columns suggests that falls on these rain days are low.

The eight years of data available may well be too short for an analysis of this type to give reliable conclusions; indeed Smith (1972) points out that most UK stations show little apparent pattern in the fluctuations of either seasonal or monthly rainfall and his examination of a long period of record showed that every month had at some time been both the wettest and driest month in any individual year. Nevertheless, the Plynlimon records do show a definite winter rainfall maximum in accordance with other western 'Atlantic' areas (Smith 1972).

The Plynlimon figures agree well with Figure 7 in the Soil Survey Record of *Soils in Powys* (Lea, 1975) where average monthly rainfall over the much longer period 1916-50, for neighbouring stations at Caersws, Gregynog, Carno, Newtown and Trefeglwys, all have a similar distribution; October to January is the wettest period with over 40% of the annual total. March to June are the driest months with around 20% of the total, June being the driest month for most of the district.

The autumn/winter of 1974/75 well illustrates the high extremes of rainfall that can occur at Plynlimon:

		No: of days with ≥ 0.2		No: of days with ≥ 1.0 (mm)		No: of days with ≥ 5.0	
	September 1974	26	*(18)*	26	*(15)*	20	*(10)*
	October 1974	26	*(19)*	22	*(16)*	12	*(10)*
(from	November 1974	25	*(24)*	25	*(21)*	19	*(14)*
Table 3)	December 1974	29	*(23)*	28	*(18)*	24	*(12)*
	January 1975	31	*(26)*	27	*(22)*	23	*(16)*

Average no: rain days for month (   )

Particularly noteworthy are the high number of rain days of 1.0 mm and over for these five months and the fact that December had a total of 29 rain days and January had 31! In the case of December and January a very high proportion of the rain days were of 5.0 mm and over, resulting in the two highest monthly totals recorded at Tanllwyth since records began in January 1968, namely 452.4 mm in December 1974 and 442.4 mm in January 1975. Only once previously has there been a monthly total at Tanllwyth above 400 mm, that of 425.8 mm in November 1970. It is interesting to compare the December 1974 catch for the highest altitude gauge in the monthly network - 612 mm - with the average annual total for areas of the Thames estuary coast, namely 500 - 550 mm!

Conclusion

The autumn/winter months at Plynlimon have the highest rainfall with a maximum in November and January. The greatest number of rain days per month also occurs in the winter. The summer months have the lowest rainfall and a correspondingly low number of rain days of over 1 mm. June is the driest month at Plynlimon which agrees with the much longer record of neighbouring stations.

4. WET AND DRY SPELLS

Persistence is well known in weather phenomena and Chatfield (1966) has found in a study of seven years rainfall data from Kew that the probability of a dry day being followed by a dry day increases with the previous number of consecutive dry days; he also found that the weather on the day following a wet day, however, may not depend on the previous day's weather. Duration of spells, especially dry spells, and short term spells as well as long, are important in terms of water resources and interception by the forest canopy; in a wider context their distribution throughout the year is the basis for many outdoor activities - farming, forestry, the construction industry and field work programs. For example, in the financial year 1974-75, 20% of working hours were booked by the Forestry Commission in Hafren Forest, Plynlimon, to "wet working", when only the basic rate is paid and workers may be sent home early as no work can be done. This exceptionally high figure (in recent years 20% but previously around 12%) for time lost due to wet weather at Hafren may be compared with that of 5.4% on average for the rest of the same District as Hafren, namely Kerry, Coed Sarnau and Radnor Forests. Part of the recent increase for Hafren may be due to more thinning and felling activity which are more sensitive to wet weather.

Although Mid-Wales is essentially a stock rearing area, heavy machinery is nevertheless used throughout the year for applying lime, fertilizers, slurry, for ploughing the grass sward and reseeding, for hay and silage harvesting and in restoring or improving the physical conditions of soils by draining using heavy diggers. Since wheels have the least detrimental effect when the soil is dry the Agricultural Advisory Council (1970) Report recommends joint consideration of both rainfall records and soil factors at times of the year critical for farming, in order to indicate the frequency of adverse soil conditions to give farmers more precise knowledge of the risks their particular farming system involves - whether soils are fit to be worked or fields to be trodden by stock.

In addition the out-wintered stock is affected by long spells of cold driving rain, as they spend more time sheltering and less eating, leading to a loss of condition. Similarly long wet spells in summer can be a great disadvantage at haytime; the MAFF (1964) bulletin on The Farmer's Weather suggests that about one year in three brings ideal harvest weather and since dry spells cover most of Britain at the same time so that good conditions are shared by all, it is in the moderate or bad years that the drier east has a great advantage over the wetter west.

Wet and dry spells in hours

Hourly tabulations of daily rainfall from the Tanllwyth Dines recording raingauge, 1.10.73. - 30.9.75, were examined and the frequency of both wet and dry consecutive hours (from 1 hour to 24 hours, and > 24 hours) was tabulated. Wet hours are defined as excluding 0.1 mm and trace, except where they occur in a run of wet hours. Conversely dry hours include 0.1 mm and trace when they are in isolation. Periods of snowfall were ignored in the analysis (along with any hours where the recorder was not working).

Figures 1 and 2 show the frequency of wet and dry hours at Plynlimon. From these it is apparent that two hours of rainfall are more common than one hour, whilst a three hour spell of rainfall occurs less than half as many times as a two hour one. There are over twice as many single dry hours as there are two consecutive dry hours. This proportionately large number of very short (ie one hour) dry periods is important in terms of understanding the effects of interception of rainfall by the forest canopy and its subsequent evaporation. It is interesting to note also that one single dry hour roughly equates to two consecutive wet hours in frequency (and two dry hours to three wet, three dry to five wet; 17 and 18 hour spells have the same frequency for both wet and dry hours).

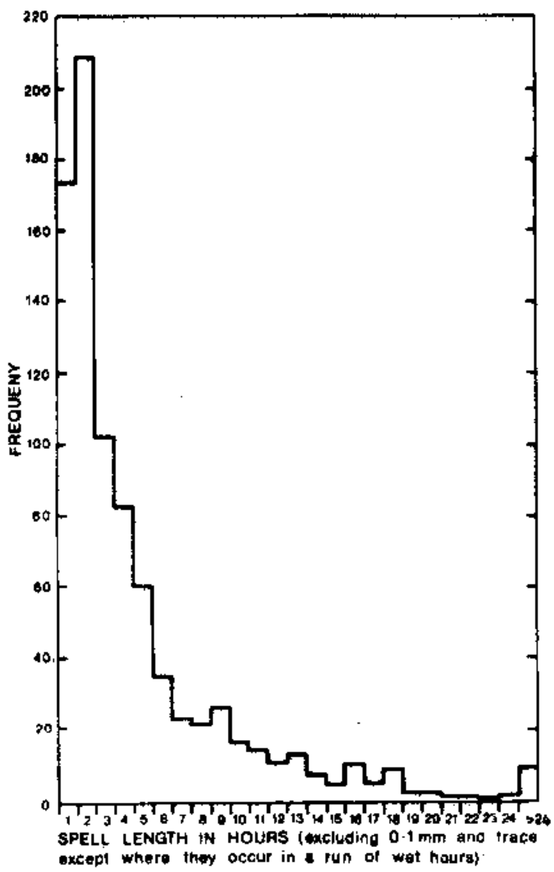

FIGURE 1 SHORT WET SPELLS
Frequency distribution of duration of sequences of wet hours hours 1.10.73-30.9.75.
(records from Tanllwyth Dines gauge ignoring snow periods and when recorder not working)

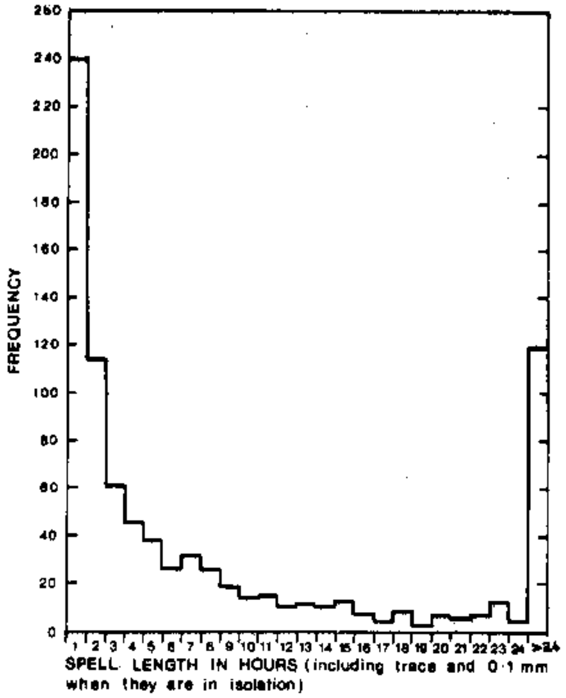

FIGURE 2 SHORT DRY SPELLS
Frequency distribution of duration of sequences of dry hours 1.10.73-30.9.75. (records from Tanllwyth Dines gauge ignoring snow periods and when recorder not working)

Wet and dry spells in days

The number of consecutive wet and dry days were separately analysed for the period 1st February 1968 - 30th September 1975 using Tanllwyth daily raingauge. A wet day is defined as having 0.2 mm or more rain, a dry day includes days with 0.1 mm or a trace of rainfall (which may be dew, frost etc). Before examining the data the point made by Williams (1952) must be borne in mind, namely the difference in form of observation of wet and dry days; one dry day is at least 24 hours without measurable rain and including up to 48 hours without rain. However the classification one wet day could result from one minute's rain to 24 hours continuous rain, whilst two wet days could result from one minute's rain spread over the artificial hour of separation, 0900 hours. Similarly two short spells of wet days can be joined to form a large one by a single shower. However at Plynlimon with such a high total rainfall the results will be less affected from this unavoidable inaccuracy than for drier regions.

