Journal of Hydrology (N.Z.) Vol. 23, No. 1, 1984

PRECIPITATION INTENSITY AND VARIABILITY AT CHILTON VALLEY, NEAR CASS, SOUTHERN ALPS

A. P. Sturman and J. M. Soons

Department of Geography, University of Canterbury

ABSTRACT

The precipitation regime of the Chilton Valley in the Southern Alps, South Island, New Zealand, is examined using monthly and half hourly data. Missing monthly totals are estimated using data from nearby stations to produce a complete time series from August 1964 to December 1982. Monthly precipitation totals indicate marked wet and dry periods. The annual precipitation regime has two distinct maxima: a maximum in spring and a sub-maximum in April. Minima are observed during February and March, and in July. There are generally weak but statistically significant links between cyclonicity, westerly airflow and precipitation. Analysis of half hourly precipitation confirms earlier studies quoting relatively low intensities, with lowest values in July, August and September. Although cyclonicity is most important for the monthly totals, westerly airflow is more important for higher intensities.

INTRODUCTION

A project for the study of micro-climate and erosion processes was initiated by the Department of Geography, University of Canterbury, in 1963 (Soons and Rayner, 1968). The site chosen was close to the University's Biological Station at Cass, in the Waimakariri catchment in the Southern Alps. Successive workers have maintained records of basic climatological elements since 1964 and have undertaken a series of studies of aspects of mountain climate (Greenland, 1973a, 1973b, 1974, 1977; Greenland and Clothier, 1975; Soons, 1971; Sturman, 1983). Precipitation measurements have been kept, with very few breaks, for the life of the station. We now have one of the more detailed records of rainfall in the mountains of the South Island, corrected for errors and omissions where possible, with much of the data available in the form of half hourly intensities up to the present.

The climate station is situated at an altitude of 760 m in a small valley on the western flank of Sugar Loaf which, together with Cass Hill, separates the Cass Basin from the Waimakariri River (Fig. 1). The basin is part of an elongated depression running along the foot of the Craigieburn Range, and is typical of the intermontane basins of the eastern or foothill ranges of the Southern Alps. Cass Basin is open to the Waimakariri Valley by low saddles at either end of the Sugar Loaf/ Cass Hill ridge — Goldney Saddle at the northern end, used by State Highway 73, and a moraine covered ridge between Sugar Loaf and Long Hill on the eastern side. Winds affecting the basin are thus channeled either up or down valley but local variations develop

