REVIEW OF SNOW SURVEY METHODS, AND SNOW SURVEYS IN THE FRASER CATCHMENT, CENTRAL OTAGO

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SUMMARY

The need for snow surveys in the high altitude catchments in this country — to complete the precipitation record, to assist with flood forecasting, to regulate storage for consumptive use and to enable experimental work to be undertaken in these catchments — is briefly considered. Outlines of methods which could be used to gather the necessary field data for such surveys are examined; and experiences in the application of some of these methods in the upper Fraser Catchment, Central Otago, reasonably typical of southern New Zealand seasonal snow conditions, are discussed in some detail.

INTRODUCTION

This review of current methods in use for snow measurement has as its origin some investigational work carried out in the past two winters in the upper Fraser Regional Catchment in Central Otago.

Snowmelt accounts directly and indirectly for a significant portion of the run-off in many of the southern catchments. The greater proportion of this snow accumulates between the winter snowline at about 3,500ft, and the summer snowline somewhere above 6,500ft. Because of wide variations in this Island's climate, snow accumulation is not a continuous cumulative process as in continental snowfields; but it thaws, recedes and reforms at intervals throughout the winter, so that the water content of the snowpack is variable and hence difficult to measure. Storage in the form of snow plays a little-recognised but important part in this country's economy. As the demands on our water resources increase, so does the need increase for more fundamental information on the yield from this source.

Snow studies have not been actively pursued in this country; their lack till now being probably due to there being little need for serious water conservation studies for our snow-fed rivers — except for some rather unimportant and isolated instances. There

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also appears to have been an almost casual reliance on the most generalized assumptions where snow melt is a significant factor in flood control studies.

Probably some of the reluctance to carry out practical measurements on snow, stems firstly from the general uncertainty as to the likely benefits from such work; secondly from the very real observational difficulties which exist; and thirdly from the expense, and the often extremely arduous nature of these investigations under typical New Zealand mountain conditions.

Hereafter described are, firstly, some general reasons for studying the snow pack; secondly, an account of the usual methods which are in use to determine the water equivalent of the snow pack; and thirdly, some local experiences in the application of some of these, together with some interim conclusions.

MAIN REASONS FOR SNOW STUDIES

Completion of Precipitation Record

An essential requirement for any index or regional catchment is the annual total of the precipitation falling on that catchment so that a water balance can be computed. The mean height of the South Island is 2,800ft, so that it is not surprising to find a number of regional catchments located above this elevation. High altitude catchments present special problems, for in the majority of them the winter precipitation falls as snow. It is therefore necessary to convert such precipitation into the equivalent volume of water to enable the water balance equation to be completed.

Flood Forecasting

The amount of water stored in a snowfield, and its potential rate of melting, frequently has a significant influence on winter and spring flood discharges. Even in those cases where no controllable storage lies between the snow field and the spillway or flood control scheme, this information can be a pertinent factor in design; but it is of much greater influence and importance where reservoir levels have to be, or should be, regulated in accordance with the snow load.

Consumptive Use

High level accumulations of snow are just as an effective method of storage as multi acre-feet reservoirs except that such storage is purely seasonal and frequently out of step with demand. This winter's snowfall is often next summer's irrigation supply or next winter's power output. Better control should therefore be possible if all relevant factors are known in advance. If the actual water equivalent of the snow load is known, the system can be controlled to that degree during the period of greatest demand, irrespective of the variations in the subsequent season's rainfall.

At present very little appears to be known of the proportions of the water crop used either for hydro or irrigation purposes that are actually derived from snow melt. And until such information is obtained any correlation process is scarcely possible.

Catchment Standardization

Before any treatment affecting precipitation and run-off relationships can be effectively applied, a complete understanding of the hydrological processes in the study area is required. Furthermore, a period of probably five years and certainly not less than three is required on the untreated or control areas.

The tussock grasslands of the South Island are being increasingly studied, and most of these are under snow for several months of the year. Before any valid conclusions can be reached, it would appear that seasonal variations must firstly be evaluated; and the only way to do this is by accurate measurements of both precipitation and run-off.