Table 3 shows the annual average number of rain days to be 231 days or 64% of the total. The average length of dry spells at Plynlimon is much less than that of wet spells; this may be contrasted with the results from Williams' (1952) study of Harpenden (Herts) rainfall when the lengths of wet and dry spells were similar (over 10 years, 49% of days in a year were wet). The shorter length of dry spells compared to wet for Plynlimon is shown up by comparing the frequency distributions of the two spell types (Figures 3 and 4). There are almost twice as many single dry days as single wet days, approximately two consecutive dry days to every wet single one (the opposite of dry and wet hours). However, while the frequency of longer dry spells is reduced that of the longer wet spells is sustained such that there are almost three times the number of five day wet spells as five day dry spells; at the

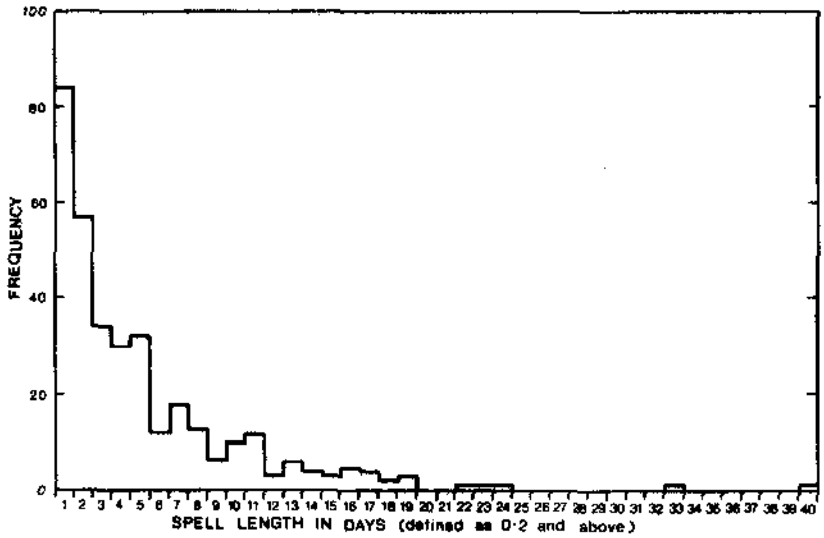

FIGURE 3 LONG WET SPELLS Frequency distribution of duration of sequences of wet days 1.2.68-30.9.75. (records from Tanllwyth standard daily raingauge

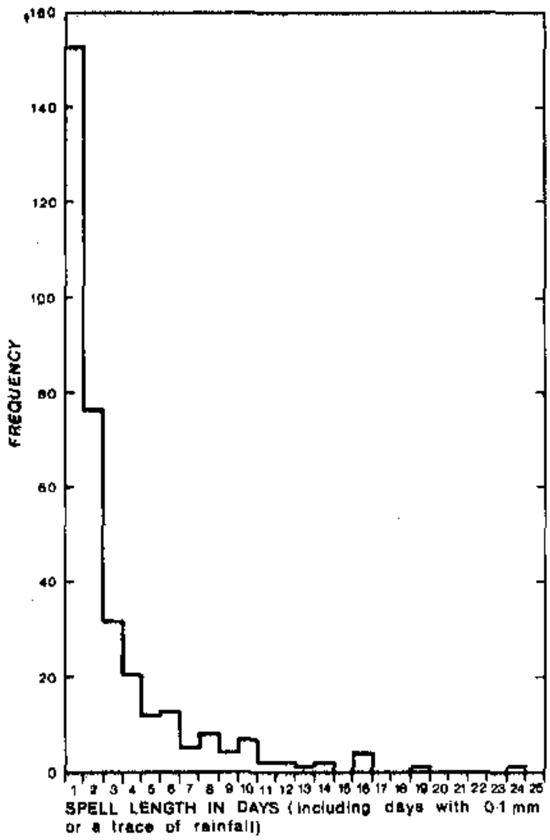

FIGURE 4 LONG DRY SPELLS Frequency distribution of duration of sequences of fine days 1.2.68-30.9.75. (records from Tanllwyth standard daily raingauge)

far end of the spell duration scale there are only two long dry spells above 16 days in the 7½ years of record compared with 14 long wet spells, which accounts for the higher overall annual number of wet days.

The annual average frequency of wet spells suggests that the likelihood of a two or three day wet spell is the same as that for a single wet day (11 ≃ 7 + 5). This again accentuates the surprisingly few single wet days in a year and the comparative large spread of longer spell lengths.

TABLE 5 Annual average frequency of wet spell lengths

Wet spell length in days	1	2	3	4	5	6	7	8	9	10	11	12–19	22 23 24 33 40
Annual average frequency	11	7	5	4	5	2	2	2	1	1	2	between 0 and 1*	Once each in eight calendar-years

This again accentuates the surprisingly few single wet days in a year and the comparative large spread of longer spell lengths.

* can be broken down as follows:

Wet spell length in days	Frequency in 8 years
12	3
13	[illegible]
14	4
15	3
16	5
17	4
18	2
19	3

For comparison the annual average frequency of dry spells is as follows:

TABLE 6 Annual average frequency of dry spell lengths

Dry spell length in days	1	2	3	4	5	6	7	8	9	10	11–14	16	19 and 24
Annual average frequency	20	10	4	3	2	2	1	1	1	1	once or twice each in eight calendar years	four times in eight years	Once each in eight years

To investigate the possibility of seasonality in the distribution of long wet and dry spells, all runs of ten consecutive wet days and over (from 1.2.68 - 30.9.75) were tabulated (Table 7) and the number of days for each spell were totalled according to the months in which they fell. The months were ranked in order of decreasing number of long wet spell days (included in brackets):

January	(136)
February	(98)
November	(95)
December	(92)
June	(73)
October	(63)
July) August)	(58)
March	(53)
April	(48)
September	(31)
May	(25)

TABLE 7 Run of ten days and over of CONSECUTIVE WET DAYS (0.2 mm and over) 1968 - September 1975 in water years, Tanllwyth

			Number of days	Total number per water year
13 March 1968	-	25 March 1968	13	
2 May 1968	-	12 May 1968	11	incomplete water year
19 June 1968	-	28 June 1968	10	
19 September 1968	-	(3 October 1968)	15	(12 in September)
(19 September 1968)	-	3 October 1968	15	(3 in October)
9 October 1968	-	19 October 68	11	
24 October 1968	-	2 November 1968	10	
19 November 1968	-	1 December 1968	13	
14 December 1968	-	25 December 1968	12	
6 January 1969	-	24 January 1969	19	1968-1969
4 February 1969	-	14 February 1969	11	(129)
18 February 1969	-	2 March 1969	13	
5 May 1969	-	18 May 1969	14	
14 June 1969	-	26 June 1969	13	
17 August 1969	-	26 August 1969	10	
7 November 1969	-	22 November 1969	16	
13 December 1969	-	25 December 1969	13	
8 January 1970	-	26 January 1970	19	
15 February 1970	-	24 February 1970	10	
1 March 1970	-	13 March 1970	13	1969-1970
23 March 1970	-	5 April 1970	14	(134)
14 April 1970	-	29 April 1970	16	
26 June 1970	-	5 July 1970	10	
18 July 1970	-	28 July 1970	11	
5 August 1970	-	16 August 1970	12	
23 October 1970	-	4 November 1970	13	
6 November 1970	-	23 November 1970	18	
26 November 1970	-	6 December 1970	11	1970-1971
16 January 1971	-	1 February 1971	17	(101)
11 February 1971	-	21 February 1971	11	
8 June 1971	-	21 June 1971	14	
30 July 1971	-	15 August 1971	17	
17 December 1971	-	27 December 1971	11	
7 January 1972	-	29 January 1972	23	
31 January 1972	-	16 February 1972	17	
24 February 1972	-	9 March 1972	15	1971-1972
25 March 1972	-	11 April 1972	18	(125)
2 June 1972	-	12 June 1972	11	
16 June 1972	-	4 July 1972	19	
30 July 1972	-	9 August 1972	11	
23 October 1972	-	15 November 1972	24	
27 November 1972	-	13 December 1972	17	1972-1973
4 February 1973	-	13 February 1973	10	(67)
9 July 1973	-	24 July 1973	16	
12 October 1973	-	23 October 1973	12	
9 December 1973	-	22 December 1973	14	
3 January 1974	-	18 January 1974	16	
21 January 1974	-	22 February 1974	33	1973-1974
26 June 1974	-	5 July 1974	10	(116)
7 August 1974	-	16 August 1974	10	
30 August 1974	-	9 September 1974	11	
20 September 1974	-	29 September 1974	10	
12 October 1974	-	22 October 1974	11	
5 November 1974	-	14 November 1974	10	
22 November 1974	-	13 December 1974	22	1974-1975
23 December 1974	-	31 January 1974	40	(112)
6 April 1975	-	21 April 1975	16	
12 July 1975	-	24 July 1975	13	

