COMPARISON OF PRECIPITATION-GAUGE AND SNOWPILLOW DATA FROM A SEVERE APRIL SNOWSTORM IN A MOUNTAIN WATERSHED

616-76

By

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Introduction

Severe spring storms are by no means rare in southern Alberta. The Waterton Storm of June 1964 (Warner, 1973) and the twin storms of April 1967 (Janz and Treffry, 1968) were two of the more spectacular in the past decade. The storm of April 26-27, 1974 is therefore not unique. It is, however, the most severe storm of this type to strike the heavily instrumented Marmot Creek Experimental Watershed since its instrumentation in 1963, and so offers an opportunity for a meso-analysis and comparison of data collected by various methods.

Basin Description

Marmot Creek is a small, 3.7 mile^2 (9.6 km^2) experimental watershed at latitude 50°57'N, longitude 115°10'W, on the west side of the Kananaskis Valley, just east of the continental divide in Alberta. Elevations range from 5200 to 9200 ft (1585 to 2805 m), with an average slope of 39% which causes access problems, especially in winter and spring seasons. The general aspect is easterly.

The lower reaches of the basin are covered with a dense stand of young lodgepole pine (*Pinus contorta* Dougl.). with mature spruce (*Picea engelmanni* Parry), alpine fir (*Abies lasiocarpa* (Hook) Nutt.), and pine extending to 7000 ft (2135 m), and alpine fir and alpine larch (*Larix lyallii* Parl.) to treeline at 7500 ft (2285 m). In the alpine zone, shrubs and grasses give way to talus slopes and bare rock.

Basin Instrumentation

There are three recording weighing-type precipitation gauges in the basin which provide data applicable to this study. One Leupold-Stevens Q12M gauge at Con 5 (5750 ft, 1753 m) records continuously with a resolution of approximately 0.05 in. (1.25 mm). Two Fischer and Porter gauges at Cabin 5 (5800 ft, 2073 m) and Twin 1 (7500 ft, 2286 m) record every 15 min but the amounts are in increments of 0.1 in (2.54 mm). There are also nine Sacramento-type storage gauges installed in small clearings in the trees that are read manually when access is possible, but only three of these provided data applicable to this study: M5 at 5850 ft (1785 m), M4 at 7280 ft (2220 m), and M6 at 7660 ft (2335 m).

Six anemometers about 35-50 ft (10-15 m) above the ground surface or tree-tops record the wind continuously in the basin, but five of these require line power and stopped operating about midnight April 26 when the power supply was broken by fallen lines in the Kananaskis Valley. Fortunately, the anemometer at Twin 1 is battery operated and provided continuous data throughout the period under study. It is located on an exposed ridge above treeline and is reasonably representative of the windiest area in the basin.

Data from seven hygrothermographs are available for the period under study. They are located at Con 1, 5298 ft (1615 m); Con 5, 5750 ft (1753 m); Cabin 1, 6800 ft (2073 m); Cabin 5, 6800 ft (2073 m); C64, 6400 ft (1951 m); C62, 6200 ft (1890 m); and Twin 1, 7500 ft (2286 m). Five hexagonal butyl-rubber snowpillows were in service at 5850 ft (1785 m), 6400 ft (1950 m), 7070 ft (2155 m), 7450 ft (2270 m), and 8050 ft (2455 m). The lowest pillow is 10 ft (3.05 m) in diameter, the other four are 8 ft (2.44 m). The pillows are filled with a 50% methyl alcohol in water solution and connected to a standpipe and float assembly from which the w.e. (water equivalent) of the snowpack is recorded continuously on a monthly chart.

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Synoptic Development

The synoptic development of the storm has been discussed in detail by Saulesleja and Bowkett (1974) and will be summarized very briefly here. A low pressure area at 500 mb moved slowly east-northeast across Oregon and Idaho on April 25 and 26, with southerly winds ahead of it bringing warm, moist air into Montana and southern Alberta. As the upper low approached, a surface low formed in southeastern Alberta, causing northeast upslope surface winds against the Rocky Mountains and their foothills while the upper winds were still southeasterly. This surface low moved slowly and erratically eastward until April 28 while a new 500 mb low formed over Montana and accompanied the surface low eastward, thus shifting the upper winds to northeast also. The paths of these low pressure areas are shown in Figure 1.