METHODS OF MEASUREMENT

With the exception of the radiation method, the methods in the approximate order of presumed accuracy are: (a) storage gauges, (b) ground sampling, (c) aerial inspection, (d) photography and (e) gamma radiation. It is possible that the order of the first two should be reversed. Some details of each method are given.

Storage Gauges

These can be of a variety of types of either non-recording or recording gauges and may be either shielded or unshielded. Recording snow gauges are mainly of the weighing type.

It has long been recognised that wind has a significant influence on the catch of various types of precipitation gauges. Unshielded storage gauges have often been used and continue to be used to record snow catches, but their accuracy is conditional on their degree of exposure to wind and its velocity. The whole problem of snow measurement is bound up with trying to mitigate or normalize the effect of wind on the movement of snow; as snow when it falls has a density of about 5% of that of water and has a tremendous surface area in relation to its weight. Aerodynamically it has a high ratio of lift to weight and it behaves accordingly.

Warnick (1953) described the effect of carefully conducted experiments with artificial snow on gauges of various types with and without shields, at wind speeds up to 16.5 m.p.h. in a specially designed wind tunnel. He also comments on the performance of various types of flexible shielding on two field experiments.

Both he and Brooks (1938) record higher deficiencies with snow measurements made in windy locations. The most widely used snow shield was developed by Alter who first began experimenting in 1909 (Bernard, 1938).

The Alter shield consists of individually shaped baffle strips, arranged around the gauge orifice, which are designed to prevent the build up of snow on the shield and between it and the gauge. This type of shielding, although the most successful to date, is definitely limited to conditions of moderate wind velocities and temperatures below 20° to 25° F.

At high wind velocities snow sticks to most surfaces, building up on the windward side, completely encrusting the shield and the gauge with ice which, on melting and re-freezing, forms long dangling icicles. The same effect is evident when snow forms at temperatures at or near 32° F, when the so called "sticky" snow will adhere to almost anything.

Satisfactory shielding for very exposed blizzard type of conditions has not yet been developed. The only solution may be a form of heated shield to prevent build-up, but the cost of operating many such shields could well be prohibitive (Allen and others, 1955).

At sheltered sites, or where snow falls in quiet conditions, shielding is unimportant and can even result in sampling errors. Even with the flexible type of shield, the snow has built up between shield and gauge under particularly sheltered conditions, and has partly or completely capped the gauge. The same can occur in exposed locations if the gauge is not sited high enough above the surrounding snow.

Ground Sampling

The limitations and uncertainties arising from the catch recorded in storage gauges had let to the development of direct sampling techniques.

The first of these was apparently the use of "snow boards"; varying sized sections of material laid on top of the existing snow to record the depth of a particular snowfall. The latter, when sampled with the aid of the standard orifice of a manual gauge, and the snow therein then melted, gave both the depth and the water content.

Although still in use in some localities, especially on manned stations where it is a relatively convenient method of recording each fall as it occurs, the use of snow boards has been superseded by the use of hand operated samplers of various patterns, e.g. Mount Rosse and Utah samplers. These extract a cone of snow in a tube fitted with cutters, which is weighed in the field to determine snow densities more or less directly.

Associated with the developments of this sampling equipment were the investigations into the requirements for, or the design of, snow courses.

The primary objective in the design of a snow course is to select the minimum number of stations to establish the mean depth and water content of the area being studied. It is not possible to do more than generalize as to what is required as no two situations are exactly similar, but two distinct types of sampling are involved in every snow course. The first involves the selection of a course, or courses, to sample the snow conditions on the watershed; the second is to locate selected points of measurement on the actual course itself.

The first selection is the more difficult for it is not possible to utilize statistical methods to determine the location of the course. As far as possible, personal bias must be eliminated. In say a forest area, the location is often governed by the available open space between stands rather than a uniform coverage, while in steep, open country ski-able routes are often the predetermining factor.

Sampling on a specific course is, however, open to the use of statistics. Ideally, the points should be drawn from a single homogeneous population and if obtained at definite fixed intervals, should eliminate nearly all bias of selection. Working on this basis it is possible to determine whether too few or too many stations are being occupied and sampled, or whether any individual station is unduly influencing the results.

Unfortunately, such are the vagaries of snow fall in this country, both year by year and during the winter, that a drift at one station one year may be bare the next; so that caution has to be exercised in the application of statistical methods. Different numbers of stations may have to be occupied in different years on the same snow course.