As expected, the months with long wet spells are shown to be November to February with January well ahead. It is surprising however, to find June in fifth position, closely followed by the other summer months of July and August, particularly since June has the lowest monthly rainfall average. Stevens (1974) using ten years of data from Southampton, also found June to have unexpectedly more consecutive wet days than July, but concludes that this may be due to the relatively short period of data examined. June may have a tendency to periods of consecutive rain days of low amounts rather than many isolated ones as investigation has already shown June to also have among the lowest average number of rain days per month at Plynlimon. Stevens found that the longest wet spells at Southampton, apart from the isolated occasion in June, are confined to the months November-April, (differing slightly from Plynlimon); similarly Blair-Fish (1975), using Oxford data, found winter wet spells to be slightly longer than those of other seasons. It is notable from the Plynlimon long wet spell ranking that October and September (particularly the latter) hold such low positions when compared to their high average monthly rainfall totals (see Table 2).

The study of seasonal distribution of long wet spells was extended by considering only wet spells of 15 days and over, and ranking as before:

January	(136)
November	(62)
February	(45)
April	(43)
December	(35)
July	(22)
March	(16)
June) August)	(15)
September) October)	(12)
May	(-)

The ranking now is more in accord with Stevens' findings for Southampton with November to April containing the longest wet spells (only March is one position out). January has over twice as many days which are part of very long wet spells as any other month. The longest wet spell lengths in the eight years of data examined, again not surprisingly, all fall into the late autumn/winter season:

(from Table 7)

Wet spell length in days	date
22	22.11.74 - 13.12.74
33	21.1.74 - 22.2.74
40	23.12.74 - 31.1.75

all of which fell within 12½ months and

23	7.1.72 - 29.1.72
24	23.10.72 - 15.11.72

which occurred within the same calendar year.

The very high numbers of consecutive wet days throughout the whole year, but particularly during the winter, in this area of Wales has important implications for the many weather-dependent activities mentioned in the introduction to this section. Stevens (1974) investigating the numbers of consecutive wet working days at Southampton found from ten years of data that they averaged 75 days a year. He defined a "wet working day" as one with 1 mm or more rainfall between 0600 hours GMT and 1800 hours GMT; a comparison with Stevens' results is therefore difficult. However, since rainfall during the night is often as important as rainfall during working hours in terms of waterlogged fields and trampling by stock, wet building foundations, bogged tractors and winches in forestry operations, it is more valid at Plynlimon to consider a wet day in terms of 24 hour rainfall. It is interesting to note that the Plynlimon annual average (from eight years of record) of days of 1 mm and over is 193 days whilst that for days of 5.0 mm and over is 122 days - still many more than the 75 days for Southampton.

The seasonal distribution of long wet spells suggests that the period November to February may well be unsuitable for certain kinds of field activity. (This period by chance included the time the foundations and concreting of the Institute's new office building at Dolydd were being constructed under very difficult conditions throughout the wet winter of 1973-74). May is the best month for outdoor projects as it has the lowest ranking of days forming part of long wet spells - a fact long recognised by the local Forestry Commission.

Long dry spells were investigated in a similar way to the wet spells except that the criterion of ten consecutive wet days was halved to five consecutive dry days to give a similar sized sample. From Table 8 of spells of five days and over, the number of dry days per month were totalled and ranked in order of decreasing number of long spell days (in brackets):

April	(77)
June	(65)
August	(63)
July	(62)
September	(60)
May	(57)
March	(52)
February	(36)
October	(34)
December	(17)
January	(9)
November	(6)

TABLE 8 Runs of five days and over of CONSECUTIVE FINE DAYS, 1968 - September 1975, in water years, Tanllwyth

Days with a trace and 0.1 mm rainfall are counted as dry days

		Number of days	Total number per water year
18 February 1968	- 4 March 1968	16	
7 April 1968	- 14 April 1968	8	
18 May 1968	- 23 May 1968	6	
9 June 1968	- 18 June 1968	10	(incomplete year)
23 July 1968	- 2 August 1968	11	
25 August 1968	- 29 August 1968	5	
11 November 1968	- 16 November 1968	6	
3 March 1969	- 10 March 1969	8	1968-1969
1 April 1969	- 8 April 1969	8	(53)
4 June 1969	- 13 June 1969	10	
11 July 1969	- 17 July 1969	7	
27 August 1969	- 9 September 1969	14	
30 April 1970	- 5 May 1970	6	
22 May 1970	- 29 May 1970	8	1969-1970
1 June 1970	- 9 June 1970	9	(30)
23 August 1970	- 29 August 1970	7	
12 October 1970	- 17 October 1970	6	
7 December 1970	- 11 December 1970	5	
3 February 1971	- 7 February 1971	5	
22 February 1971	- 26 February 1971	5	1970-1971
6 April 1971	- 14 April 1971	9	(93)
1 May 1971	- 5 May 1971	5	
11 May 1971	- 15 May 1971	5	
17 May 1971	- 21 May 1971	5	
28 June 1971	- 8 July 1971	11	
10 July 1971	- 21 July 1971	12	
20 August 1971	- 25 August 1971	6	
4 September 1971	- 22 September 1971	19	
4 October 1971	- 9 October 1971	6	
5 December 1971	- 10 December 1971	6	
15 March 1972	- 24 March 1972	10	1971-1972
16 April 1972	- 27 April 1972	12	(96)
13 May 1972	- 19 May 1972	7	
13 July 1972	- 20 July 1972	8	
22 July 1972	- 29 July 1972	8	
10 August 1972	- 15 August 1972	6	
21 August 1972	- 5 September 1972	16	
14 September 1972	- (7 October 1972)	24	(17 in September)
(14 September 1972)	- 7 October 1972	24	(7 in October)
12 October 1972	- 18 October 1972	7	
17 December 1972	- 22 December 1972	6	
4 January 1973	- 12 January 1973	9	1972-1973
7 March 1973	- 22 March 1973	16	(80)
14 April 1973	- 18 April 1973	5	
24 April 1973	- 29 April 1973	6	
3 June 1973	- 8 June 1973	6	
11 August 1973	- 18 August 1973	8	
4 September 1973	- 13 September 1973	10	
24 October 1973	- 31 October 1973	8	
25 March 1974	- 9 April 1974	16	1973-1974
13 April 1974	- 25 April 1974	13	(43)
20 June 1974	- 25 June 1974	6	
1 February 1975	- 9 February 1975	9	
24 February 1975	- 28 February 1975	5	
14 March 1975	- 20 March 1975	7	
22 April 1975	- 27 April 1975	6	1974-1975
15 May 1975	- 24 May 1975	10	(87)
26 May 1975	- 31 May 1975	6	
5 June 1975	- 14 June 1975	10	
20 June 1975	- 3 July 1975	14	
25 July 1975	- 3 August 1975	10	
9 August 1975	- 13 August 1975	5	
24 August 1975	- 28 August 1975	5	

It is not unexpected that the late spring to early autumn should have the most long dry spells - the converse of the long wet spells. It is surprising, however, that the month with the highest total of dry spell days is not May but April by a clear margin, with June, August, July, September and May grouped closely together, behind. The position of April is the more unexpected since it ranks highly among the months forming part of the very long wet spells. It is possible that this result may be in part due to the comparatively short period of data examined or that April is prone to either wet or dry spells depending on the circulation patterns of the particular year, with single wet or dry days less common.

In spite of the clear seasonal trend to longer or more dry spells in April to September, the particularly wet summer of 1974 went against the seasonal norm such that between April 1974 and February 1975 there was only <u>one</u> dry spell of five days and over, that of six dry days in June!

5. SYNOPTIC ORIGINS OF RAINFALL

Now that the experimental radar scheme on the Dee at Bala is approaching its conclusion and is unlikely to be continued for financial reasons, the continuing investigation of synoptic association with rainfall seems one of the best approaches to forecasting rainfall, (particularly heavy rainfall), since it is one which can be adapted to the requirements of both Water Authorities and farmers.