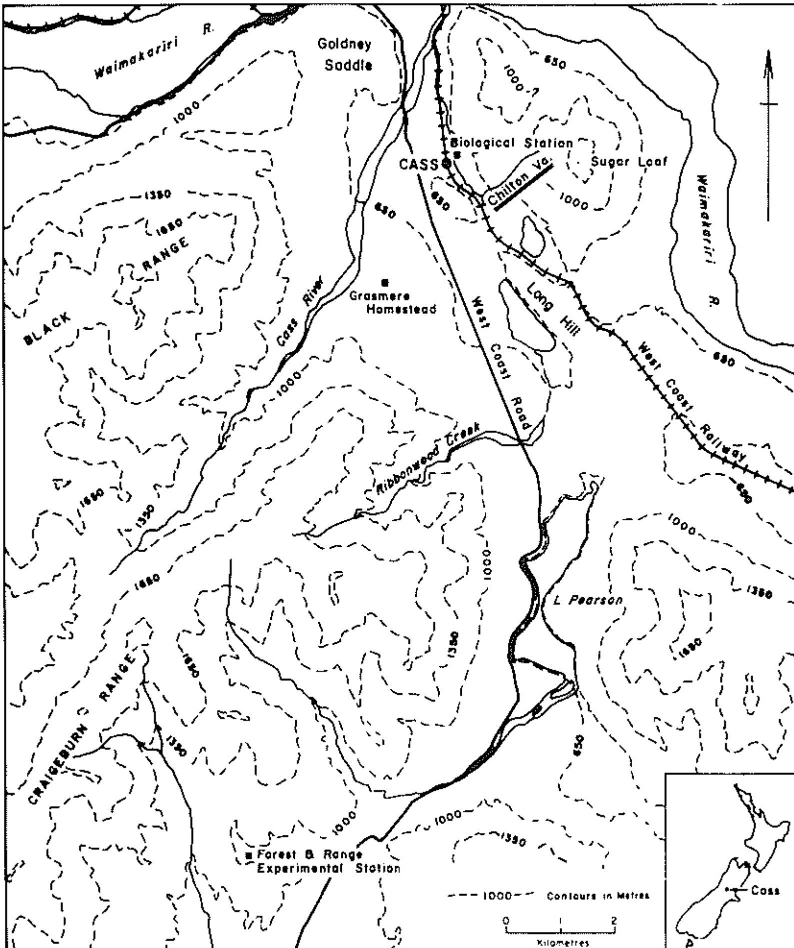

FIG. 1—Location map showing the relationship of Chilton Valley to the Cass Basin and surrounding ranges.

as a result of the topography around Chilton Valley (Sturman, 1983).

THE RAINFALL RECORD

At various times storage raingauges have been installed around the station in Chilton Valley, but the most complete record comes from a Lambrecht Recording Raingauge using monthly charts. Although the Lambrecht siphon system occasionally gives trouble, especially in winter, and the clockwork mechanism has needed overhaul from time to time, it is nevertheless a remarkably reliable system. A low-powered electric light bulb is installed in the casing alongside the siphon, and this usually prevents freezing and damage to the float. Breaks in the record caused by failure of the bulb or the power supply during a period of low temperatures have resulted in loss of data on a half hourly basis, but it has been possible to complete the record of monthly totals by correlation with records from other, nearby stations (Appendix A). Records are available from the Forest Research Institute's station in the Craigieburn Forest Park, 14 km from Chilton Valley, from the Ministry of Works and Development gauge at Cass (closed 1975), within 1 km of Chilton Valley, and from Grasmere Station, 4 km away across the Cass Basin (Table 1 and Fig. 1).

Chilton Valley monthly precipitation is most closely correlated with Cass, but correlations with the other two stations are similarly high (Table 1). The R^2 values indicate that estimates of monthly totals from Chilton Valley can be made quite confidently using data from the other stations. Consequently, the complete monthly time series has been synthesized for August 1964 to December 1982. Figure 2 shows the complete series as well as twelve monthly moving averages calculated from it. Monthly precipitation is quite variable throughout the period with a minimum of 5.6 mm in February 1973 and maximum of 382.6 mm in November 1967. In particular, 1968 stands out as a particularly wet year as do 1975 and 1979/80. Drier years include 1966 and 1977, while 1969, 1971 and 1973 are also relatively dry.

TABLE 1—Analysis of monthly precipitation totals used in estimation of missing data for Chilton Valley, August 1964 to December 1982.

	Chilton Valley	Craigieburn Forest Park	Cass	Grasmere
Altitude (m)	760	914	610	690
Sample size[1]	180	179	94	126
Average monthly precipitation (mm)	102.1	120.9	97.6	99.4
Correlation with Chilton Valley[2]	1.00	0.91	0.96	0.94
Multiple correlation with Chilton Valley[2]	R = 0.98 R^2 = 0.96			

[1] Number of months with data available for both Chilton Valley and named station.

[2] All four data sets were log transformed before analysis.