The simplest and most direct approach, and probably all that is justified to determine the improper or inadequate sampling of a snow course, is to use the arithmetic average and the standard deviation in their most elementary form (Connaughton, 1937).

To determine whether enough samples have been selected, it is first necessary to decide on some arbitrary standard, e.g. that the results are satisfactory if the error of sampling for the water content for any one course is within the plus or minus 10% of the average water content for that course. This infers directly that had other courses been established in the vicinity of the first, 19 out of 20 of them would not vary, by chance alone, by more than $\pm$ 10% of the average of the first.

With the standard error adopted directly and the standard deviation being taken as 5% of the average, (i.e. 10% from the normal curve of error is equivalent to two standard errors — one standard error is therefore 5%), the number of observations required can be determined from the following formula:

$$SEa = SD/\sqrt{N}$$

Where SEa is the standard error, SD is the standard deviation, and N is the number of observations required. As conditions are seldom, if ever, such that those calculations can be performed en route in the field, they are used primarily to determine: (a) if the snow course has been sampled sufficiently to establish an average value within certain limits of accuracy, (b) the accuracy of the sampling, (c) if the course should be resited or altered, (d) if the sampling points in a snow course, or actual snow courses, can be reduced in number.

Only the latter case is really of practical importance, as generally the effort involved in actual measurements on a course is small compared with the effort expended in getting there.

Variations in the layout of snow courses from a straight or more or less straight line are frequently required. Cruciform arrays around a central point are probably more satisfactory when sampling a specific area, such as a clearing, basin, etc.; and grid arrays are the best method in sampling to determine the effect of say a snow fence.

Aerial Inspection

There is little doubt that a helicopter is the ideal method of inspecting a snow field as it permits direct sampling with ease and rapidity of movement. Unfortunately they are not readily available in this country and are also prohibitively expensive to hire.

If suitably calibrated ground markers are installed, conventional light aircraft can be used to rapidly record snow depths and the extent of snow cover.

The number of actual observations made are generally restricted; firstly because of the more elaborate targets required, secondly because they have to be spaced at convenient intervals (not closer than a ½ mile apart) for them to be read consecutively without repeated passes. A simple colour sequence at foot intervals is sufficient as it is not possible to read more accurately than $\pm$ 3in. and the usual accuracy is $\pm$ 6in. Colours require careful selection. Contrasting colours such as red and black in some light conditions are scarcely identifiable.

The method records only snow depths but on isolated snow fields when conditions prohibit the approach by wheeled vehicles, or the terrain is too steep, it permits regular inspction of snow conditions which would otherwise involve many hours of hard climbing.

Photographic Methods

This is the least accurate and least satisfactory method of directly estimating the available water contained in the snow pack, but it is a very useful adjunct to the preceding methods. Both vertical and oblique photographs may be used to give a permanent record which can be used either for comparative purposes or to establish, if possible, some form of correlation between the extent of snow cover and its water content (Totts, 1937).

Gamma Radiation Absorption Counters

Gamma rays are emitted from a suspended source above the snow on a geiger counter buried in the earth beneath. The counter, when coupled to suitable transmitting or recording equipment, records the changes in the water content of the snow cover, as a function of the energy absorption in the water layer between the source and the counter.

The method is mentioned here for it appears to be the only reliable automatic method of recording water contents of the snow pack.

EXPERIENCES WITH SNOW MEASUREMENT IN THE UPPER FRASER CATCHMENT

A number of methods outlined have been tried, during the past two winters, in this catchment and on the Old Man Range adjacent to it.

The work is partly the outcome of the Soil Conservation and Rivers Control Council's regional catchment scheme, and partly a continuation of work started by the Otago Catchment Board's High Country Survey Team which made an intensive study of the catchment (Mark, and others), and maintained a series of storage gauges and other meteorological eqquipment on the Old Man Range for a period of three years (Mark, 1962).

The upper Fraser catchment above the irrigation dam, which covers 48 sq. miles, was selected as a regional catchment. The investigations were started to complete the precipitation record for the catchment; and to study contribution of snowmelt both to flood discharges and as a source of water for irrigation and power.