The synoptic classification devised by Lamb (1972) was used together with the Meteorological Office Daily Weather Report to identify the synoptic type for every day of the period October 1973 to September 1975. Lamb defines seven types of circulation patterns: Anticyclonic (A), Cyclonic (C), Westerly (W), North-Westerly (NW), Northerly (N), Easterly (E), and Southerly (S). They are recognised by surface maps of pressure

TABLE 9 *Rainfall and synoptic weather type*

	Westerly	North-Westerly	Northerly	Easterly	Southerly	Anticyclonic	Cyclonic
Percentage of weather types							
Year I*	40.1	5.2	4.9	9.7	4.3	25.9	9.2
Year II	48.9	6.3	10.7	1.6	2.3	24.5	5.6
Year I and II mean %	44.5	5.8	7.8	5.7	3.6	25.2	7.4
Lamb† 1960–9	[illegible]	6.3	8.1	9.4	6.4	23.2	[illegible]
Number of days of each weather type							
Year I	146.5	19	18	35.5	18	94.5	33.5
Year II	178.5	23	39	6	8.5	89.5	20.5
Total rainfall (mm) for each weather type (mm)							
Year I	1740.4	135.3	72.4	38.5	84.1	72.7	355.8
% of annual total	69.6	5.4	2.9	1.5	3.4	2.9	14.2
Year II	1914.1	180.5	105.9	9.8	5.1	33.1	162.2
% of annual total	79.4	7.5	4.4	0.4	0.2	1.4	6.7
Mean 2 years in %	74.5	6.5	3.6	0.9	1.6	2.2	10.5
Average daily rainfall (mm) for each weather type							
Year I	11.9	7.1	4.0	1.1	4.7	0.8	10.6
Year II	10.7	7.8	2.7	1.6	0.6	0.4	7.9
Mean 2 years	11.3	7.5	3.4	1.4	2.7	0.6	9.3

*Year I October 1973 – September 1974. Year II October 1974 – September 1975. † From Lamb 1972, Page 15.

distribution, winds and weather; the classification works best as an indicator of the steering of the circulation systems over a sequence of days. The classification is used in this report on a daily basis, although Lamb recommended that ideally it should be used for groups of days.

In classifying the days, there were occasions when there were small scale systems of unlike character across the British Isles, rapidly-changing systems or chaotic or weak patterns; these days were, however, allocated to whichever of Lamb's classes appeared most relevant to the situation affecting Mid-Wales, so that no day remained unclassified. This is despite the fact that Lamb regards some synoptic conditions (about 6% per year) as unclassifiable.

The daily rainfall (read at 0900 hours GMT and thrown back a day) from Tanllwyth standard gauge was tabulated against the daily register of circulation patterns and the precipitation totals for each weather type were obtained. The totals were then divided by the number of days of each weather type to obtain the average daily precipitation per weather type. In the case of hybrid days (days satisfying the definitions of two or more weather types), the day was apportioned accordingly in half or thirds to each component and similarly with its accompanying rainfall amount.

Table 9 shows firstly the percentage and actual number of days of each weather type for each of the two years in question. Comparing these figures with those obtained using the same method (except for unclassifiable days) by Lamb (1972), but averaged over a decade, it would appear that many days may have been classified as westerly which should have been classified as cyclonic. However, the two weather types are very closely linked, often occurring as hybrids. Otherwise the percentage types obtained for October 1973 to September 1975 agree with Lamb's for 1960-69. Thus westerly weather type ($\pm$ cyclonic) accounts for the largest number of days in the two years (over 40% of days) whilst anticyclonic type accounts for about a quarter of the days in each year.

The total rainfall for each weather type shows westerly days as contributing 74.5% of the precipitation during October 73 - September 75, with the type occurring on 44.5% of days in the year and cyclonic days an important 10.5% of the precipitation occurring on 7.4% of days in the year. Of the other synoptic types, only north-westerly type contributes significantly (6.5%) to the annual total, occurring on 5.8% of the days in the year.

The table finally shows average daily rainfall for each weather type, and it is significant that westerly, cyclonic and north westerly daily averages are all well above the Meteorological Office cut-off point of 5.0 mm for heavy rainfall in a day on their met. form number 3208.

Westerly type weather involves high pressure in the south of the British Isles, low to the north. Linear sequences of depressions, fronts, troughs and ridges travel eastward giving unsettled weather, with heaviest rain in windward western coastal areas. Elevation and exposure effects are marked. This gives Plynlimon the highest average daily rainfall for any type (11.3 mm).

Cyclonic type involves depressions stagnating over or passing across the British Isles. The definition requires that the depression should be centred over the mainland at some time during the day. The associated weather is wet and disturbed with very variable wind directions (cf westerly type). Again a high mean daily rainfall (9.3 mm) at Plynlimon, approaching that for westerly days.

North-westerly type results from displacement north-east of the Azores High which produces north-westerly air flow. Depressions forming near Iceland travel south-east into the North Sea. The associated weather is unsettled, especially in northern and eastern British Isles. Elevation and exposure are again important as in the westerly type and help to explain its fairly high daily average rainfall of 7.5 mm at Plynlimon.

Northerly type results from high pressure to the west and north west of the British Isles with low pressure over north-west Europe. The surface cold northerly flow often accompanies a cold upper-level trough causing unstable conditions with snow, hail or rain showers. These tend to be heaviest on windward northern coasts hence Plynlimon is largely protected by Snowdonia and the Berwyn Range, although this type still registers a significant mean daily precipitation of 3.4 mm. However, like the precipitation associated with the remaining synoptic types to be described, northerly type days contribute only a very minor amount (3.6%) to the annual total rainfall.

Southerly type is caused by high pressure over central and northern Europe, blocking Atlantic depressions to the West of the British Isles. The resulting southerly flow can cause thunderstorms in spring and summer. Southerly type is infrequent (possibly under-estimated by the author - occurring on 3.6% of the days in Year I and II, cf Lamb's 8.4% for 1960-9) and accounts for only 1.8% of the annual total rainfall with a mean daily rainfall of 2.7 mm. Thunderstorms are uncommon at Plynlimon.

Easterly type results from anticyclones extending over Scandinavia with depressions circulating over the western North Atlantic. The easterly winds give very dry weather in the Western British Isles. The mean daily rainfall at Plynlimon for this type is 1.4 mm, which contributes only 0.9% of the annual total rainfall.

Anticyclonic type weather occurs when an anticyclone is centred over or near the British Isles. Anticyclones produce by far the smallest mean daily precipitation of any weather type, which is as expected - a mere 0.6 mm.

Finally, it is interesting to compare the Plynlimon average daily rainfall for each weather type with figures obtained by Houghton and Cinnéide (1976) for 17 stations throughout Ireland and averaged for the year 1970-71.

In order of decreasing mean daily precipitation in mm with weather type for Plynlimon:

Plynlimon	W	C	NW	N	S	E	A
October 1973-September 1975	11.3	9.3	7.5	3.4	2.7	1.4	0.6
Ireland							
1970-71	3.5	4.7	1.8	1.0	3.2	1.1	0.6

Although cyclonic type days had overall the highest mean daily precipitation value for Ireland, on the north-west coast Houghton and Cinnéide found that the mean daily westerly type precipitation of 5.0 mm exceeds all others, as at Plynlimon, but decreases markedly eastward with leeward rain shadow effects.

Conclusion

Westerly and cylonic days provide the larger part of the precipitation at Plynlimon; they have both the highest mean daily amounts and together with anticyclonic are by far the most common types (accepting that some westerly days should probably have been classified cyclonic or cyclonic westerly hybrid). Together they provide 85% of the annual rainfall for Plynlimon from October 1973 - September 1975. Of the other types, north-westerly contributes the most with 6.5% while northerly, easterly, southerly and anticyclonic together contribute the remaining 8.5% of the annual total. Anticyclonic days contribute a not inconsiderable 2.2% of the annual total considering that the mean rainfall for such days is 0.6 mm, the explanation being that over 25% of days in the year are of this weather type.

The description given earlier of the two above average wet winters and the one very wet and one very dry summer which make up this two-year sample of detailed study, rather strongly suggests that they were not typical of the second half of the twentieth century. Lamb (1972) and Houghton and Cinnéide (1976) find an increase in the frequency of non-westerly days since 1955 as compared with the long-term period 1868-1967. The Plynlimon data show that the combination of westerly and cyclonic days accounts for 52% of all days in the two years, which is higher than Lamb's mean percentage frequency of the two types for 1868-1967 of 43% and for 1960-69 of 41%. Although part of the Plynlimon excess may be the result of adding part or all of the average 6% of days a year which are unclassifiable to the westerly cyclonic categories, it appears that the study period represents a higher than average frequency of westerly and cyclonic days particularly throughout the calendar year 1974, with a return to blocking anticyclones predominating from Spring 1975.

HEAVY RAINFALL

The remainder of this section looks at individual heavy rain days resulting from westerly or westerly cyclonic synoptic situations.

Storms of over 50 mm

The number of rain days of over 50 mm at Tanllwyth in the eight year period January 1968 to December 1975 is shown in Table 10. The figure of 50 mm in 24 hours was chosen as the Severn and Wye River Authorities had found it related to important past floods. 50 mm falls average four per year, ranging from two in 1969 to seven in 1973. November and April have the highest number of such days (six) in the eight years, while only July has none. Most heavy falls occur in the winter half of the year (November-April) although there are some high 24-hour totals in summer. This agrees with Benwell's (1967) geographical and seasonal distribution of heavy falls on rainfall days - highest monthly totals of heavy falls in the north-west of Britain occur in the winter season, unlike the south-east of England where the highest monthly totals of heavy falls are for July and August.

