SNOW INVESTIGATIONS IN THE CRAIGIEBURN RANGE

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SUMMARY

In a study designed to test snow-survey techniques, samples were collected over a three-year period from headwater basins where snow usually lies only in winter and spring. Depth and density were recorded on one snow course at 5,600ft and one at 4,700ft. Total accumulation (water equivalent) for the three years averaged 20in. at the higher course and 5in. at the lower. Snow density varied from 0.11 g/cm³ to 0.60 g/cm³. In future surveys, sites selected must represent all topographic and vegetation types within a small basin, to ensure adequate sampling. Such surveys of representative basins, coupled with stream flow records, should give a reliable picture of catchment water balance.

INTRODUCTION

Watershed - management research conducted by the New Zealand Forest Service in the South Island of New Zealand is centred on the Craigieburn Range in Canterbury (Fig. 1). The present paper describes the measures being taken to assess snowfall in the area.

The factor that complicates precipitation measurements most in rugged terrain is wind. With snow, the difficulties are increased by its lightness and, more seriously, by the ease with which freshly fallen snow is redistributed. While shielded catch gauges can increase the accuracy of measurement, they cannot overcome problems caused by shifting snow. A more accurate assessment can be made by sampling the depth and density of fallen snow at a number of points, and this is the basis of the snow-surveying techniques originally developed in North America (Marr, 1940; Church, 1935). Since the early work of Church in Nevada more than 50 years ago, snow surveying has spread to Europe, the Far East, and Australasia (Levi, 1958; Higashi, 1958; Costin *et al.*, 1961) until it has become an accepted method of forecasting spring run-off from winter snow in most countries.

When climate investigations were begun in the Craigieburn Range in 1959, an assessment of snowfall was attempted by means of unshielded catch gauges with a 5in. orifice and a capacity in

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excess of 50in. of rain. Catches from a number of these, distributed through the upper Broken River catchment (Fig. 2), varied widely, depending on the degree of exposure at each site. Added to this, on many occasions after snowfall, wind-blown snow was observed entering gauges under clear-sky conditions. At this stage it was decided that a trial of snow-survey methods was warranted, and in 1962 a set of sampling tubes was imported from Italy. Surveying began in July 1962.

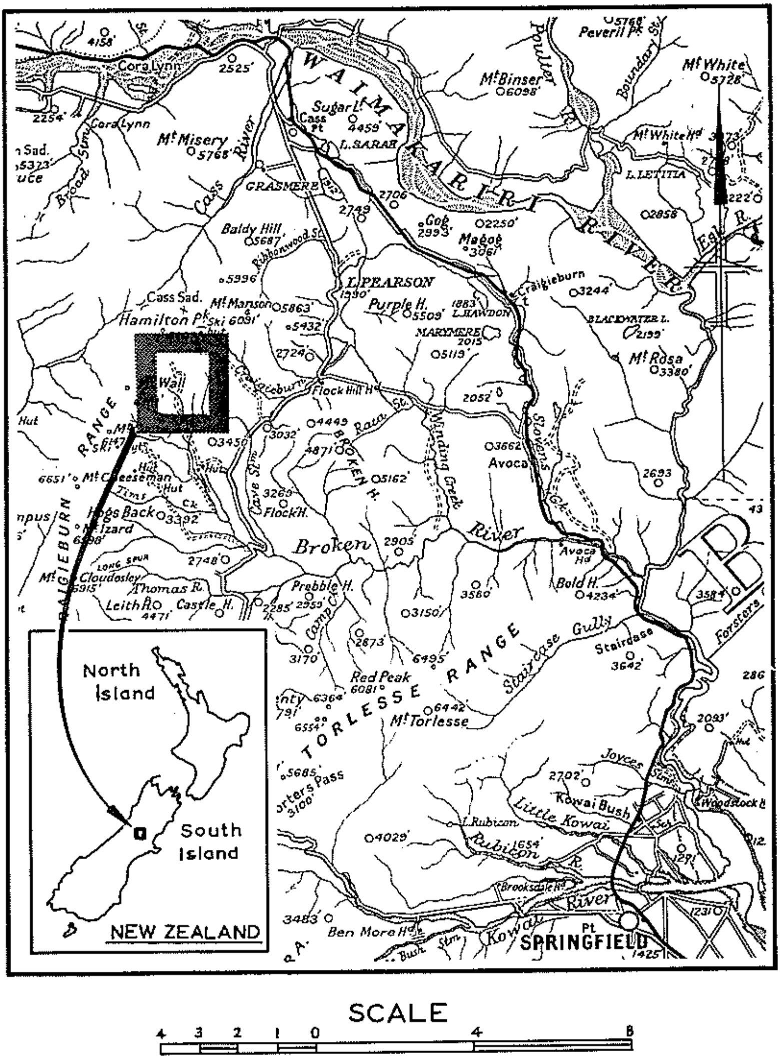

Fig. 1—LOCATION OF RESEARCH AREA on Craigieburn Range.