The area is typical of some hundreds of square miles of Central Otago range country. It is exposed to south and SW gales; blizzard conditions and extremely high winds are common. Under these conditions, even if it is not snowing, fresh snow is whipped up and out of the basin, producing "white out" conditions on otherwise fine and clear days. Most of the catchment is above 4,000ft. Both the large central basin and a small upper basin are rimmed by smooth-topped mountains between 5,000 and 5,500ft high (Fig. 1).

Summer access to the area, between the Old Man and Carrick ranges, is by jeep track either from Symes Road which leaves the Roxburgh-Alexandra highway at Fruitlands, or via the Fraser Dam road from the Earnscleugh Flat. Access in winter is by foot from Symes Road; this is generally a climb of 2-3,000ft.

Snow Courses

It was decided to establish a semi-circular snow course in the middle and upper portions of the catchment, which could be inspected from the air if necessary (Fig. 1). The course was 12 miles long and it was possible to cover it on foot, or on skis, in a day. Stations which were really cruciform type arrays about a central snow pole, were established at roughly half-mile intervals, so that they would be representative of the snow cover in their vicinity. Each station consisted of a 9ft pole, 4in. square, sunk 2ft into the ground, and guyed three ways with No. 8 gauge wire (Fig. 2). The 20 poles were colour-coded in black, red and orange bands each 1ft wide.

Aerial Inspections

Approximately 10 flights and two ground traverses, to record densities, were intended during the first winter. Actually, only four flights were attempted in the first season, and the last of these at the end of the season had to be abandoned because of low cloud over the basin. A photographic record of the snow depths at the poles was intended, but this was found to be impossible with the cameras available. The greatest accuracy with which the snow depth could be observed was $\pm$ 3-6in. as a safe altitude had to be maintained. (Tight turns in NW air are far from pleasant and observers selected for this work should be highly resistant to air sickness — otherwise they rapidly lose interest in what is happening).

The first ground survey party reported that the snow around the poles had cratered and that depths were being considerably