TABLE 10 Rainfall days producing 50.0 mm or more at Tanllwyth, January 1968 - December 1975

Date	Rainfall in mm	Date	Rainfall in mm
15 March 1966	53.3	28 April 1972	52.6
1 April 1966	51.4	9 November 1972	62.0
12 May 1966	52.5	12 November 1972	63.8
26 June 1968	50.3	7 February 1973	52.3
20 January 1969	50.4	11 February 1973	56.1
2 December 1969	53.9	1 April 1973	85.4
15 April 1970	50.4	5 August 1973	100.6
20 April 1970	52.7	2 September 1973	61.6
22 April 1970	52.1	18 October 1973	63.5
27 October 1970	66.6	5 November 1973	61.2
1 November 1970	54.9	14 January 1974	74.[illegible]
12 February 1971	75.8	8 February 1974	[illegible]
18 June 1971	62.5	7 September 1974	61.7
18 October 1971	77.2	21 January 1975	60.8
7 November 1971	58.3	24 September 1975	66.9
20 November 1971	77.5	1 December 1975	102.8

Heavy rainfall in the water-years October 1973 - September 1975 is considered in more detail for the rest of this section. In this period daily falls of 50.0 mm or more have occurred seven times; two consecutive days have given 70.0 mm or over six times; three days have give 100 mm or over four times; five days have produced 155 mm or over, once. The synoptic situations associated with these heavy rainfall spells (each of the single heavy rain days was associated with one or more other days in the subsequent grouping) always contained a mainly westerly component, in some cases accompanied by days with westerly cyclonic hybrids or north-westerly type.

The seven heaviest (i.e. 50 mm and over) rainfall days in this two water-year period were looked at in detail as they represented the major storms for which flood warnings were given to the respective River Authorities, if not always also the major flood producing storms of the two years in question. They were also all on westerly type days.

Data examined For each day with a daily rainfall total 50 mm or more from the Tanllwyth daily standard raingauge, the appropriate Dines recording gauge hourly tabulations were examined for the active duration of the storm. Having isolated the storm centre the ends are each defined by an hour with no rain unless the rain an hour before or after this dry hour is clearly another prolonged heavy spell (this latter was only once the case). The rainfall is generally of continuous variety except for 7.9.74 - see the differences between total and actual duration in Table 11. The breakdown of each storm in terms of total rainfall, duration, maximum and average intensity etc is given in Table 11. Each storm is also divided into quartiles of duration and the percentage of the total storm which fell in each quartile calculated.

Discussion of data: Table 11 shows all the storms to be lengthy, ranging in terms of actual hours and parts of hours of rain falling from nearly 15 hours to nearly 25 hours. Average intensity, however, is fairly low, ranging from 2 mm/hr to 4.4 mm/hr (dividing total storm rainfall by total storm duration in whole clock hours remembering that part of some hours may have been dry). Maximum intensities also are not particularly high (5.8 mm/hr to 10.6 mm/hr) and Figure 5 of the average intensity-duration relationship for the seven storms shows that even these intensities are not long maintained; rather the curve shows a steady slow decline suggesting moderate/heavy rainfall is maintained over a long period rather than any sudden jump in rainfall amount. Holgate (1973) in his evaluation of major falls likely to cause flooding has adopted the criterion that more than 35 mm of rain has to fall within six hours in short steep catchments such as Langdale Valley, Lake District and Gwynedd, N. Wales, and within 12 hours for other catchments. Therefore 6 mm/hr appears to be the critical rate for steep, hilly catchments. Of the seven heaviest Plynlimon storms in the two

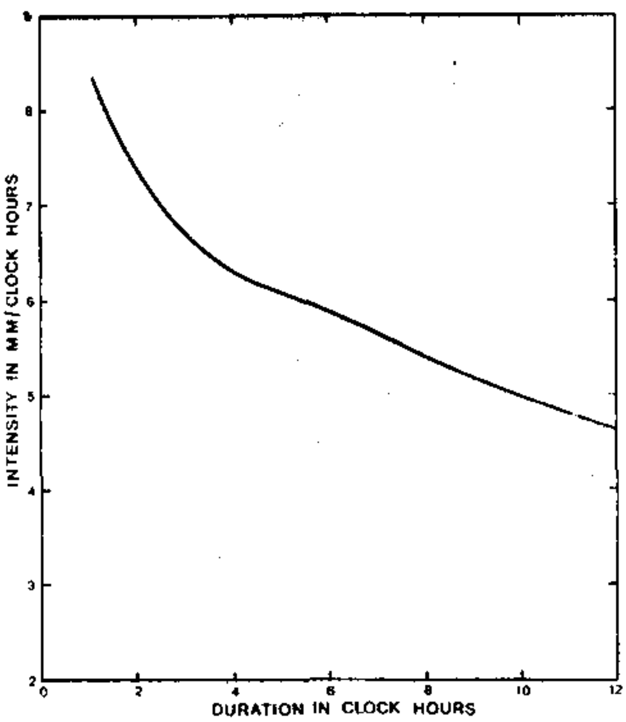

FIGURE 5 Intensity duration graph for the seven heaviest storms occuring October 1973 - September 1975

TABLE 11 **Heaviest storms, October 1973 - September 1975**

Date	Synoptic situation on day of storm, day preceeding and following	Standard daily rainfall 0900-0900 hours in mm	Dines recording gauge rainfall for duration of storm in mm	Total storm duration in whole clock hours	Average rainfall intensity (Dines storm rainfall ÷ total duration in clock hours in mm/hour	Actual rainfall duration in fractions of clock hours	Actual average rainfall intensity (Dines rainfall ÷ actual duration in fractions of clock hours) in mm/hr	Maximum rainfall intensity for one clock hour in mm	Percentage of total storm rainfall which fell in each quartile of total duration				
									1st	2nd	3rd	4th quartile	
18.10.73	N-W-W	63.5	75.5	17	4.4	14.9	5.1	10.5	13.4	19.6	44.6	22.4 %	
9.11.73	A/W-W-NW	63.2	64.2	22	2.9	21.9	2.9	5.8	26.6	37.4	26.6	9.3 %	
14.1.74	W-W-C/W	74.2	64.5	16	4.0	14.8	4.4	10.6	15.8	41.7	24.8	17.7 %	
8.2.74	N-W-W	52.4	41.1	15	2.7	14.6	2.8	7.1	6.8	33.8	46.5	12.9 %	
7.9.74	W-W/C-W	61.7	74.9	38	2.0	23.2	3.2	7.6	13.2	54.2	18.7	13.9 %	
21.1.75	W-W-W	60.8	85.2	24	3.6	22.4	3.8	8.1	13.4	23.8	44.0	18.8 %	
24.9.75	W-W-W/C	66.9	77.0	28	2.8	24.9	3.1	9.3	14.5	29.5	39.9	16.1 %	
							average:	8.4	14.8	34.3	35.0	15.9 %	- Average percentage
									14.8	49.1	84.1	10.0 %	- Average cumulative percentage

years, three meet the criteria of at least 35 mm in 6 hours while the remaining four storms all have this amount in eight hours (underlined in Table 12). It would seem likely then that the rainfall of 18.10.73., 14.1.74 and 21.1.75 would almost certainly have resulted in flooding; storms on the other dates given would probably have resulted in flooding also. Holgate adds that for the Gwynedd area River Authority experience has shown that a fall of 50 mm in 24 hours is often on its own sufficient to produce flooding, regardless of detailed rates of fall.

TABLE 12 Maximum rainfall amounts, mm, for consecutive hours within the seven heaviest storms

Date	2 hrs	4 hrs	6 hrs	8 hrs
18.10.73	19.7	33.5	44.9	55.1
9.11.73	11.3	20.7	29.7	35.2
14. 1.74	18.7	29.8	36.6	43.8
8.2.74	11.1	19.5	28.8	35.5
7.9.74	12.5	21.8	32.5	38.2
21.1.75	15.0	28.6	40.7	51.3
24.9.75	13.5	21.3	32.6	40.8

It is of interest, but probably coincidental, that Figure 5 shows the average intensity for the seven storms for six hours duration to be 5.9 mm/hr, almost exactly Holgate's critical rate.