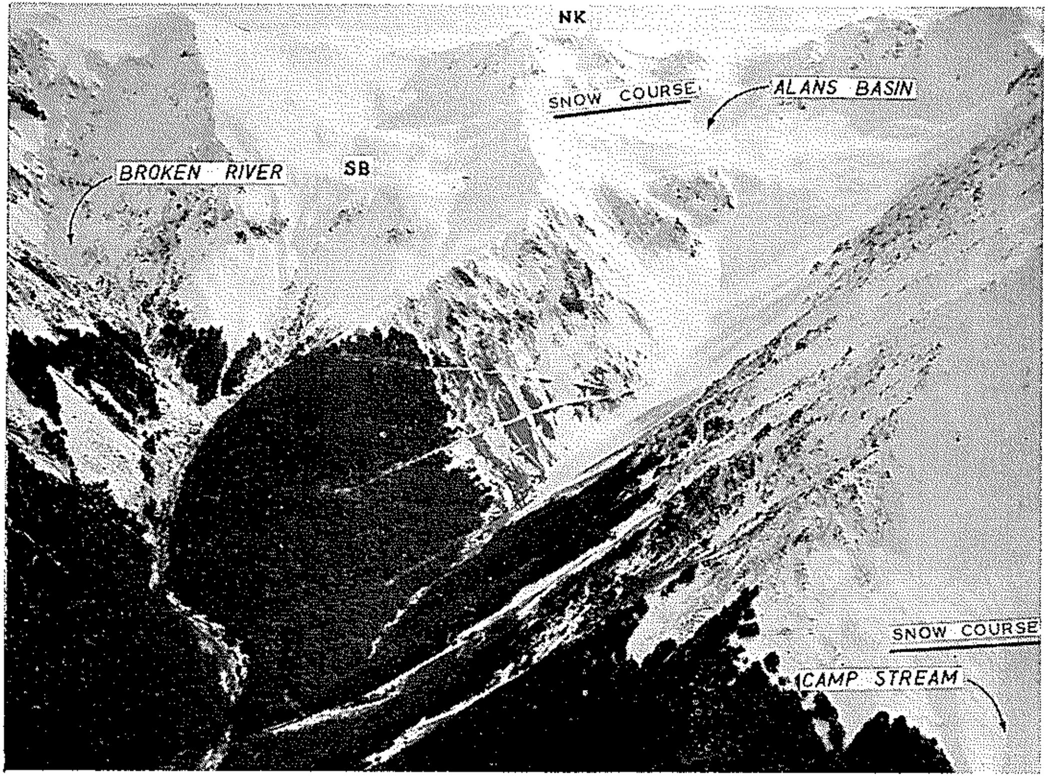

Fig. 2—HEADWATERS OF BROKEN RIVER, Craigieburn Range, showing the two snow courses.

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THE SNOW COURSES

The topography of the Craigieburn Range, and indeed of most mountain regions in New Zealand, is characteristically steep and broken. Broad, even, and often bare slopes alternate with steep gullies and cliffs, which may extend from valley floors to range summits.

Many factors influence the choice of location for snow courses. The site must be as representative as possible of the surrounding area; there should be a minimum of snow drift; the course must be reasonably accessible, and above all, it must be safe. These requirements are difficult enough to fulfil individually; together they are practically impossible to attain. Eventually it was decided to locate the courses in two headwater sub-catchments of Broken River—Alans Basin and Camp Stream (Figs. 1 and 2).

Both courses are located on reasonably smooth, even slopes above timber line; Camp Stream at 4,700ft and Alans Basin at 5,600ft above sea level. Gross irregularities of surface configuration and vegetative cover have been avoided as far as possible. Drifting is very uncommon on these slopes, which average about 30 degrees. Both courses are situated on lee slopes sheltered from the NW, from which direction most of the rainfall and snowfall comes. Because of this, accumulation is not seriously influenced by stripping of the snow cover, as is frequently the case on windward slopes. Table 1 provides details of the two courses.

