The FORESTRY CHRONICLE

SNOW SURVEYS FOR THE PURPOSE OF FORECASTING STREAMFLOW

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Introduction

THE maximum flow of our streams on the Pacific slope is largely due to melting snows. In the semi-arid states of California, Utah and Nevada, it is estimated that over 95% of the stream-flow originates as snow in the High Sierras, and while the percentage diminishes as one comes north, it is evident that snow is the predominant factor for most streams in B.C., even in our wet Coastal belt. It has been found that the average of some 200 typical streams in B.C. produce 85% of their volume in the seven high months—March to September. This peak run-off represents the storable surplus which power companies, irrigationists and urban communities endeavour to hold against the months of low flow.

Snow is an elastic element; its depth gives no indication of its water content. This year on B.C. courses the density of snow on the ground varied from 19.4 to 71.1%. Even newly-fallen snow, which the meteorological services assume at a constant density of 10%, has been found to vary as much as 100% from this figure and has been known to have a density as low as 5%. From this it follows that forecasts based on snow depth alone are liable to large errors, and are quite undependable. A knowledge of the snow-cover and its water content is, therefore, of prime importance, and dependable forecasts of resultant stream-flow of inestimable value.

History

Snow surveying was first conceived in Europe in the study of the density of snow, but it remained for the demands of the arid south-west of the U.S.A. to give birth to this new branch of the natural science of hydrology.

It will be of interest to Forest Engineers that this new development came into being as the result of studies on a purely forestry problem, and, further, that from the standpoint of snow-surveying, forests are of vast importance.

Dr. J. E. Church, meteorologist of the University of Nevada, can justly claim the honour of being the father of snow-surveying in its present form.

Under his direction, and sponsored by his university, the Mt. Rose snow observatory was established in 1904, and the Sierra Nevada became a vast laboratory, where weather, snow cover and density, evaporation and melting were given continuous and scientific study. It was established to study the effects of forests on the conservation of snow, but the crying problem of Lake Tahoe floods soon claimed its attention, and from the solution of this problem forecasting of stream-flow emerged from the mazes of research.

As its practical value became apparent, more and more agencies contributed to the common cause, until now snow-surveying may be said to have reached its maturity, and a co-operative system of snow surveys has been built up embracing power companies, irrigationists and State departments over the States of California, Nevada, Utah, Washington and Oregon.

In 1934 snow surveying invaded B.C. The Comptroller of Water Rights, Major J. C. MacDonald, M.E.I.C., who had been following its development, decided to initiate a modest system in the Province as a step towards more economic use of our water resources, particularly in the semi-arid sections where irrigation is necessary, and available water supplies severely taxed.

Fundamental Relationships

At Mt. Rose observatory, two fundamental facts emerged:

First: That over a given basin the relative snow cover was the same wherever measured, provided neither drifting nor melting had taken place. In other words, if the water content at some point was found to be, say, 75% of normal, it would also be 75% of normal at other points in the same basin within a very small margin of error, regardless of the depth of snow at either point.

Second: That the percentage of normal of the water content of the snow pack at the end of the snow-fall season agreed closely with the percentage of normal streamflow to be expected during the ensuing run-off months.

On these fundamentals the Nevada, or percentage method, of snow-surveying and of forecasting run-off was built up.

Distorting Factors

The principal factor in causing divergence between snow and run-off is a departure from normal of the precipitation during run-off, so that the expectancy of a discordant water-content-run-off ratio is governed by the normal ratio of precipitation during run-off to snow. That is, when the normal proportion of spring and summer rains to water content of snow in the precipitation year is small, even wide variations in the rainfall will not materially affect the forecast. When the proportion is great, the reverse is true.

It was a most fortunate coincidence that the area chosen for research was in the High Sierras, an area which proved to be remarkably free from distorting factors, which might otherwise have befogged the fundamental facts.

An accuracy of forecast within 10% is usually possible, and on many well-established snow surveys in favorable areas accuracies to within 2% and 3% are being obtained. In other cases where consistently discordant results were obtained, the disturbing factors have been isolated and studied and normals weighted accordingly.

Unprotected Mountain Slopes Subject to Extreme Snow Evaporation.

The following summary gives the accuracy attained in a group of 63 comparatively new snow courses in the U.S.A.:—

Accuracy within following percentage	No. of Forecasts
Based on normal run-off	
0 to 5%	27
5 to 10%	14
10 to 15%	7
15 to 20%	6
20 to 25%	5

25 to 30%	3
30 to 35%	1
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	63

In individual cases some factors of the "total loss" between snowfall and run-off exerting an abnormal influence will distort the water-content-run-off ratio. The principal components of total loss are evaporation, transpiration, and deep storage or percolation water which does not find its way to the streams. In such cases these factors have to be studied. Much could be written on this phase alone, but in a brief article it is only possible to sketch a mere outline of snow-surveying.