The combination of upslope winds and convergence in the low pressure area which had a closed circulation to all levels probably produced greater than average efficiency in extracting the moisture from the warm moist air. At stations below approximately 4290 ft (1500 m) MSL (where all the synoptic and climatological stations are located), the precipitation in southern Alberta began as rain on April 26 and changed to snow by the 27th. At higher elevations, the best evidence available indicates that all the precipitation occurred as snow. Although much of the data from the climatological stations are suspect due to the use of the 10:1 conversion factor for snow depth to water equivalent, several stations across southern Alberta reported over 5 in. (12.7 cm) of total precipitation over 3 days and many along the foothills reported 2-4 in. (5-10 cm) (Saulesleja and Bowkett, 1974). Winds over 70 mph (31 m/s) at the height of the storm east of the Rockies no doubt affected the accuracy of precipitation measurement. The combination of strong winds and heavy wet snow accumulating on power lines and poles also caused numerous power and telephone disruptions and damage of over a million dollars.

It should perhaps be mentioned here that in spite of the damage, the storm probably saved the agricultural industry in southern Alberta from a disastrous 1974 season. After a very dry summer in 1973 and very low winter snowfall, soil moisture reserves were extremely low. Oosterveld (1974) has estimated that with wheat worth \$5 per bushel (14¢ per litre), each 1 in. (2.5 cm) of soil moisture in the critical lower range of the supply-yield curve is worth \$15-\$25 per acre (\$37-\$62 per hectare). The precipitation from this storm over southern Alberta might therefore be conservatively estimated to have been worth \$100-\$200 million to agriculture alone, many times the damage done.

Meso-Analysis at Marmot Creek

Within the limits of accuracy of the time resolution of the various instruments, all three precipitation gauges and the five snow pillows recorded the precipitation starting shortly before noon April 26, and the precipitation gauges show the storm ending about 1100 h April 27. Figure 2 shows the cumulative precipitation recorded at the three precipitation gauges and the temperatures at Con 5 and Cabin 5 (the warmest and coolest respectively of the seven sites) for the period April 26-30. Figure 3 shows the cumulative change in water equivalent of the snowpack on the five pillows and the wind speed at Twin 1 for the same period.

A number of questions are posed by these data in any attempt to determine basin average precipitation or patterns of precipitation within the basin. The first, which is of importance to hydrologists, is how much, if any, of the precipitation fell in the form of rain. Rain was reported in the afternoon of April 26 at the ranger station at 4800 ft MSL (1460 m) in the valley below Marmot Creek, but an eyewitness at noon on April 26 less than 5 miles (8 km) northwest of Marmot Creek reported fine rain below 5000 ft (1525 m) but only snow above that level. Rain has never been observed at Marmot Creek with screen temperature below 3°C so it is assumed that all or practically all the precipitation in this storm was in the form of snow at Marmot Creek.

Another important question is whether the precipitation gauges were capped by the heavy fall of wet snow. All three gauges recorded a rapid increase in accumulation until about 1000 h MST, April 27 so they could not have been capped before that time. Later in the day, Con 5 and Cabin 5 both showed sudden vertical increases in total amount, Con 5 at 1100 h and Cabin 5 at 1400 h. At each gauge, air temperature was 1-2°C at the time of the jump, suggesting that snow which had adhered to the rim or the upper part of the gauge