TABLE 1—Details of Snow Courses.

	Altitude (ft)	Aspect	Average Slope	Length (yd)	Sampling Points
Alans Basin ...	5,600	NE	28°	264	13
Camp Stream ...	4,700	E	33°	264	13

SURVEY PROCEDURE

Sampling is carried out by a two-man team using an Italian tubular sampler. This equipment is described by Levi (1958) and differs from most American samplers in having a larger cross-sectional area and shorter length. The mechanics of sampling differ little from standard procedures described by Marr (1940).

Briefly, snow cores are taken from sampling points situated 22yd apart on a line which follows as closely as possible the local contour. The density and depth of snow at each point are recorded. Distances between sampling points are measured by tape, a constant sampling line being maintained by means of fixed marker poles.

Initially, surveys were carried out at four-weekly intervals, but it soon became obvious that, at least at the lower level, considerable snow melt was occurring between measurements. From 1963 onwards, therefore, surveys have been carried out at fortnightly intervals.

At this early stage no attempt is being made to assess the water equivalent of the snow pack on a catchment basis. These initial experiments were designed solely to test the feasibility of the techniques under ground conditions differing from those for which they were designed, and to build up a yearly record of snow cover for two permanent courses. Any assessment of water equivalent for a large catchment would require a much wider sampling pattern than that covered by the two existing courses.

SNOW CONDITIONS

Practically all precipitation in the area is from a westerly quarter. Most rainfalls are accompanied by winds from the NW, though some rain comes with the colder south-westerly winds. The latter can bring snow in any month of the year, but the bulk of winter snowfall is probably from the NW.

According to the season, accumulation of the winter snow pack may begin as early as mid-May or as late as the end of June, even at altitudes above 5,000ft. Occasional heavy falls in late autumn may persist at the highest levels, but generally there is no accumulation, even on colder south-facing slopes, before mid-May. On the warmer north-facing slopes accumulation is usually delayed by a month or more and, below 5,000ft, cover rarely persists throughout the winter.

In Alans Basin snow depth on the slopes rarely exceeds 6ft, except in local small depressions; but in the larger depressions on the basin floor, depths in excess of 20ft have been measured.

Even in mid-winter it is not uncommon for the wind to strip away as much as 2–3ft of freshly fallen snow, leaving the soil bared on ridge crests and on other very exposed areas. This is the factor that makes it essential to sample a large number of sites throughout a catchment, either by gauging or by surveying, if a reasonably reliable estimate of water equivalent is needed.

Snow cover continues to build up through July and August and, in most years, reaches a peak in September. With the onset of warmer temperatures in October, snowfalls at the higher elevations give way to rain, and the snow pack begins to diminish. The effect of wind and warmer temperatures on the thinner cover on north and west-facing slopes usually means that these are bare of snow up to 6,000ft by the end of October. On colder faces the cover usually persists above 5,000ft until mid or late November, and odd patches may last until well into December. There are no permanent snowfields on the Craigieburn Range, and no instances are known of deep drifts lasting through a summer, so that the snow cover is purely seasonal.

ACCUMULATION OF SNOW PACK

Table 2 gives details of surveys made in the two courses during the three-year period. The values show a steady build-up of water content throughout winter in the higher (Alans Basin) course, despite fluctuations in snow depth due to settling. In the lower (Camp Stream) course the position is confused to some extent by thawing throughout the winter. Fig. 3 indicates the

TABLE 2—Details of Snow Survey during 1962, 1963, and 1964

Date of Survey	Location	Average Depth (in.)	Average Density (g/cm³)	Average Water Content (in.)	Remarks
1962					
17 Jul	Alans Basin	22.2	0.30	7.1 ± 1.5	Compacted powder snow
1 Aug	,, ,,	27.9	0.30	9.4 ± 1.8	Compacted powder snow
4 Sep	,, ,,	48.4	0.31	15.0 ± 3.1	Compacted powder snow with ice layers
4 Oct	,, ,,	52.0	0.43	22.3 ± 4.0	Wet, slushy snow
1 Aug	Camp Stream	13.8	0.17	2.3 ± 0.6	Fresh powder snow
5 Sep	,, ,,	15.8	0.27	4.3 ± 1.0	Thawing powder snow