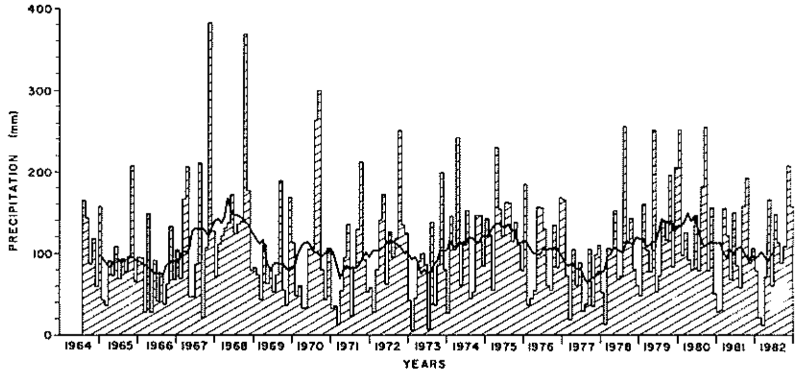

FIG. 2—Time series of monthly precipitation totals for Chilton Valley, August 1964 to December 1982. Thick line represents 12-monthly moving average.

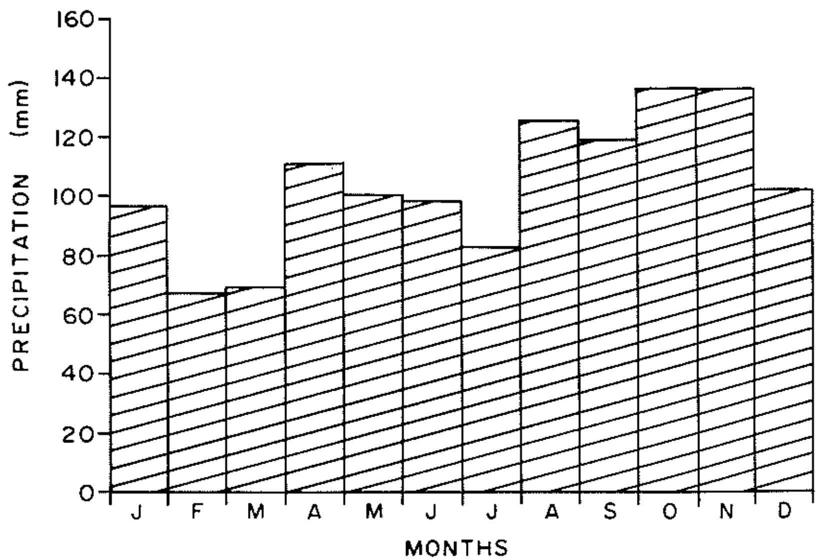

FIG. 3—Monthly average precipitation for Chilton Valley for the period August 1964 to December 1982.

Bearing in mind the variability shown by the monthly time series, monthly means can be used to illustrate the annual precipitation regime (Figure 3). There appears to be no simple annual cycle in precipitation. A clear minimum occurs during February and March followed by a sharp increase to a sub-maximum in April. This is followed by a decline into winter with a secondary minimum in July. There is a second marked increase to August with a maximum occurring during October and November. This annual variability must relate to the increased frequency of northwesterly flow in late winter and spring, bringing high precipitation to the Southern Alps. The settled anticyclonic conditions of February and March reduce precipitation at this time. Similarly, calmer conditions occur in mid-winter largely due to reduced westerly flow, resulting in reduced precipitation. The marked increase in April may relate to the breakdown of the settled summer circulation; this particular feature will require further examination.

The Waimakariri River has a very similar variation in its annual flow regime. River flow increases between March and April, and the mean monthly variation from December through to July is very similar to the monthly precipitation regime at Chilton Valley (see Figure 5 of Hayward and Ackley, 1983). The difference in the two regimes between August and November is presumably related to spring snowmelt. For example, the marked increase of precipitation between July and August at Chilton Valley does not produce a corresponding increase in river flow. Much of the increased precipitation in the Waimakariri catchment at this time falls as snow which is not melted until the following months. This would also account for the marked increase in river flow in September continuing into October and November, which is not mirrored by a similar precipitation change. Goulter's (1982) analysis of precipitation over Canterbury concentrated mainly on the plains where he found a December maximum along the foothills and over South Canterbury which he ascribed to summer convective activity. However, he notes that the small number of alpine stations have a distinctly different precipitation regime.