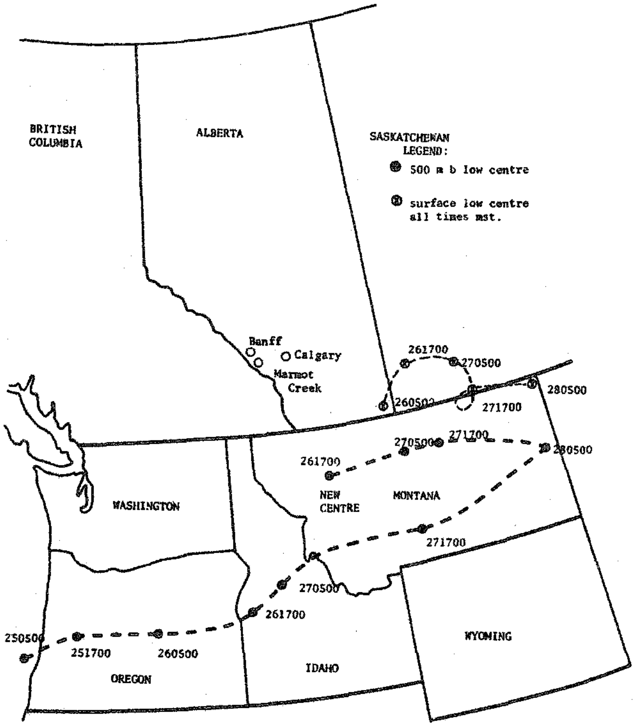

FIGURE 1: PATHS OF LOW PRESSURE AREAS APRIL 25 - 28, 1974.

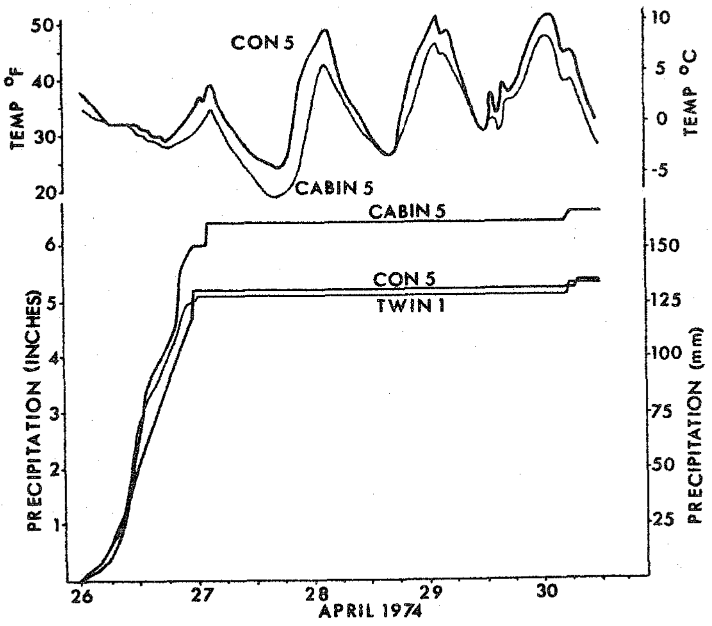

FIGURE 2: SCREEN TEMPERATURES AND CUMULATIVE PRECIPITATION

funnel had melted and fallen into the bucket. There is a weaker suggestion of the same occurring at Twin 1. If this interpretation is correct, the gauge orifices were clear for the next 3 days. Looking at it from another viewpoint, if the gauges had been capped near the end of the storm and the caps did not melt off on April 27, they would surely have done so and fallen into the gauge on April 28 or 29 when the air temperatures reached 8-10°C. This does not show on the precipitation record so it must be assumed that the orifices were clear for most of the storm and the minor degree of capping near the end melted into the bucket on April 27.

Wind speeds during the storm at all six anemometers were only 2.2-4.5 mph (1-2m/s) on April 26 and reached 8.9 mph (4 m/s) for only 1 h at Twin 1 near noon on April 27. The snowflakes therefore must have fallen almost vertically, and with no turbulence over the orifice, the gauge catch should be close to ground truth. In a previous study (Storr, 1973) it was found that 80% of the snow in the basin falls when winds at Twin 1 are less than 8.9 mph (4 m/s). The wind pattern during this storm was therefore not unusual.