TABLE 2—Continued

Date of Survey	Location	Average Depth (in.)	Average Density (g/cm³)	Average Water Content (in.)	Remarks
1963					
31 May	Alans Basin	17.3	0.18	3.1 ± 0.3	Fresh powder snow
19 Jun	„ „	23.3	0.24	5.6 ± 0.7	Compacted powder snow
26 Jun	„ „	37.2	0.26	9.7 ± 0.9	Compacted powder snow
11 Jul	„ „	35.1	0.28	9.8 ± 0.6	Hard compacted snow
14 Aug	„ „	64.2	0.28	18.2 ± 1.0	Hard compacted snow
10 Sep	„ „	77.6	0.33	25.3 ± 1.4	Wet compacted snow
2 Oct	„ „	63.0	0.37	23.2 ± 1.4	Wet slushy snow
4 Nov	„ „	18.0	0.43	7.7 ± 1.7	Wet slushy snow
8 Nov	„ „	31.7	0.24	7.5 ± 1.8	Fresh powder snow over wet slushy snow
27 Jun	Camp Stream	18.3	0.25	4.5 ± 0.6	Compacted powder snow
11 Jul	„ „	13.4	0.27	3.6 ± 0.4	Wet compacted powder snow
25 Jul	„ „	22.4	0.27	6.1 ± 0.6	Compacted snow with ice
15 Aug	„ „	36.8	0.25	9.2 ± 0.8	Compacted snow with icy crust
9 Sep	„ „	31.8	0.32	10.1 ± 1.3	Wet compacted snow
1964					
5 Jun	Alans Basin	18.1	0.28	5.1 ± 0.6	Compacted powder snow
30 Jun	„ „	22.0	0.27	5.8 ± 0.4	Compacted powder snow
14 Jul	„ „	19.5	0.35	6.9 ± 0.9	Compacted snow with ice layers
29 Jul	„ „	53.5	0.24	13.1 ± 0.9	Fresh snow over compacted snow
14 Aug	„ „	74.8	0.32	24.0 ± 2.0	Hard compacted snow
25 Aug	„ „	67.3	0.32	21.7 ± 1.4	Hard compacted snow
9 Sep	„ „	81.0	0.30	24.6 ± 2.3	Soft compacted snow
25 Sep	„ „	86.9	0.33	28.4 ± 3.1	Moist, soft compacted snow
8 Oct	„ „	74.7	0.37	27.9 ± 2.6	Wet compacted snow
29 Oct	„ „	66.5	0.42	27.5	Wet slushy snow
12 Nov	„ „	56.1	0.42	23.7	Wet slushy snow
25 Nov	„ „	20.2	0.45	11.2	Wet compacted snow
15 Dec	„ „	2.9	0.48	1.4	Wet compacted crystalline snow
4 Jun	Camp Stream	5.3	0.30	1.9 ± 0.3	Icy crystalline snow
29 Jun	„ „	4.5	0.31	1.4 ± 0.1	Icy crystalline snow
14 Jul	„ „	7.3	0.25	2.1 ± 0.4	Compacted powder snow
29 Jul	„ „	24.0	0.23	5.5 ± 0.6	Soft compacted powder snow
26 Aug	„ „	28.0	0.31	8.9 ± 0.7	Compacted snow with ice layers
9 Sep	„ „	30.8	0.29	9.0 ± 0.7	Compacted powder snow
24 Sep	„ „	34.5	0.27	9.2 ± 1.0	Compacted powder snow
8 Oct	„ „	28.7	0.33	9.5 ± 1.4	Wet compacted snow
29 Oct	„ „	11.4	0.41	4.6	Wet slushy snow
11 Nov	„ „	4.0	0.47	1.9	Wet slushy snow