An initial analysis of the relationship between precipitation and atmospheric circulation was undertaken using a daily classification of isobaric patterns over South Island based on Lamb (1950, 1965, 1972). Monthly circulation indices were developed following a technique similar to that of Murray and Lewis (1966). The monthly indices were obtained by classifying each day, firstly on the basis of isobaric curvature, into major categories of anticyclonic, cyclonic and unspecified (meaning straight isobars or a mixture of the first two), and secondly into categories of gradient wind direction. Following Lamb (1950, 1965, 1972), this produced 27 possible classifications (for example, anticyclonic, anticyclonic northwesterly, cyclonic easterly, etc.). This daily classification was converted into a numerical index as described in Table 2 and summed to give four monthly circulation indices. Monthly precipitation at Chilton Valley was regressed with the four indices of cyclonicity, westerly, southerly and easterly. The results indicate a weak but statistically significant relationship, in which cyclonicity exhibits the strongest correlation with monthly totals (Table 3). The best combination of variables in the regression indicates that cyclonic northwesterly circulation is of importance, although the low correlation suggests that local factors are probably of greater significance.

RAINFALL INTENSITY

Analyses of rainfall intensity in New Zealand (Coulter and Hessell, 1980; Tomlinson, 1980) give estimates of return periods of intensities for various

TABLE 2—Daily index values used to calculate monthly circulation indices. Where an index value is given for a directional classification (e.g. westerly), it is the same for all classifications having that direction (e.g. unspecified westerly, anticyclonic westerly and cyclonic westerly).

CYCLONICITY INDEX	Non-directional anticyclonic	-2
	Directional anticyclonic	-1
	All unspecified	0
	Directional cyclonic	1
	Non-directional cyclonic	2
WESTERLY INDEX	Westerly	2
	Northwesterly or southwesterly	1
	All other classifications	0
SOUTHERLY INDEX	Northerly	-2
	Northwesterly or northeasterly	-1
	Westerly, easterly, anticyclonic, cyclonic or unspecified	0
	Southwesterly or southeasterly	1
	Southerly	2
EASTERLY INDEX	Easterly	2
	Northeasterly or southeasterly	1
	All other classifications	0

TABLE 3—Regression and correlation of Chilton Valley monthly precipitation with atmospheric circulation indices for South Island, August 1964 to December 1980.

Correlations	Cyclonicity	Westerly	Southerly	Easterly
Monthly precipitation[1]	0.41**	0.27**	-0.04	-0.14*

[1] the monthly precipitation data were transformed by taking the square root of each value.

** significant at 0.1% level (1-tailed test).

* significant at 5% level (1-tailed test).

n = 197.

Regression

$\sqrt{\text{Monthly precipitation}} = 8.614 + 0.12\ \text{Cyclonicity} + 0.098\ \text{Westerly} - 0.051\ \text{Southerly}.$

R = 0.466 $R^2 = 0.217$

time intervals. Reference has also been made to observed intensities in connection with soil erosion studies. For the eastern mountain areas, Hayward (1978) noted that intensities recorded in the Torlesse Research Area were generally low, and cited maximum rates of the order of 30mm h^{-1}, for a period of about 6 years of measurement. Soons (1971) also on the basis of a limited sample size, noted that intensities recorded in Chilton Valley were low, a rate of 3 mm/half hour being exceeded for only a small percentage of the time that rain was falling, with a maximum value of only 7.5 mm/half hour. The Chilton Valley maximum intensity is within the range of estimates of half hourly maxima for return periods of 5 and 10 years as calculated by Coulter and Hessell (1980) for Lake Coleridge, the nearest and geographically most similar station for which values are given.

Data now available for Chilton Valley confirm the relatively low intensities observed during the early period of the climate station. Only 2.1% of the wet half hours received greater than 3 mm, with 0.7% greater than 4 mm. The percentage frequencies of half hourly precipitation are given for each month in Figure 4. Note that the frequency of half hours in each class is expressed as a percentage of the number of wet half hours. The most outstanding feature is the annual variation of the higher intensity precipitation, particularly that greater than 3 mm. July, August and September have lower frequencies in these classes in spite of higher precipitation in August and September (see also Fig. 3). This ties in well with the 95 percentile values of precipitable water (surface of 400 mb) at Christchurch, Invercargill and Chatham Island where low values occur in July, August and September (Tomlinson, 1973). Although the duration of precipitation is greater in late winter, the frequency of higher intensity precipitation is greater in summer, particularly early summer (November and December), when more moisture is available. Moderate intensity precipitation dominates in April, a month with relatively high total precipitation. The reasons for this can be clarified only through further study.