A major problem in this study has been reconciling the apparent discrepancy between amount and rate of snowfall indicated by the precipitation gauges and that shown on the snowpillow charts (Table 1). At the end of the storm, about noon on April 27, storm snowfall as shown by the precipitation gauges ranged from 5.1 in. (13.0 cm) to 6.4 in. (16.3 cm) w.e., whereas snowpillow charts showed a fall of 3.6 in. (9.1 cm) to 4.4 in. (11.2 cm) w.e. Also, the chart traces for the upper pillows, P71, P75, and P80, showed a continued accumulation after the precipitation gauges and the lower snowpillows indicated that the snowfall had stopped, P71 until midnight of April 27, and P75 and P80 until April 30.

TABLE 1. Snowfall at Gauge Sites on Marmot Creek Experimental Watershed for the Storm of April 26-27, 1974.

Elevation		No.	Snowpillow Water equivalent End of storm		Adjusted		Recording ppt. gauge No.	Water equivalent		Storage ppt. gauge No.	Water equivalent	
(ft)	(m)		(in.)	(mm)	(in.)	(mm)		(in.)	(mm)		(in.)	(mm)
5750	1753						Con 5	5.2	132			
5850	1783	P59	3.6	91						M5	4.9	124
6800	2073						Cabin 5	6.4	163			
7070	2155	P71	3.6	91	5.4	137						
7280	2219									M4	7.1	180
7450	2271	P75	3.8	97	5.8	147						
7500	2286						Twin 1	5.1	130			
7660	2335									M6	5.5	140
8050	2454	P80	4.4	112	6.6	168						

There are three possible reasons why P75 and P80 might record increments on April 28, 29, and 30. The first is that snow continued to fall at high elevations after it had stopped at the lower. However, the P75 pillow is in the same small clearing in the forest as the Fischer and Porter gauge which has been shown to be uncapped and which recorded no snow after noon of April 27. The Banff weather office, 25 miles (40 km) northwest, reported variable cloud and sun during the daylight hours of April 28 and 29 and mostly clear overnight. The wide spread between maximum and minimum temperatures at Cabin 5 (Figure 2) would confirm for the higher elevations the Banff cloud conditions. Therefore, continued snowfall can be ruled out.

A second possibility is that snow may have been drifting onto the pillows April 28-30 but not lifting high enough to fall into the gauges. However, winds were mainly under 6.7 mph (3 m/s) in the alpine area and only above 11.2 mph (5 m/s) for 1 h. Also, with thawing temperatures during afternoon hours and as low as -8°C at night, the new snow would be well crusted by the 28th and would require very strong and persistent winds to cause drifting. Therefore, this possibility must also be ruled out.

The third possible reason for the anomalous records for the pillows involves the response time of the pillows. Tarble (1968) has reported that the smaller the pillow, the longer it takes to transmit all the added weight of the snow. He reported that with 45 in. (114 cm) of snow on 5-ft pillows, it has taken up to 10 days to reach equilibrium. Twelve-foot pillows respond more readily but may have up to 5 h delay. Ord (1968) presents data showing some occasions where a 12-ft pillow had a lag of several days behind a gamma attenuation gauge. The lag appears to be a function not only of pillow size but also of snow depth, rate of accumulation, and temperature conditions during the settling period.

Interpreting the data in Figures 2 and 3 in this light explains the slower rate of accumulation by the pillows and removes some of the conflict over the amount. The P64 pillow is in a very small clearing in the forest, barely large enough for the pillow, so the adjoining 66-ft (20-m) spruce intercept a great deal of the snow, making the record non-representative of open area accumulation. Therefore, data from this pillow will not be considered.