The proportions of the total rainfall for 25,50, 75% of the storm duration show in Table 11 that in every case the middle sections (25-75% of duration) of the storm have the most rainfall. About half the rainfall (49.1% on average) has fallen by half the storm duration. This may be compared with results in the storm profiles section of the Flood Studies Report (NERC, 1975) in which for U.K. stations as a whole half the storm rainfall fell in one quarter of the duration. However the differences in result may be due to the Flood Studies method of centering the storms as well as to the small Plynlimon sample of seven. A simpler method was justifiable for Plynlimon storms since they were all of the same geographical location and produced by the same synoptic type and the author's method is similar to that used by Huff (1967) for storms in the Midwest, USA. The two forms of rainfall profiles presented, Figures 6 and 7, emphasise the points shown up by Table 11. Figure 6, cumulative percentage rainfall against duration, shows that the shortest duration in which half the storm rainfall fell was 38%, i.e. the rainfall is generally evenly distributed throughout the storm. The maximum and minimum quartile proportion's profiles for the storms are not far from the mean profile emphasising the similarities of the seven heaviest storms. Figure 7 shows the rainfall profile of each storm in mm of rain per hour. Again the general "flatness" of the profiles bears out earlier points as to the even, steady nature of the rain, well distributed throughout the storms. November 9-10, 1973 and January 21-22, 1975 are particularly good examples of storms without a peak. These may be compared with the storm profile for 5-6 August, 1973 (Newson, 1975,

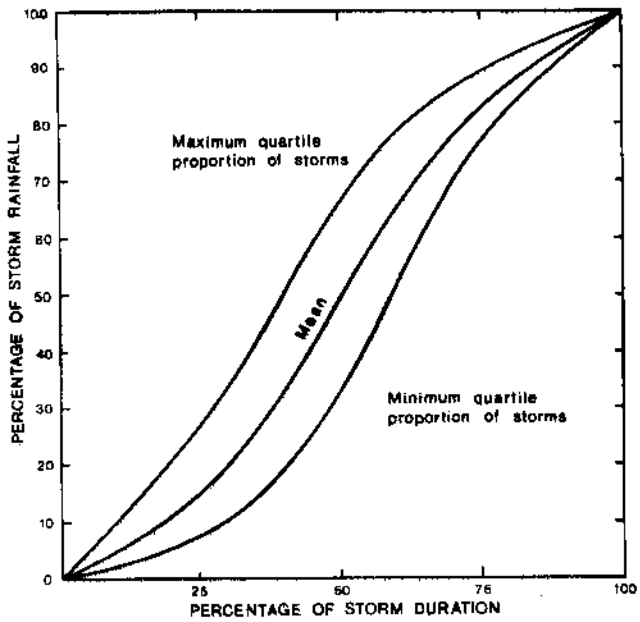

FIGURE 6 Rainfall profiles for the heaviest storms, October 1973 - September 1975, Tanllwyth

page 12) which produced the highest flood peaks ever recorded in the Upper Severn and Wye Catchments; the storm peaked late with a very pronounced two hour "core" of 50 mm, after 50% of the storm rain had already fallen. The type of storm and the nature of its "peakiness" is important not only in the more obvious effects on flooding but also in terms of sediment movements as exemplified in the University College, Aberystwyth report on sedimentation of Aberystwyth harbour: Figure 24 in the report shows streamflow and suspended sediment concentration for the river flowing into Aberystwyth, for two differing rainfall events. The first had short duration (5 hours), high intensity rainfall of 14 mm total with a clear peak of 4 mm, giving rise to a short sharp hydrograph and a similar suspended sediment concentration peak. The second event was intermittent light rain over a long period (24 hours) but with a similar total, 13 mm, to the first. The hydrograph showed a clear streamflow peak but only a very low suspended sediment concentration peak, thus showing the importance of variations in duration and intensity of rainfall. These effects are now being investigated in the study of bedload movement in the Plynlimon catchments.

Storms of 30-50 mm

For the two water-years under consideration (October 1973 - September 1975) the storms associated with daily rainfall totals of between 30 and 50 mm at Tanllwyth were examined by the method already described for storms giving daily totals of over 50 mm, but with particular attention paid to the spread of rainfall throughout the storm. On examining the hourly Dines tabulations for storms recording between 30 and 50 mm in the standard gauge, five storms had to be discounted for reasons including the following: snow accounted for part of the precipitation; the rainfall total was made up from discrete heavy showers all of which were much less than 30 mm; the daily rainfall total overlapped a storm which had already been investigated. The remaining storms are tabulated

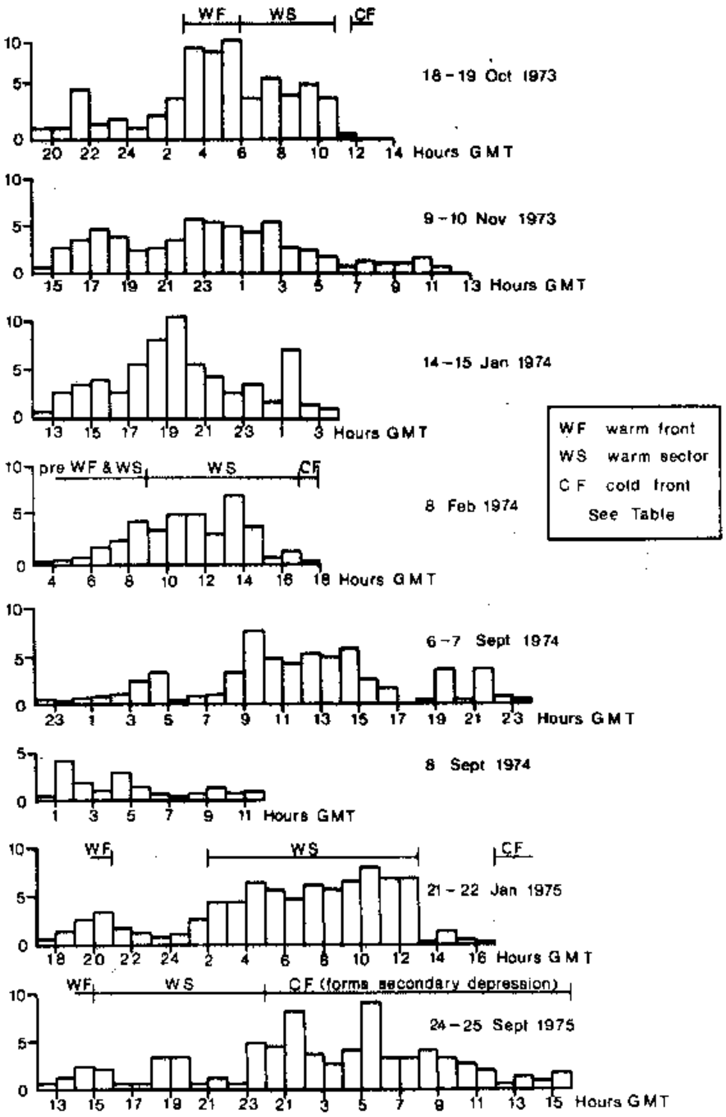

FIGURE 7 Rainfall profiles for the heaviest storms, October 1973 - September 1975, Tanllwyth

(Table 13) to show the rainfall for each quartile of the storm as a cumulative percentage of the total as before. The table also shows that almost all the storms were again associated with a westerly synoptic situation, with only one case of a pure cyclonic situation, and again mainly occurring in the winter months. It is not unexpected to find the total rainfall from the Dines recorder for some (three) storms to be greater than the 50 mm original criteria because they are split by the arbitrarily drawn convention of 0900 hrs rainfall day (just as the storm on 8.2.74 in the over 50 mm section was picked on meeting the > 50 mm in a rainfall day criteria, but on examination the storm only totalled 41 mm itself), but with the exception of 3-4.7.74 their total rainfall was

TABLE 13 Rainfall for each quartile of 30-50 mm storms as cumulative percentage of total storm rainfall

Date	Dines rainfall for storm duration in mm	25%	50%	75%	Synoptic situation on day of storm and day preceding and following
14.11.73	38.3	3.6	44.1	80.9	NW-W-W
7.12.73	40.9	9.5	37.4	81.7	W-C/W-N
10.12.73	31.4	11.1	46.5	84.4	W-W-W
12.12.73	34.0	25.9	58.2	85.0	W-W-NW
15.12.73	40.8	12.2	31.1	85.3	NW-N-NW
3-4.7.74	66.3	22.3	55.6	69.2	W-W-W
5.9.74	39.4	22.1	41.6	47.7	W-W-W
24.9.74	41.0	21.2	43.6	80.7	C-C-C
18.10.74	52.6	15.8	46.4	83.3	W-W-W
10.11.74	33.9	2.1	28.0	77.0	W-W-C/W
2.12.74	32.6	43.3	83.8	89.9	W-W-W
20-21.12.74	36.2	56.4	78.2	88.7	W-W-W
27.12.74	36.4	28.0	63.2	80.5	W-W-W
6.1.75	39.0	23.1	51.8	75.6	W-W-W
1.5.75	42.6	7.0	31.9	66.2	W-W-W
22.7.75	59.1	25.2	37.4	60.2	W-W-W
11.9.75	31.1	27.0	56.9	77.2	W-W/C-W/C
	AV.	20.9	49.2	77.3	

less than the heaviest storms described earlier (excepting 8.2.74!) thereby justifying the sample division criteria. The rainfall of 3-4.7.74 while high in total was very prolonged in duration and hence intensities were low. Several of the storms in Table 13 however did require flood warnings to the respective authorities and some were in fact flood producing.