Snow Conservation

The principal agencies in conserving snow are mountains and forests. The two must be considered as inseparable in this regard. The former conserve by their altitude, and by acting as a reservoir for snow, which they yield up gradually in response to advancing spring and summer. The effective altitude varies more or less in direct proportion to the latitude.

It is little realized how great is the loss from evaporation on exposed wind-swept snow slopes. Evaporation takes place regardless of even sub-zero temperatures and must not be confused with erosion.

The extent of evaporation loss was examined at Mt. Rose observatory (Elev. 10,800). Measurements taken during a continuous 69-hour period in April, 1911, on the windward face showed a total evaporation of 2.32

High Alpine Type of Cover Affording Good Snow Protection. Fourteen Feet of Snow.

Ideal Forest Cover for Snow Conservation. Nineteen Feet of Snow in the Coast Range.

inches (water content) or 24.21 inches per month under an average wind velocity of 30.6 miles per hour; it was noted, however, that erosion began to occur at the higher velocities. On the lee side there was a total evaporation of only 0.687 inches, or 7.17 inches per month under an average wind velocity of 10.8 miles per hour. It will be noticed that acceleration of the rate of evaporation was almost directly proportional to the increase in wind velocity. Other experiments tend to substantiate these results.

In contrast to this high rate of loss on bare exposed slopes the effectiveness of forests in gathering and retaining snow is most marked, as indicated by measurements made on the bare summit of Mt. Rose and in the lower timbered slopes at 47 stations in April, 1910. The following is quoted from Dr. J. E. Church's article in the "Geographical Review," Vol. XXIII, No. 4, Oct. 1933. Depth of snow is given in inches, water content in inches in brackets.

"Unforested talus slope, 40.8 (18.4), distributed thus: cornice below Observatory, 52.5 (25.1); wind-swept slope, 8.1 (2.6); protected slope, 78.1 (35.1); forested slope, 88.6 (41.1)."

The superiority of the forested slope is even more evident in the following comparison made the same year:

	March 1	April 5	Net gain
Forested slope	88.1 (36.8)	88.6 (41.1)	0.5 (4.3)
Protected slope	81.3 (32.3)	78.1 (35.1)	3.2 (2.8)

The influence of scrub of varying heights is shown by measurements made April, 1910, at 52 stations:

"Talus slope covered with low scrub,	32.4 (13.4)
"Slightly steeper talus dotted with timber screens 10 to 20 ft. high	61.4 (26.5)

"In a season of normal or heavy precipitation the snow on the first slope rises as high as the tips of the scrub, but no higher for the slope is then exposed to the unobstructed sweep of the wind."

Those who have travelled the mountains in winter and spring will have noted the implication of the above measurements; that, area for area, forests are far more efficient than open slopes in conserving snow. It is only in the heavier cornices and the slide areas in gulches that the snow outlasts that in the forested areas below.

Even the interception of snow by the crowns of the trees, and the resulting evaporation, is recognized to be much lighter than that of rain. Again quoting Dr. Church:

"That the factor is small is suggested by the following comparison of the net gathering power of open and forested areas in Tahoe Basin (California):

	Net gathering power March 11, 1910	Net retention in spring April, 20, 1910
"Treeless meadow	29.8 (11.7)	Gone Apr. 10-13, 1910
"Forest of pine and fir	31.4 (12.1)	1.3 (0.6)
"Fir forest	30.4 (11.0)	7.1 (2.7)

"A further comparison of various types of forest at Blackwood creek indicates that the dense forest with glades has a maximum gathering and retaining power:

	March 13-14	April 25
"Open forest of pine and cedar	34.9 (13.5)	0.5 (0.2)
"Very dense fir forest	31.0 (10.9)	2.1 (0.9)
"Dense fir forest with glades	42.7 (16.5)	7.8 (3.2)

(Note: depth of snow in inches; water content in inches in brackets. R.C.F.)

"The index of protection capacity is confirmed in figures (inches of water) for total evaporation, December to May, 1913-14, at Tahoe City: small fir glades, 1.492; large forest opening, 2.152; open meadow, 4.766; deforested southern slope, 5.865."⁽¹⁾

- (¹) See also by Dr. J. E. Church: *The Conservation of Snow: its Dependence on Forests and Mountains*, "Scientific American Suppl. No. 1914, Vol. 74, 1912, Sept. 7, pp. 152-155; *Recent Studies of Snow in the United States*, "Quart. Journ. Royal Meteorol. Soc., Vol. 40, 1914, pp. 43-52.

The importance of the conserving function of our forests cannot be over-emphasized when it is remembered what a high proportion of the run-off is due to melting snow. It is a rare drainage system indeed which has natural or artificial features which affect a complete balance of flow, and could therefore dispense with the restraining effect of forests. In all other cases their lack would produce vast spring floods followed by months of lean run-off.