It should be a simple task to correct the pillow records for delayed response, as long as there has been no further snow fall until the pillow has reached equilibrium. However, two other factors confound the situation. First, snowmelt had already begun before the April 26-27 storm, 17 days before in the case of P59, 9 days for P64 and P75, and 1-2 days for P71; and had not yet started at P80. Therefore, the loss to the pack due to melt masked the delayed response. From the chart traces for P75 and P80 shown in Figure 3, it appears as if the amount of delayed response is greater than any loss due to melt, if there was any melt, because for the whole period of 3 days there is a positive net change. For P64, delayed response and melt loss appear to be in balance as shown by the zero net change. For P59, melt loss is greater than the amount of delayed response, resulting in a negative net change in w.e. P71 seems to alternate between periods of positive and negative net change. This illustrates the second factor confounding the adjustment for delayed response, and that is diurnal fluctuations that are unrelated to the amount of the snow on the pillow. The cause of these diurnal fluctuations is open to question. They become noticeable on the chart trace about 3 weeks before melt begins, unlike the fluctuations described by Penton and Robertson (1967) that began when melt begun. An example of the appearance of the trace is given in Figure 4 for P71. The fluctuations become apparent about March 29, the snow temperature at P71 reached 0°C by April 16, and melt became significant by April 25. The minima of the diurnal cycles are reached at about 10 a.m., the maxima from 8 p.m. to 4 a.m. The minima are sharply defined whereas the maxima are on broad plateaus. P71 had 3-4 ft of snow on it when the fluctuations began; they were masked in the period of rapidly increasing snow pack during the storm and the period of rapid melt following the storm, but reappear when the snow had disappeared from the pillow (Figure 4). At this latter stage, the minima are even more sharply defined, although appearing at 1200 h rather than 1000 h, whereas the maxima have even wider time bases.

The first thought is that diurnal temperature fluctuations are responsible. The difficulty here is that (1) the pillow has 3-4 ft of snow on it when the fluctuations first appear, and (2) the temperature fluctuations are out of phase with the fluctuations on the chart. Another possible cause is diurnal fluctuations in barometric pressure. Barograph charts of this area show a single daily cycle with a maximum about 7 a.m. and minimum about 7 p.m. The snowpillow trace shows a single cycle also, but with the minimum, not the maximum, in the morning, at about 10 a.m. Another question is, why do these daily pressure variations not manifest themselves on the chart trace in winter? Perhaps the atmospheric pressure can be transmitted to the pillow chart only after the snow has attained a particular quality, coincident with a snowpack temperature of about -2°C.

Therefore, to obtain storm snowfall measurements for the snowpillows it was assumed that values shown on the trace for P75 and P80 are reasonable estimates of actual snowfall. For P71 it was assumed that the diurnal fluctuations were not due to melt and delayed response, and that the time-to-equilibrium was the same as for P75 and P80. Therefore, the P71 value at the end of the storm at noon, April 27, was increased by prorating with the amount of the delayed response of P75 (using P80 as the base gave the same result within 0.1 in.). Because P59 is a 10-ft pillow, not 8-ft as are the others, its time-to-equilibrium is less. Therefore, the actual snowfall on P59 lies between 3.6 in. (9.1 cm), the value at noon April 27, and 5.4 in. (13.7 cm), the value obtained by prorating with P75 as if the time-to-equilibrium were the same. These values are given in Table 1 along with those for the recording precipitation and storage gauges. Storage gauge values for the storm were obtained by prorating with the closest recording gauge (either Twin 1 or Cabin 5).

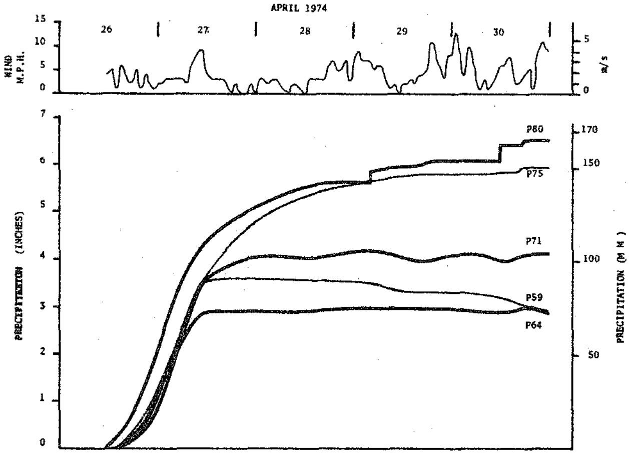

FIGURE 3: WIND SPEED AND CUMULATIVE SNOWPACK WATER EQUIVALENT ON 5 SNOWPILLOWS.