Comparing the distribution of storm rainfall in time for the two sub-divisions of heavy rainfall (Table 11 and 13) the characteristics established with the seven heaviest storms are again apparent in the larger and more varied sample of 30-50 mm events. Although a few storms in Table 13 stand out as peaking early or late, over half the storms resemble the heavier events in that most of the rain falls in the middle sectors, within 25 to 75% of the duration. Amonst the exceptions were 5.9.74 where over 50% of the rain fell in the last quarter of the duration; 2.12.74 where over 80% of the rain had fallen by half of the duration; 21.12.74 where over 50% of the rain fell in the first quarter of the duration. It is the exceptions which give the shape to the maximum and minimum quartile proportion curves in Figure 8. However, the average percentage rainfall for each storm duration quartile is similar for both the two subdivisions of heavy rainfall. In fact both groups have on average just under half the storm rainfall in half the duration, while the profile of the 30-50 mm storms is on average even "flatter" and the rainfall more evenly spread than for the heaviest ones.

From Tables 11 and 13 — Average rainfall for both groups of storms as a cumulative percentage of total storm rainfall:

Duration:	25%	50%	75%
Storms > 50 mm	14.8	49.1	84.1
Storms 30 - < 50 mm	20.9	49.2	77.3

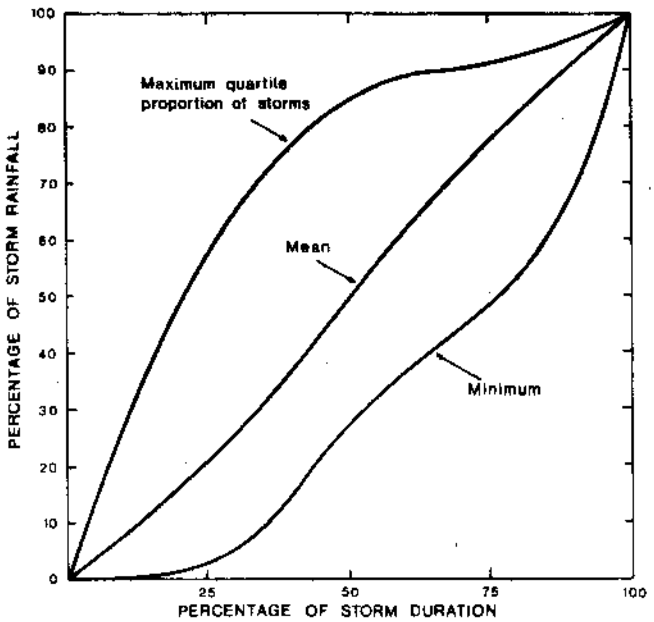

FIGURE 8 Rainfall profiles for storms of between 30-50 mm (in daily total) October 1973 - September 1975, Tanllwyth

Synoptic criteria and heavy rainfall forecasting

Several investigations have been made into linking synoptic criteria with heavy rainfall amounts for use as a basis for flood forecasting, notably by Holgate (1973) Finch (1972), Lowndes (1968) and Nicholass and Harrold (1975). The areas of heavy rainfall studied were mainly the Lake District, the Upper Dee and Gwynedd, in North Wales; the synoptic criteria identified in association with high falls were similar for all these areas and can be combined into the following summary (which does not cover the thunderstorm occasion):

a. Westerly airstream, often with the active cold front (or occasionally the warm front) of very deep depressions becoming retarded and slow moving by wave development as it approaches the area with the waves contributing a large proportion of the final total, and orographic effects important.

b. An occluding warm sector of a developing deepening depression across the area; relative humidity in the warm air ahead of the cold front is high from the surface to the 700-mb level.

c. The geostrophic wind speed ahead of the front is at least 35 knots and from the south-west, and maintained for some time.

d. The central pressure falls to 988 mb or less on the rainfall day; pressure falls 3 mb or more per three hours ahead of the warm front and in the warm sector.

Since Plynlimon is similarly exposed to the moist south-westerlies it would seem likely that the synoptic criteria developed for North Wales and the Lake District would be equally applicable here. With that in mind the detailed synoptic situation for each of the 24

TABLE 14 The twenty-four heaviest rainfall events, October 1973 - September 1975, in relation to prevailing synoptic weather type

√ = produced rain
x = present during event, but no associated rain
- = not present at time of event

Date	Total storm rainfall in mm (Tanllwyth Dines)	Warm Front (WF)	Warm Sector (WS)	Cold Front (CF)	Remarks
18.10.73	75.5	√ (core of storm)	√ (5 hrs steady)	x	
9-10.11.73	64.2	-	-	(+ waves)	No distinct depression
14.11.73	38.3	fronts cannot be separated			Fast moving
7.12.73	40.9	√	√	√ (peak rainfall)	Fast moving
10.12.73	31.4	-	-	√	
12.12.73	34.0	√ (1st peak)	√ (most rain)	√ (no intensity increase although CF passed)	Fast moving
15.12.73	40.8	√ / Pre WF	√	√ (slight intensity rise)	
14-15. 1.74	64.5	-	-	√ (wave type front in CF position)	CF proper did not contribute rain
8. 2.74	41.1	√ /	√ (included peak)	√ (no increase in intensity)	Slow moving
3- 4. 7.74	66.3	√ (peak)	√ (stationary and long lasting. Heavier at pre CF)	x	Very slack system
5. 9.74	39.4	-	-	-	No fronts. Wave depression to South
6-8. 9.74	74.9	x	x	x	Fronts crossed but little rain. Rain corresponded with centre of depression over N. England.
24. 9.74	41.0	√ x Pre WF	x	Post CF √ x	similar to 6-8. 9.74 Cyclonic
18.10.74	52.6	√ Pre WF fronts cannot be separated			Fast moving
10.11.74	31.9	Cannot be separated		√ (intensity increases)	
2.12.74	32.8	-	-	√ (wave)	Wave across N. Wales. Highest intensity as wave crosses Plynlimon southwards.
21.12.74	36.2	-	-	-	No fronts
27.12.74	36.4	√ Pre WF / (1st peak)	√ (steady rain)	√ (2nd peak)	
6. 1.75	39.0	-	-	√ (wave over N. Wales moves S. giving high intensity era)	
21. 1.75	85.2	√ (1st peak)	√ (most rain)	x	
1. 5.75	42.6	-	-	(wave)	
22. 7.75	59.1	√	√	√ (high intensities)	
11. 9.75	31.1	-	-	-	No fronts. Shallow depression over Ireland
24-25. 9.75	77.0	√ (1st peak)	√ (very little rain)	√ (long peak to storm)	CF forms a secondary depression

Total occurrences of rain associated with each synoptic type:

WF	13
WS	13
CF or CF wave	16
Rain not associated with well defined frontal system e.g. cyclonic	5

heaviest storm events (although the criteria are principally expected to cover the seven heaviest events over 50 mm) in the two years October 1973 to September 1975 were examined using the Daily Weather Report in conjunction with the Tanllwyth Dines recording raingauge tabulations. The results are summarised in Table 14. The heavy rainfall events are nearly all associated with westerly frontal situations, in particular with cold front waves and with the warm sector of depressions contributing greater rainfall amounts than the warm front. Heavy rain not associated with a well defined frontal system occurred on only five out of the 24 storm events. In addition the Dines tabulations for each storm were looked at in conjunction with the charts from the Dolydd Office barograph. The barograph was installed February 1974 and so only fifteen of the storm events are covered. Of these, four had a lowest pressure of 988 mb or less (5.9.74; 7.9.74; 24.9.74; 24.9.75 - two of these are two out of the three heaviest events). Three out of the four (not 5.9.74) had pressure falls of at least three mb per three hours but only one of these occasions was frontal, the other two being cyclonic. The rain ceased at or soon after the lowest pressure was reached in nine out of fifteen events. The cold front waves were associated with steady or rising pressure.

HEAVY RAINFALL - THUNDERSTORM TYPE

The frequency of thunderstorms over Plynlimon is very low. Crossley and Lofthouse (1964) have mapped the total number of days of severe or widespread thunderstorms over Britain in twenty years (1930-39 and 1948-57); isopleths at five day intervals from nil to over 30 days show for each month, May to September, Plynlimon in the lowest, less than five day, band, compared to Central England and the London area with over 30 days. The map of annual average number of days of thunder (over 20 years) for July shows Plynlimon crossed by the one day isopleth, i.e. thunderstorms range on average from 0 to 3 days occurrence in July.

The following description is of the only severe thunderstorm to occur at Plynlimon during the study period October 1973 to September 1975.