As an initial step in examining precipitation intensity and atmospheric circulation relationships, 15 months having greater than 6% of wet half hours with greater than 3 mm of precipitation were extracted. The average circulation indices were calculated for this sample and compared with the means for the period 1961 to 1980. Two of the sample means were significantly different, those for the westerly and easterly index. The sample mean for the westerly index was significantly greater than the long term mean (at 1% level, one-tailed t test), while that for the easterly index was significantly less (at 5% level, one-tailed t test). It appears, from this initial study, that although cyclonicity is most important for the monthly totals, westerly flow is more important for higher intensity precipitation.

CONCLUSION

This analysis of the Chilton Valley rainfall data has confirmed the broad pattern of annual rainfall variation identified by Greenland and Owens (1967). A clear summer minimum follows a spring rainfall peak, although the use of a longer period of records has demonstrated a sub-maximum in April, rather than in May. The generally low intensity of rainfall noted earlier by Soons (1971) is also confirmed.

The seasonal variation of rainfall at Chilton Valley shows some correlation with patterns of atmospheric circulation. The high mean value of rainfall

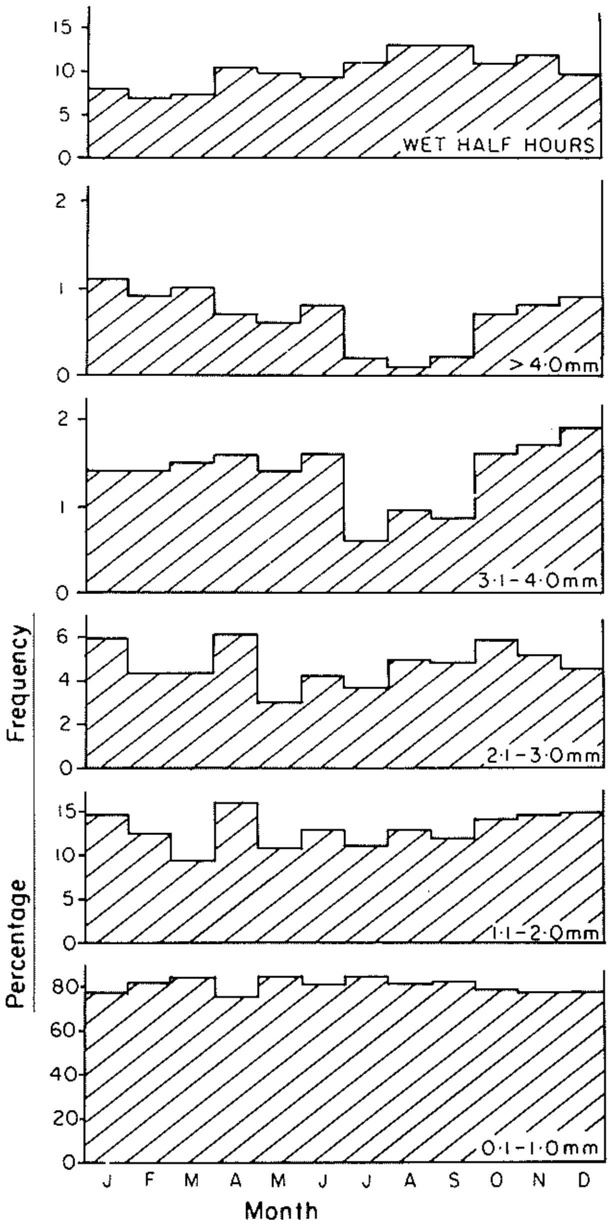

FIG. 4—Percentage frequencies of wet half hours by month, and for different precipitation classes, for Chilton Valley, August 1964 to December 1982.