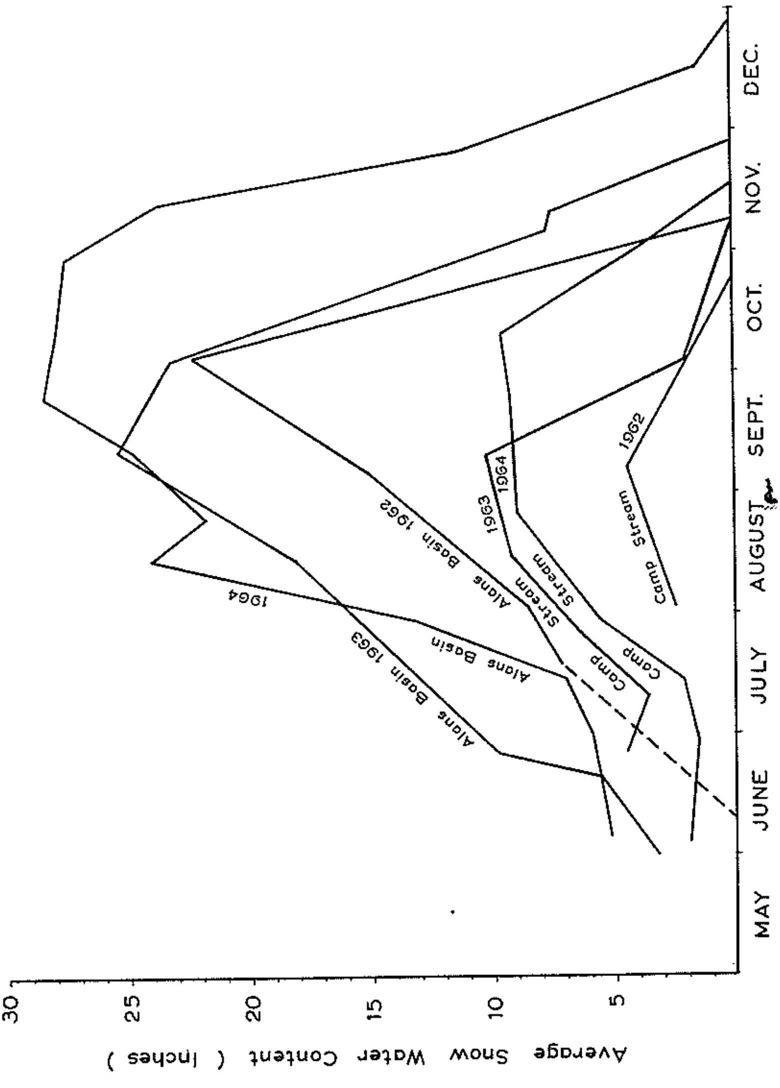

Fig. 3—AVAILABLE WATER in snow pack; 1962, 1963, and 1964.

build-up in water content; it also shows how snowfall varies in different years. For Alans Basin the pattern in 1962 and 1963 is similar, the difference being one of degree: water content built up steadily to a maximum in late September and early October, and declined rapidly thereafter. In August 1964, heavy snowfalls raised the water content to a high level early in the season, but it fell slightly during the latter half of the month. It increased to a maximum near the end of September, and remained near that level for another month, during which there was little thaw. Rapid thawing commenced only in mid November and some snow was still present along the course in mid December. The Camp Stream values follow the same pattern, with the 1964 maximum occurring in October, a date at which snow has usually disappeared from the course. Mean temperature for October 1964 was more than 5°F below the average for the previous three years.

Table 3 attempts to show rate of accumulation on the two courses.

TABLE 3—Snow Pack Accumulation Rates 1962, 1963, and 1964

Measured Accumulation Period	Total Accumulation during Period*	Accumulation Rate†
Alans Basin		
1962: 17 Jul–4 Oct (79 days)	15.69	0.20
1963: 31 May–10 Sep (102 days)	22.17	0.22
1964: 5 Jun–8 Oct (125 days)	22.80	0.18
Camp Stream		
1962: 1 Aug–5 Sep (35 days)	1.91	0.05
1963: 27 Jun–9 Sep (74 days	5.55	0.08
1964: 4 Jun–8 Oct (126 days)	7.60	0.06

* Water equivalent in inches.
† Inches of water per day.

The values show a daily accumulation of snow pack water of the order of 0.20in. for Alans Basin and only 0.05–0.08in. for the Camp Stream course, with little variation from year to year. The accumulation period is considered to begin on the date of the first survey, and to end when snow-pack water content is at its maximum. Water equivalent already on the ground is, of course, deducted in calculating accumulation figures.

DENSITY OF THE SNOW PACK

Table 2 gives details of snow density throughout the season, and Fig. 4 shows the increase as the season advances. Densities along the more elevated Alans Basin course were generally higher than those recorded at Camp Stream. This is taken as a reflection of the tendency for densities to be higher with greater depth, a tendency noted by Martinelli (1959) in Colorado. Occasionally, densities from Camp Stream exceeded those from the higher stations; this usually coincided with periods of winter thaw on the lower course.