Thunderstorm of 16 June 1974

The synoptic situation on the night of the thunderstorm consisted of a frontal trough, associated with complex low pressure over Iceland; the trough was progressing slowly eastwards into the British Isles although no frontal development was clearly defined. The wind direction for the period before and up to the beginning of the storm was recorded by all the catchment wind measuring stations (six sites in all) as south-east. In the hour from midnight containing the bulk of the storm and for the rest of the night all stations showed a consistent south-south-west direction. The amount and duration of the rainfall recorded by each of the Dines gauges in the catchments during the storm is shown (uncorrected for syphoning losses) in Table 15. All but Tanllwyth (which has a daily changed chart graduated in ten-minute intervals) have three-weekly charts marked in six-minute intervals. Both Carreg Wen and Esgair-y-Maen recorded 'noteworthy falls', according to the Bilham classification of heavy falls in short periods. At the same time

TABLE 15 Thunderstorm rainfall totals, 16 June, 1974

Location of Dines recording raingauge	EISTEDDFA GURIG	ESGAIR-Y-MAEN	WATERSHED	CEFN BRWYN	CARREG WEN	TANLLWYTH	
			Rainfall in mm			Time in 10 minute divisions	
TIME GMT							
2348-2354	0.7	0.2			-		
2354-0000	3.2	0.9	-	-	0.1		
0000-0006	3.0	4.6	-	-	2.9		
0006-0012	5.0	3.8	-	-	5.0		
0012-0018	2.2	4.8	0.6	0.2	2.8	0.3	(0015-0025)
0018-0024	3.2	3.2	1.0	0.2	8.0		
0024-0030	1.8	3.6	1.0	1.3	4.0	0.6	(0025-0035)
0030-0036	0.8	1.7	3.7	3.2	1.6		
0036-0042	0.5	2.8	1.7	0.3	3.0	1.3	(0035-0045)
0042-0048	0.1	0.2	2.6	-	0.6		
0048-0054	-	-	0.2		-	1.5	(0045-0055)
0054-0100			-			-	
0100-0106							
Total of catches (mm)	*18.4 mm*	*24.5**	*11.6*	*4.5*	*27.3**	*2.8*	
>1 mm/6 mins (or >1 mm/10 mins at Tanllwyth)	*in 36 mins*	*in 42 mins*	*in 36 mins*	*in 12 mins*	*in 42 mins*	*in 20 mins*	

*Noteworthy falls

the low total rainfall and short duration of nearby Tanllwyth and Cefn Brwyn is equally remarkable (these totals were all confirmed by automatic weather station ground level raingauges at the same sites), indicating a "spotty" spatial distribution of the rainfall, while the timing of the peaks suggest movement of the storm centres (Esgair-y-Maen and Carreg Wen) down the catchments, not a usual situation.

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APPENDIX

Daily rainfall (mm), Tanllwyth daily standard gauge

	1973 OCT	NOV	DEC	1974 JAN	FEB	MAR	APL	MAY	JUNE	JULY	AUG	SEPT
1	0.1	0.2	-	0.1	15.6	10.1	-	11.5	17.8	0.5	0.6	12.7
2	1.4	0.1	5.4	-	13.7	2.0	TR	2.7	0.6	19.8	TR	25.5
3	0.3	2.5	5.8	1.1	3.1	0.6	-	0.5	TR	30.3	-	11.2
4	TR	14.0	7.1	29.3	4.7	2.6	-	0.2	-	37.7	2.2	18.9
5	0.2	5.5	9.8	11.0	9.1	0.1	-	-	16.0	1.3	TR	46.2
6	TR	0.2	10.4	17.8	3.3	8.1	-	-	12.1	TR	TR	17.5
7	0.1	3.8	37.3	15.4	11.2	0.1	-	-	8.5	TR	2.5	61.7
8	14.6	TR	-	23.9	52.4	TR	-	-	0.4	0.5	5.1	7.8
9	19.0	63.2	0.3	2.0	22.1	0.1	-	11.8	8.1	9.4	29.7	16.7
10	19.0	5.5	32.9	15.7	20.9	10.3	9.3	7.1	1.5	4.7	0.9	-
11	TR	27.1	1.7	5.3	16.1	TR	1.6	4.7	TR	0.4	15.0	1.6
12	1.4	19.8	39.8	8.3	2.2	TR	2.5	7.4	-	TR	1.0	15.4
13	3.7	12.3	19.3	7.9	1.5	0.4	-	0.7	-	10.5	12.8	3.6
14	4.8	39.9	2.4	74.2	13.3	12.3	-	TR	-	23.3	9.4	1.0
15	3.7	6.7	42.1	8.2	13.0	12.9	TR	-	7.1	23.6	1.0	1.0
16	1.1	0.1	10.8	34.5	5.3	3.8	-	0.3	18.4	2.3	5.2	1.2
17	5.6	TR	7.2	6.5	0.2	33.6	-	TR	2.4	TR	-	1.7
18	63.5	5.3	0.4	1.6	1.2	2.4	-	4.2	22.0	-	0.6	TR
19	17.6	0.1	10.2	TR	0.2	4.9	-	-	1.2	1.9	0.1	TR
20	21.9	TR	4.7	-	0.7	-	-	2.0	-	-	-	14.1
21	1.3	-	4.2	0.4	7.1	TR	-	3.8	-	0.9	TR	7.1
22	20.7	0.3	13.4	17.3	1.9	-	-	16.2	-	19.9	1.1	24.2
23	0.2	0.2	0.1	7.6	TR	-	-	6.7	-	4.7	1.8	7.7
24	-	3.5	-	0.4	0.1	0.6	-	2.3	-	0.1	8.1	40.8
25	-	0.6	1.5	1.0	0.4	0.1	TR	TR	-	8.9	13.7	10.2
26	TR	0.5	1.0	27.4	TR	TR	0.3	-	9.4	2.7	6.6	6.9
27	-	2.8	16.4	14.8	TR	-	1.1	0.2	0.5	7.6	TR	6.3
28	TR	28.2	15.9	3.2	7.4	TR	0.3	8.3	1.3	6.3	TR	15.2
29	TR	0.1	11.7	15.3	////	-	TR	TR	2.4	16.4	TR	9.3
30	-	1.2	-	19.1	////	-	6.8	-	6.5	27.7	0.4	0.1
31	-	///	0.1	2.3	////	TR	////	-	////	25.5	2.1	////
Monthly Total	200.2	243.7	311.9	371.6	226.7	105.0	21.9	91.5	106.2	286.9	119.9	385.7

	1974 OCT	NOV	DEC	1975 JAN	FEB	MAR	APL	MAY	JUNE	JULY	AUG	SEPT
1	13.2	2.9	20.4	10.6	0.1	4.1	12.3	34.8	6.5	-	-	0.1
2	5.3	12.9	34.1	0.5	TR	7.4	2.6	5.5	12.7	-	-	0.7
3	3.0	16.8	7.2	0.8	-	5.0	1.8	TR	-	-	-	TR
4	0.4	TR	6.2	0.2	-	8.5	0.2	TR	1.5	0.7	6.5	2.6
5	0.1	2.1	0.5	3.2	-	2.6	0.1	-	TR	-	TR	0.1
6	30.5	2.1	5.2	41.7	-	13.4	11.0	-	TR	-	-	1.5
7	8.9	4.1	10.0	10.2	-	0.7	11.0	4.5	-	5.1	-	2.8
8	-	13.6	20.2	0.3	TR	TR	7.2	0.2	-	TR	9.1	24.3
9	1.3	19.6	2.7	1.0	-	2.5	0.8	TR	-	11.1	-	20.0
10	2.4	43.7	29.8	12.6	5.1	8.4	10.0	TR	-	11.5	TR	6.1
11	TR	19.2	13.2	5.3	3.7	5.7	3.5	1.3	-	0.1	-	30.2
12	0.4	6.2	13.0	15.0	6.3	0.6	0.3	14.2	-	29.5	-	7.8
13	3.5	38.2	13.7	5.7	15.5	3.2	16.0	2.5	-	5.5	-	-
14	0.6	11.2	0.1	11.2	10.9	0.1	8.2	6.4	-	4.9	3.7	TR
15	1.0	0.1	28.8	12.2	0.3	-	1.2	0.1	0.5	4.2	9.2	TR
16	1.7	-	15.5	10.3	5.7	TR	8.8	-	TR	0.6	TR	-
17	17.1	-	10.7	15.3	5.8	-	1.3	-	2.4	0.4	0.1	12.3
18	43.6	1.8	9.8	2.1	0.4	-	18.8	-	3.9	3.3	6.1	0.9
19	23.0	7.0	20.1	26.4	TR	-	2.0	-	14.5	2.7	29.0	7.5
20	14.6	29.3	22.1	16.9	5.7	-	24.6	-	TR	1.7	3.5	3.3
21	6.7	0.1	32.0	60.8	TR	15.5	4.3	-	TR	15.2	3.3	TR
22	0.2	5.5	TR	40.0	-	8.0	-	TR	-	44.6	1.1	16.6
23	-	5.7	12.3	2.6	13.2	2.6	-	-	-	8.2	3.7	5.4
24	1.2	8.0	3.5	23.5	TR	0.1	-	-	-	0.6	TR	66.9
25	4.3	9.6	23.5	15.7	TR	9.5	-	1.1	-	TR	0.1	17.0
26	3.9	3.3	23.7	10.2	TR	9.8	-	TR	-	-	-	6.1
27	17.7	10.1	42.2	22.7	TR	4.2	-	TR	-	-	-	11.7
28	7.4	7.9	17.6	7.9	0.1	1.3	16.1	-	-	-	-	0.1
29	0.1	26.1	3.7	22.6	////	2.8	3.2	-	-	-	0.7	2.1
30	7.1	7.5	8.4	18.6	////	TR	26.5	-	-	-	3.0	12.0
31	3.3	////	2.2	16.3	////	1.4	////	TR	////	-	-	////
Monthly total	222.5	314.6	452.4	442.4	72.8	117.4	191.8	69.6	42.0	149.9	79.1	258.1