Appendix A CHILTON VALLEY MONTHLY PRECIPITATION (mm)

	J	F	M	A	M	J	J	A	S	O	N	D	Annual Total
1964								165.6	143.6	86.6	118.1	59.6	———
1965	157.7	42.8	36.3	91.1*	73.4	109.3	68.5	93.5	76.3	96.3	207.6*	65.0*	1117.8
1966	95.0*	94.3	27.7	148.6	27.4*	91.7	41.0	75.4	37.8	62.2*	132.8	68.0	901.9
1967	104.5	69.6	166.6	206.4	46.1	47.0	86.7	210.7	20.8	106.5*	382.6*	126.5	1574.0
1968	71.2	111.7	122.6	131.3*	137.5*	172.1	123.9	136.0	138.5	369.1	176.7	79.2	1769.8
1969	82.8	73.8	42.3	110.3	62.4	81.8	52.4	74.0	188.2	54.3	36.1	169.7	1028.1
1970	113.2	47.6	61.1	32.7	32.2*	105.7*	105.7	263.7	299.9	79.8	43.1	102.1	1286.8
1971	32.0	35.9	13.2	54.2	95.2	134.7	21.9	82.4	129.4	211.8	91.9*	54.0*	956.6
1972	58.6*	28.0	80.3	140.9	172.6*	62.5	126.3	95.1*	119.1*	250.6*	135.6	124.8	1344.4
1973	42.3	5.6	45.2	90.1	99.8*	87.7*	6.6	139.0*	36.9*	86.2	199.6	81.4	920.4
1974	27.4	146.0	105.2	242.5	61.0*	115.2*	152.6*	45.0*	53.6*	147.9*	146.3	85.2	1327.0
1975	143.0	123.4	54.4	230.5	154.3	121.8	163.5	161.9*	114.2	139.4	105.7	78.8	1590.9
1976	185.2	36.8	45.2	54.6	157.7**	156.9**	130.0*	60.6	55.5**	135.3**	83.4	168.6**	1269.8
1977	165.9*	72.5	19.0	105.8	60.2	89.7*	28.8*	37.5	105.1	35.0	98.9	110.2	928.6
1978	52.2**	13.0**	107.5	105.1	152.8	69.1	72.2	256.2	112.9	143.9	80.7	61.2	1226.8
1979	48.2	161.6	104.3	78.1	252.4*	53.3	73.4	141.5	116.1	196.9	83.8	202.1	1511.7
1980	252.7	98.0	125.5	92.3	80.3	146.5	78.5	182.8*	255.6*	78.3	156.4	51.8	1598.7
1981	29.2**	30.4	156.1*	122.0	69.0	142.6	85.8	58.5*	158.6*	193.8*	89.2*	106.6	1241.8
1982	79.8	22.1	12.3	72.4	167.5	60.2	149.0	113.6	89.8	108.8	208.8	158.6	1242.9
Monthly Average	96.7	67.4	73.6	117.2	105.7	102.7	87.0	125.9	118.5	136.1	135.6	102.8	
Annual Average													1268.8

* monthly total estimated using correlations with data from Craigieburn Forest Park, Cass and Grassmere.

** a few days estimated using correlation with Craigieburn Forest Park.

for April seems to demand further study, occurring as it does in the period of transition from summer to winter circulation patterns. Relatively high-intensity rainfalls are related to a westerly circulation. The absence of really high-intensity rainfalls in the record is important. Largely anecdotal evidence indicates that the eastern foothills of the Southern Alps are subject to occasional highly-localised severe storms, with intensities of rainfall well above those recorded at Chilton Valley. Such storms cause considerable damage, but present problems of prediction from records such as that from Chilton Valley.

There is a quasi-periodic variation of wet and dry years, as noted by Greenland and Owens (1967). Continuation of records should permit the reality or otherwise of this to be demonstrated.