Densities of freshly fallen snow varied from 0.11 g/cm³ to 0.20 g/cm³, the average being about 0.15 g/cm³. The lower end of the range approaches European and North American values, and the higher densities, even for fresh snow, are probably a reflection of the comparatively mild winter conditions experienced in the region. Certainly there are no instances of recorded densities as low as 0.01 g/cm³, a figure which is not exceptional for Scandinavia.

Fig. 4 shows that, as the snow pack ages, its density increases. Heine (1962), in his study of snow structure on Mount Ruapehu, noted the same increase with age, and his values are close to the Craigieburn ones. Gillies (1964), in his description of snow studies on the high plateau country of inland Otago, records a density range of 0.10 g/cm³ to 0.50 g/cm³ with an average of 0.30 g/cm³. These densities do not appear to be as low as would be expected in view of the lower temperatures generally experienced further south; the mean winter value of 0.30 g/cm³ is similar to that at Craigieburn.

Higashi (1958) reports spring values of 0.35 g/cm³ to 0.48 g/cm³ for snow above timber line in Hokkaido. Craigieburn values for the same season range from about 0.33 g/cm³ to 0.45 g/cm³. The climate of both regions would be subjected to strong oceanic influences, and latitudes are comparable.

The very high densities under summer conditions reported by Martinelli (1959) for alpine snow pack in Colorado have not been found in the Craigieburn studies. This is probably due to the fact that, while snow cover is not permanent in either area, drifts in Colorado last throughout the summer months; whereas in most years they disappear by early December in the Craigieburn Range. Maximum recorded density for the Craigieburn area is 0.60 g/cm³, which was obtained in late November Values similar to the 0.80 g/cm³ of Martinelli would probably be found in midsummer at altitudes above 7,000ft in the higher mountains of inland Canterbury.