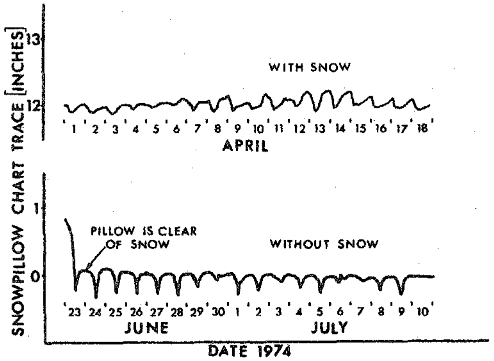

FIGURE 4-SNOWPILLOW P71 CHART TRACE ILLUSTRATING DIURNAL FLUCTUATIONS

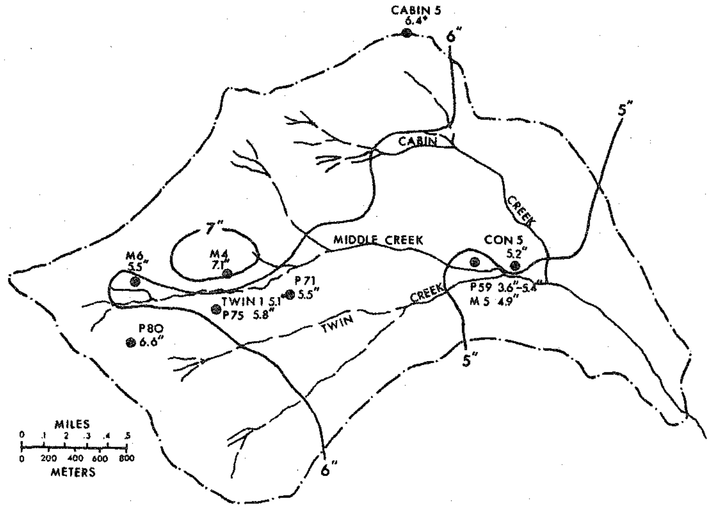

FIGURE 5: ISOHYETAL MAP OF SNOW-WATER EQUIVALENT FOR STORM OF APRIL 26-27, 1974 ON MARMOT CREEK EXPERIMENTAL WATERSHED

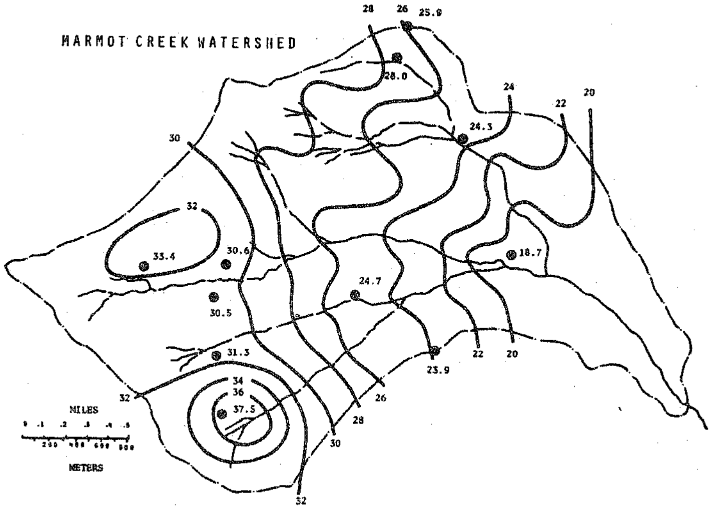

FIGURE 6: MEAN WINTER SNOWFALL WATER EQUIVALENT (INCHES) 1963-1973

Data Interpretation

The limited areal distribution of data points makes the storm isohyetal pattern (Figure 5) rather speculative, but there is no major conflict with the mean winter snowfall pattern (Figure 6). The flatter snowfall gradient for the storm between the confluence area and the alpine zone suggests that convergence in the low pressure area is more important than the upslope geostrophic wind in extracting the moisture from the air.