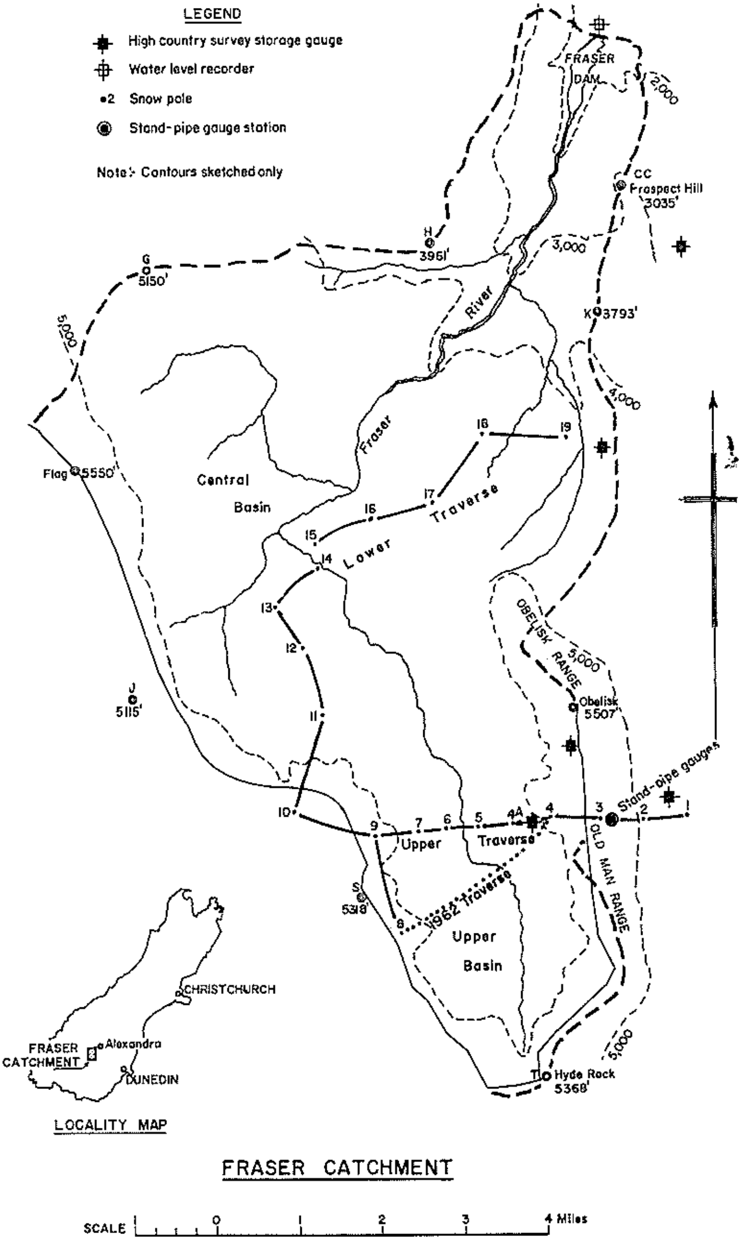

Fig. 1 — LOCALITY MAP

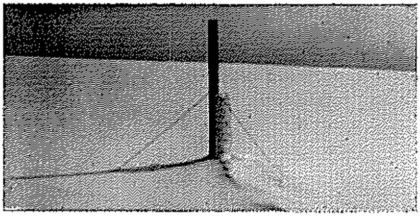

Fig. 2

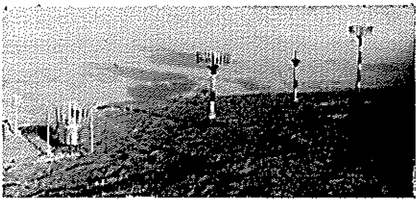

Fig. 3

Fig. 4

Fig. 5

Fig. 2 — SNOW POLE with ice build-up.

Fig. 3 — STORAGE GAUGE SITE; from left: recording thermometer at rear, shielded C type gauge at 4ft, shielded and unshielded standpipe gauges at 8ft, and shielded standpipe gauge at 12ft.

Fig. 4 — STORAGE GAUGE SITE, snowed over; from foreground: unshielded C type gauge orifice at 4ft, shielded C type gauge at 4ft, and standpipe gauges at 8ft and 12ft.

Fig. 5 — ICE AND SNOW BUILD-UP on Alter shield and standpipe gauge.

Fig. 6 — ICE BUILD-UP on cup anemometer.

Fig. 6

under-estimated. Last winter, snow pole inspections revealed that the opposite had occurred — there was actually a build up round the pole (Fig. 2); but end-of-season observations on a few of the poles showed that cratering was again occurring, and it is therefore a seasonal effect introducing a further source of error from aerial inspections.

Experiences with Storage Gauges

The first season's experiences indicated that investigations using storage gauges should first be concentrated on a smaller, more accessible area. An area was selected near the head of Symes Road which was slightly in the lee of the exposed top of the Old Man Range. Meteorological instruments were already at this site.

Three 5in. diameter standpipe gauges (modified from the U.S. Weather Bureau pattern) and two C type storage gauges (Grant, 1960) were erected. Wind shields were fitted to one 12ft standpipe, one 8ft standpipe and one 4ft C type gauge (Fig. 3). One 8ft standpipe, one 4ft C type and the existing 12in. high storage gauge were not shielded. The C type gauges were fitted with inner containers to avoid condensation increases and to permit the catch to be weighed if necessary. Kerosene to prevent evaporation and a glycol-based antifreeze were added to the five new gauges. The original storage gauge contained calcium chloride solution which was later found to have corroded the inner container. Gauge orifices were sited at different elevations to see if it were possible to determine a consistent difference between the catches, on the assumption that the catch might possibly be related to the movement of the wind-blown snow. The effect of shielding on the catch was also studied.

The first two observations made in April on two isolated snow storms, indicated that the method might have promise. Unfortunately the lower gauges were disturbed by musterers, thus eliminating any possibility of correlation. Later these gauges were completely snowed over (Fig. 4). The design of the standpipe gauges also gave trouble. Snow which failed to reach the antifreeze inside the standpipe bridged over and blocked the opening. Ice and snow debris that dropped from the shields during thaws, built up around the base of the standpipes and made entry into the valve chamber impossible. The Alter windshields became iced up as in Figure 5. Figure 6 shows the extent of ice build-up on the anemometer on top of the ridge. Observations made during a blizzard showed that the snow was being blown up through the shield — not quite what had been expected from the wind tunnel tests on the design. On the unshielded gauges, thick ice and snow built up on the inside and outside of the orifice. All cases were expected to give false readings.