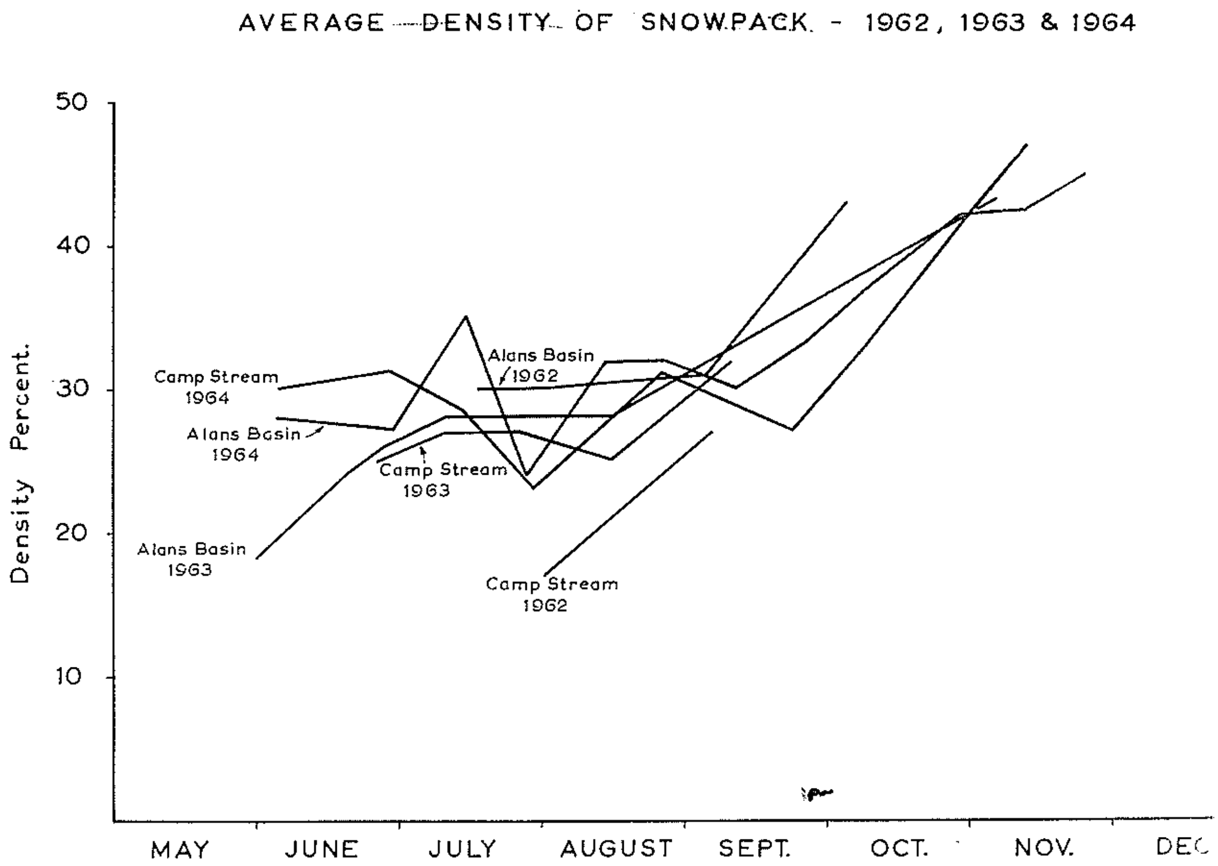

Fig. 4—AVERAGE DENSITY of snow pack; 1962, 1963, and 1964.

MELTING OF THE SNOW PACK

Winter thaw on the top course is rarely sufficient to cause loss of accumulated water. Thawing above 5,000ft seems to be restricted to the snow surface, and resulting melt water normally runs into the pack and refreezes to form ice layers. Only once during the three-year period did significant winter melt occur on the Alans Basin course. This was in late August 1964, during a week of strong north-westerly winds, when frosts were light and temperatures rose, with rain falling even at high elevations. During the 10-day period between two surveys, more than 2in. of water was lost from the pack and, because of the hard, compacted nature of the snow, it is unlikely that it was lost through wind action. The fact that this was an exceptionally windy month for winter is significant, and bears out the contention of U.S. investigators that "the amount of snow that can be melted by a strong, warm wind, such as a chinook wind, is much greater than any other natural source, including solar radiation" (Anon. 1961a). The NW wind, which is the prevailing wind in most of the South Island mountain country, has much in common with the chinook of North America and the föhn of the European Alps. Winter months in the South Island ranges are usually comparatively windless, with clear night skies and heavy frosts for long periods. When the NW wind blows continuously for more than a day or two at this time of year, it leads to a build-up of cloud over the ranges, with a consequent decrease in frost intensity. In exceptional cases, as in August 1964, it may even bring rain to levels above 5,000ft and when this happens some thawing occurs at high levels. But in general the major thaw at high altitudes begins only when the period of maximum westerly activity brings a rapid and sustained increase in day temperatures. This usually occurs in October.

At levels below 5,000ft the situation is quite different. On several occasions surveys have shown water loss during winter, and it is probable that this would be more evident if the frequency of visits were to be increased. Early in the season, light snowfalls that persist at the higher course will have disappeared between surveys in Camp Stream, and if an accurate picture of water balance is needed these falls must be taken into account. During mid-winter visits to Camp Stream, it is not unusual to hear small streams of melt water running under the snow pack, and to traverse wet ground while sampling. These conditions have not been encountered on the upper course.

Table 4 shows average daily thaw rates for the two courses for 1963 and 1964 after the beginning of the spring thaw. The end of the thaw period is taken as the time when continuous cover has disappeared and only a few isolated patches of snow remain on the course. These are so small as to have little effect on the water balance.

TABLE 4—Average Daily Thaw Rates of Camp Stream and Alans Basin Snow Pack

Year	Location	Measured Thaw Period	Average Snow Loss*	Thaw Rate*
1963	Alans Basin 5,600ft	10 Sep– 4 Nov (55 days)	17.58	0.32
1964	Alans Basin 5,600ft	8 Oct–25 Nov (48 days)	16.90	0.35
1963	Camp Stream 4,700ft	9 Sep– 2 Oct (24 days)	8.20	0.34
1964	Camp Stream 4,700ft	8 Oct–15 Nov (27 days)	9.50	0.35

* Equivalent inches of water.