The data from the four snowpillows show a linear relation between snowfall and elevation (Figure 7). The pillows are all located close to the central ridge between Twin and Middle subbasins, and have similar aspect and slope. This single-storm relationship is strongly supported by the relation shown between snow accumulation near maximum pack and elevation for five 10-point snow courses along the same ridge, for which the correlation coefficient was 0.99 (Golding 1969). However, apart from the snowpillows and snow courses along the central ridge, the relation between snowfall and elevation is rather tenuous (Figure 7), as noted in a study by Storr and Ferguson (1972). This reflects the influence on precipitation of such other factors as slope and aspect. Data from a 200-point mechanically spaced sample of snow accumulation on Marmot basin near the time of maximum pack showed the same result. The correlation of snow accumulation with elevation was only 0.25, close to that for slope, -0.23, and forest density, -0.22 (Golding 1970).

The 40-mm difference between M4 and M6 may have been caused by snow accumulating on the outside of the M4 gauge cone during the storm, building above the orifice, and a sizeable chunk of it falling into the gauge when it melted. It also may be that the M6 orifice was partly closed for a time by accumulated snow, preventing the true amount from entering. Neither speculation can be supported by observation, so the question is left unanswered. When all the data are available, annual and snowmelt period water balances will be attempted, and may shed some light on whether M4 is too high or M6 too low.

Frequency Analysis

Twelve years of data are available from the recording gauge at Con 5 so a frequency analysis of maximum 24-h snowfalls each year was carried out (Figure 8). The 1974 point is obviously an outlier, being over 50% greater than the 100-yr return-period value, as discussed by Hershfield (1973). However, with such a short period of record, no return-period estimate can be made with any degree of confidence.

Conclusions

Using Tarble's findings that snowpillows under deep snowpacks can have a delayed reaction to changes in the pack, there is no serious conflict between the pillow and the precipitation-gauge data. The storm isohyetal pattern is similar to that of mean seasonal snowfall, but the flatter gradient suggests that convergence in the low pressure area is more important than orographic lifting in precipitating the atmospheric moisture. The snowfall at Con 5 in 24 h was over 50% greater than the 100-yr return-period value which would have been expected from the data for the previous 11 yr.