Snow Sampling

Snow depths and densities were recorded, when the standpipe gauges were inspected, at a number of points adjacent to the gauge array and between the snow line and the top of the ridge. These were made with a C.N.1 (La Commissione Nevi — Snow Commission, Italy) snow sampler at two to four weekly intervals.

Last winter it was intended to restrict the work to the small study area at the top of Symes Road; but the unreliability of the storage gauge method of assessing precipitation, and the heavy snowfalls, led to the resumption of both limited aerial inspections of the original snow course, and a comprehensive ground traverse of the stations. Two flights and one full traverse, involving 86 measurements of snow depths and densities, were made. A final traverse of the full course at the beginning of October proved impossible. The thaw had just started and the snow was crusted over and hollow underneath. Ski-ing was virtually impossible and snow wading was the only means of locomotion. The far side of the basin could not be approached as the Fraser River was running too deep to be waded and no safe snow bridges existed.

Photographic Methods

Panoramic photos from the ground, and coverage from the air, were taken at intervals during the winter. The relatively smooth and broad tops of the ridges made the panoramas of only limited use. Aerial views were of more use but were limited as they were taken during the snow pole inspections. It would have been better if a separate circuit of the basin at a higher altitude had been flown for this purpose as orientation of the photos proved to be very difficult — many of the ridges under heavy snow cover looked disconcertingly alike.

RESULTS AND CONCLUSIONS FROM THE FRASER CATCHMENT STUDIES

The two season's work showed that some of our pre-conceived ideas require modification — particularly as to the use of storage gauges. The basin in winter is akin to subantarctic conditions where winds of 50 knots and upwards are common. Under such conditions, present shield designs appear to be of little use. Unshielded gauges, with their orifices located above the snow, clearly under-register; and storage gauges located near ground level record a catch which is solely goverened by the amount of snow which is blown into the gauge before the orifice caps over.

For not so exposed sites, the elevated C type gauge should be the most satisfactory but with the following provisos: that it be (a) equipped with a corrosion inhibiting inner container (Bernard, 1958) to prevent condensation from influencing the catch,

(b) filled with calcium chloride antifreeze solution, and kerosene to prevent evaporation, (c) possible to remove and weigh the inner container, and (d) that the orifice be suitably shielded. Some reservations are felt as to the use of 5in. diameter orifices on snow gauges. The U.S. standard 8in. may be better to prevent arching-over inside the gauge. Funnel cross sections should enlarge inside the orifice for the same reason.

For exposed high altitude catchments similar to the Fraser, there appears to be no substitute for snow-course sampling; unless it is the gamma radiation method, which because of expense could not be located at more than one or two places in the catchment.

Aerial inspection, with photographs, is the easiest and cheapest method of keeping track of changes in snow depths and the extent of the snow cover. Ground inspections must be used to determine densities and to check depths.

Insufficient work has been done on this catchment to determine whether the equivalent results can be obtained by sampling at only one site — if this were so, it would simplify the work tremendously. The variation in snow densities, etc., recorded for two winters gives some idea of the problem. Densities observed during the 1962 winter varied between 10 and 50%; the normal range being 20-40% with an average of 30%. At the end of September 1962, the snow cover was continuous above 4,800ft and averaged 15in. deep, so that there was approximately 5in. of water available in the snow pack at the start of the thaw. In the winter of 1963 snow depths were greater and the cover was practically continuous above 4,500ft. Mean density was nearly 35%, making about 10in. of water available.

One of the biggest difficulties which has to be faced is the physical effort needed to carry out snow surveys. The snow survey equipment and other gear required is not light and climbs of 2-3000ft are necessary before work can commence.

Once the thaw sets in, snow surveying becomes a hazardous undertaking. Deep snow often melts out from below, leaving a hard surface crust and either very soft or very little snow beneath. On ground that is rough or broken, this can lead to serious accidents: so that the last surveys must be undertaken before the thaw sets in.

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