ACKNOWLEDGMENTS

The collection and analysis of the data used in this paper has involved many individuals. We offer them our grateful thanks, and include in this the University Grants Committee and the University of Canterbury for its financial support. Drs J. N. Rayner, D. E. Greenland, and J. E. Hay were all active in developing the Chilton Valley site, together with a number of technicians over the years. We are also grateful to the Ministry of Works for assistance with the maintenance of equipment. Many students have processed data, but we would particularly like to thank Dr E. McSaveney, A. C. Trewinnard and P. A. Gorman for their work in correcting and collating the rainfall data. We are also indebted to the reviewer for his valuable comments.

REFERENCES

Coulter, J. D.; Hessell, J.W.D. 1980: *The frequency of high intensity rainfalls in New Zealand, Part II: Point Estimates.* N.Z. Meteorological Service, Wellington, 76 pp.

Goulter, S. W. 1982: Is December Canterbury's wettest month? *Weather and Climate, 2:* 25-27.

Greenland, D. E. 1973a: An estimate of the heat balance in an alpine valley in the New Zealand Southern Alps. *Agricultural Meteorology, 11:* 293-302.

Greenland, D. E. 1973b: Application of climatonomy to an alpine valley. *N.Z. Journal of Science, 16:*8-23.

Greenland, D. E. 1974: The Chilton Valley, Cass — a field experiment in physical geography. *N.Z. Geographer, 30:*172-179.

Greenland, D. E. 1977: Weather and climate at Cass. In C. J. Burrows (ed), *Cass: history and science in the Cass district, Canterbury, New Zealand.* Botany Dept., University of Canterbury.

Greenland, D. E. Clothier, B., 1975: A study of radiation in the New Zealand Southern Alps. *Geografiska Annaler 57A:* 143-151.

Greenland, D. E.; Owens, I.F. 1967: An analysis of rainfall and soil moisture characteristics in the Chilton Valley, Cass. *J. of Hydrology (N.Z.), 6:* 80-88.

Hayward, J. A. 1978: The Torlesse Research Area. Field trip notes, *Proceedings of the Erosion Assessment and Control Conference, Christchurch, 1978.* N.Z. Association of Soil Conservators.

Hayward, J. A.; Ackley, K. A. 1983: Canterbury's water resources: an overview. In R. D. Bedford; A. P. Sturman (eds.), Canterbury at the crossroads: issues for the eighties. *Miscellaneous Series No. 8, New Zealand Geographical Society, Christchurch, New Zealand.*

Lamb, H. H. 1950: Types and spells of weather around the year in the British Isles: annual trends, seasonal structure of the year, singularities. *Quart. Journal of Royal Met. Soc., 76:*393-429.

Lamb, H. H. 1965: Frequency of weather types. *Weather, 20:*9-12.

Lamb, H. H. 1972: British Isles weather types and a register of the daily sequence of circulation patterns, 1861-1971. *Geophysical Memoirs, No. 116, HMSO, London.*

Murray, R.; Lewis, R.P.W. 1966: Some aspects of the synoptic climatology of the British Isles as measured by simple indices. *Met. Mag., 95:*193-203.

Soons, J. M. 1971: Factors involved in soil erosion in the Southern Alps, New Zealand. *Zeitschrift f. Geomorphologie, 15:*460-470.

Soons, J. M.; Rayner, J. N. 1968: Micro-climate and erosion processes in the Southern Alps, New Zealand. *Geografiska Annaler, 50A*, 1-15.

Sturman, A. P. 1983: Airflow regime in a small alpine valley. *N.Z. Journal of Science, 26:*211-218.

Tomlinson, A. I. 1973: Precipitable water statistics from the surface to 400 mb at New Zealand stations from 1959 to 1972. *New Zealand Meteorological Service Misc. Pub. 144*, Wellington, 15 pp.

Tomlinson, A. I. 1980: *The frequency of high intensity rainfalls in New Zealand: Part I.* Water and Soil Technical Publication No. 19, Ministry of Works and Development for NWASCO, Wellington.