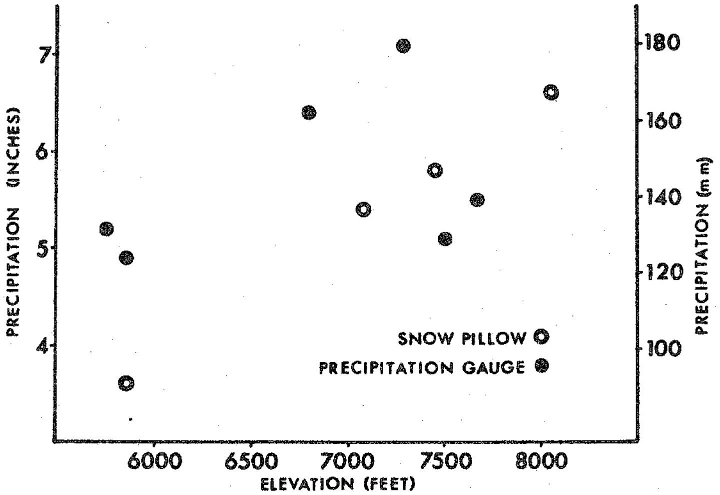

FIGURE 7 : RELATIONSHIP BETWEEN PRECIPITATION AND ELEVATION ON MARMOT CREEK FOR STORM OF APRIL 26-27, 1974

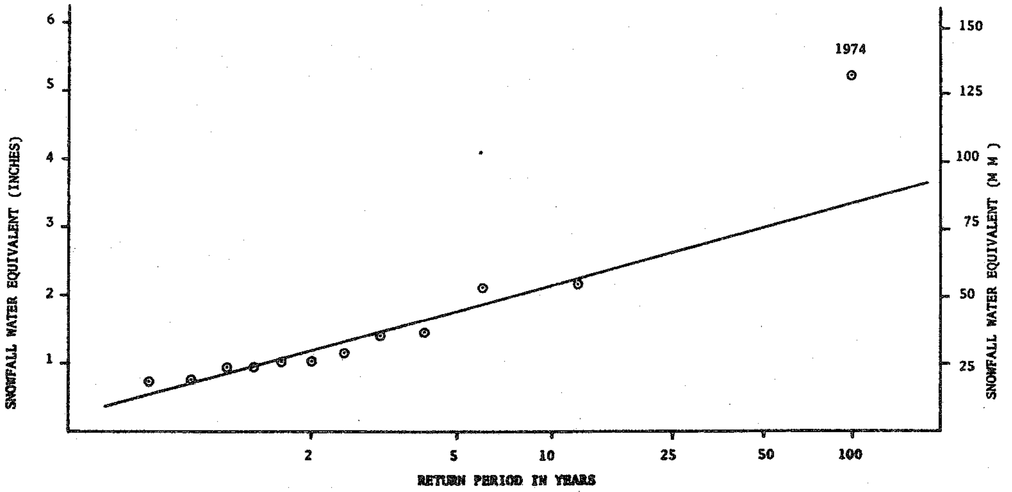

FIGURE 8 : FREQUENCY ANALYSIS OF ANNUAL MAXIMA OF 24 HOUR SNOWFALLS AT CON 5.

REFERENCES

Golding, D. L. 1969. Snow relationships on Marmot Creek experimental watershed. Can. Dept. Fish. For. Br. Bi-mon. Res. Notes 25(2): 12-13.

Golding, D. L. 1970. Computer mapping of the Marmot Creek snowpack and the influence of topographic and forest stand variables on the pack. pp. 76-83 IN Proc. 3rd Forest Microclimate Symp. Can. For. Serv., Calgary, Alberta.

Hershfield, D. M. 1973. On the problem of extreme rainfall events. Bull. Am. Meteor. Soc. 54(10).

Janz, B. and E. L. Treffry. 1968. Southern Alberta's paralyzing snowstorms in April 1967. Weatherwise 21(2):70-75, 94.

Oosterveld, M. 1974. The need for a national soil moisture network. Paper presented to Canadian National Committee for IHD seminar-workshop on hydrologic data collection, Ottawa, Ont. Oct. 1974.

Ord, M. J. 1968. Some comparisons from the use of radio reporting isotope snow gauges and the snow pressure pillows. pp. 89094 IN Proc. Western Snow Conference.

Penton, V. E. and A. C. Robertson. 1967. Experience with the pressure pillow as a snow measuring device. Water Resour. Res. 3(2):405-408.

Saulesleja, A. and B. Bowkett. 1974. Severe weather in southern Alberta, April 26-28, 1974. Unpublished report, Edmonton Weather Office, Edmonton, Alberta.

Storr, D. 1973. Wind-snow relations at Marmot Creek, Alberta. Can. J. For. Res. 3(4): 479-485.

Storr, D. and H. L. Ferguson. 1972. Distribution of precipitation in some mountainous Canadian watersheds. pp. 243-363 Proc. Geilo WMO Symp. Vol. 2 "Distribution of precipitation in mountainous areas", Geilo, Norway.

Tarble, R. D. 1968. California federal-state snow sensor investigations, problems and rewards. pp. 106-109 IN Proc. Western Snow Conference.

Warner, L. A. 1973. Flood of June 1964 in the Oldman and Milk River basins, Alberta. Environ, Can., Inland Waters Dir., Water Resour. Br. Tech. Bull. #73.