During the main thaw period daily rates are similar for the two courses. On the Alans Basin course the thaw lasts from 6 to 8 weeks and yields approximately 0.35in. of water per day. On the Camp Stream course the daily yield is much the same, but the melt period is only about four weeks. Thaw rates of this order release slightly more than one cusec daily per 100 acres of snow field. Temperature records show that during the winter months (Jun, Jul, Aug) the mean monthly temperature at the Camp Stream course does not fall below freezing. At a site (SB) some 600ft below the Alans Basin course, mean temperatures are 3–4°F lower and do not rise above freezing during the same period. At a station on the range summit (NK), mean temperatures are 5–6°F lower again, so that mean temperatures at the Alans Basin course would be expected to be some 5°F lower than those at Camp Stream. This would explain the insignificant winter melting at higher levels.

No studies have been made of evaporative loss in the Craigieburn area, and it is assumed that conditions are similar to those found by Costin in Australia. He reported for the Australian Alps that evaporative losses may be more or less balanced by condensation gains (Costin *et al.* 1961).

EFFECT OF FOREST ON SNOW PACK ACCUMULATION

The forest in the region is formed by a single species—**Nothofagus solandri** var. **cliffortioides** (mountain beech), an evergreen that forms closed stands up to an altitude of some 4,400ft. The stand canopy is usually closed and there is a distinct lack of any understorey, owing largely to the former presence of browsing animals, so that the forest is essentially single tiered.

Above 3,500ft a light snow pack accumulates on all except sunny north-facing slopes. Even at timber line, however, the pack is not permanent throughout winter, and may disappear from warm faces between snowfalls. Whether or not it is permanent, the snow pack under beech forest never reaches the depths recorded in the neighbouring grassland areas. Because of the rather flattened or rounded crowns of older trees, and the peculiar fan-shaped spread of the lower branches, considerable quantities of snow are intercepted during snowfall. Unless freshly fallen snow is very wet, much of it is removed by wind action or melts in the crowns. If it is wet, the spreading habit of the lower branches ensures that it slides off before extensive snow break occurs. Only in the latter case does it contribute to snow pack accumulation.

To gain some idea of the effect of forest on snow accumulation, depth and density were measured at a number of points in forest, and were compared with those on neighbouring grassland sites of similar topography. At two altitudes, two courses were selected which gave four sites in grass cover and four in forest. The investigation was made in late July 1964, approximately one week after a series of heavy snowfalls. Results are shown in Table 5.

TABLE 5—Average Depth, Density, and Water Content of Snow Pack under Beech Forest and in Open Grassland

	Altitude (ft)	Aspect	Depth (in.)	Density (g/cm³)	Water Content (in.)
Grassland ...	4,350	East	20.7	0.19	3.9
Forest	4,350	East	5.0	0.43	2.2
Grassland ...	4,200	East	14.8	0.27	4.0
Forest	4,200	East	5.4	0.49	2.6

There is substantially less snow under the forest, but this is partly compensated for by greatly increased density. Although less snow would be expected under forest at this altitude, where snowfall is not important, the magnitude of the loss is rather surprising. Further investigations will be needed to verify these figures. The marked increase in snow pack density under forest is attributed to rapid surface melting due to moderately high day temperatures, and to drip from the melting of intercepted snow. Kittredge (1948) records a number of instances in which the density of snow under forest is lower than it is in the open near by, but the temperature conditions in this case are probably altogether different from the warm sunny conditions at low altitude in the Craigieburn Range. The figures of Higashi (1958:27) for Hokkaido show little difference in density between forest and grassland under spring conditions, and indeed show little variation over an altitudinal range of more than 1,500m.

SNOWFALL AND TOTAL PRECIPITATION

As already indicated, the present survey was not designed to measure total winter precipitation in the Broken River basin, but to test survey techniques with a view to their ultimate application on a catchment basis.

Earlier indications were that total precipitation in the upper Broken River basin was of the order of 80in. annually. This figure was arrived at by comparing the catches of a number of gauges located throughout the upper basin with those of gauges at lower altitudes unaffected by snowfall. An estimate of snowfall was also made by means of a number of unshielded storage gauges, and although these figures must be regarded with some suspicion owing to the known deficiencies of unshielded gauges, they provide a useful general indication of total fall.

The results obtained from catch figures and from snow-survey data are of the same order. As would be expected, the catch figures tend to be lower. It would seem, then, that on the top course, and probably on all sites on the range above 5,000ft, approximately one-third of the annual precipitation falls in the form of snow. On the lower course, which has about the same annual total fall, snowfall makes up only one-fifth of the total. Below this altitude the importance of snow decreases, until at 3,000ft the amount contributed by snowfall in an average year is negligible.

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