Much controversy has raged about the forested versus the deforested area in its effect on total run-off. With regard to snow it is doubtful whether the losses from evaporation and transpiration in forests are as great as on exposed areas. The Mt. Rose experiments indicate the high evaporation loss on exposed slopes even at freezing temperatures.

Inaugurating a Snow Survey

While the fundamentals of snow-surveying are simple, their application is often complex.

Topography is the principal cause of local variations in climate and precipitation, and a complicated system of mountains, valleys and plateaus such as British Columbia causes wide variations in temperature and precipitation in relatively short distances, and accounts for the alternating wet and dry belts which are characteristic of the Province.

Having decided for which streams it is desired to make forecasts of run-off, an intensive study is made of the water-shed and its topography, and climatic variations.

Certain existing facilities have a considerable bearing on the siting of snow courses, such as the location of stream gauging stations, meteorological stations, and means of access by road and rail, having in mind the exigencies of winter travel.

It is unfortunate that precipitation stations are of necessity mostly located in valleys, where local residents can make the necessary readings. In consequence, the majority are more or less valueless as an index to conditions at the higher altitudes which produce the major portion of the run-off.

Where precipitation data do appear to be fairly representative, they have to be tabulated and studied over their entire period of record; snowfall and precipitation during run-off segregated. Run-off data are tabulated for the assumed run-off period; normals are computed for these three factors of snowfall, precipitation-during-run-off, and run-off; the percentages of normal of each, for each year of record, and percentage departures of run-off from snowfall computed. The relationship between the three are then studied both graphically and statistically.

While the precipitation records of snowfall give no reliable indication of water content, they are a valuable guide as to the relative influence of snowfall and precipitation-during-run-off on run-off. Where discordant years appear, a more detailed study of the latter by weekly or even shorter periods may be necessary. The duration and intensity of storms has an important bearing on their effect on run-off. This study should be accompanied by a detailed study of the prevailing temperatures which act as a contra to precipitation by inducing evaporation, and being a function of relative humidity.

From the above studies, the most suitable areas for snow courses can be decided on.

SNOW COURSES

A snow course is a permanently established line over which measurements of depth and water content are made each year at fixed observation points. The course should be high enough to be free from premature melting, not subject to extensive drifting, and shaded to some extent from the direct rays of the sun. The ideal site is a bench or moderate slope with an open forest cover interspersed with glades. The actual location of such a site often requires much laborious searching.

ZONING

One well-chosen course is often all that is required for a very extensive basin, although it is desirable to have two or three at varying altitudes, each representative of a fixed altitude zone. It is a safeguard against a year of abnormal thaw, which might greatly affect the lower course. Where a basin is zoned, the percentage of normal for each course is weighted according to the area it represents. Areas are planimetered from a topographical map.

SNOW SAMPLING

Snow sampling is the operation of obtaining the depth and water content on the courses. In advanced surveys not cramped for lack of adequate funds, several samplings are made throughout the winter, but the important sampling for forecasting is made about April 1, just before the winter's accumulation of snow begins to run off.

Author Snow Sampling in Good Protective Cover. Interior of Lodgepole Pine Stand.

Snow-sampling equipment consists of aluminium alloy tubes of a little over $1\frac{1}{2}$ inch diameter, made in sections which can be coupled together for any desired length according to the depth of snow encountered; they are slotted to render the snow-core visible and graduated in inches for gauging the depth. The bottom section terminates in a saw-toothed steel cutter for penetrating ice or crusted snow. A spring balance is provided for weighing the tube and snow core. The throat diameter of the cutter is such that one ounce in weight gives one inch of water content. With sets for deep snow a wrench is supplied to assist in forcing the tube down.

In snow sampling the tube is forced down through the snow to the ground beneath at each observation point, and when withdrawn retains the core. Depth of snow is recorded, and also the weights of the empty tube, and tube with core; the difference being the water content in inches. The average of all points is the water content for the course.

Where funds permit, further samplings in May and June assist greatly in correcting the April 1 forecast, when studied in conjunction with the interim run-off and precipitation data, and are of special importance where the object of the snow surveys is flood control, or flood prediction.

Snow Sampling tube and spring balance.

NORMALS

From the computed normal of stream-flow, a preliminary normal of water content is estimated, and used until such time as an independent snow course normal can be built up. The computation of stream-flow normal is often complicated by artificial storage and diversions, which necessitates reducing the given data back to a condition of theoretical unregulated flow—often a laborious operation.

For large basins involving several snow courses, the water contents of the individual courses have to be weighted according to the estimated influence which they exert upon the whole. In weighting, altitude zones, areas represented, and precipitation zones (if anything is known of the latter) have to be taken into consideration. No general procedure can be laid down for such cases. Each requires intensive study and experimentation, in order to determine the best method of approach.

FORECASTING

As soon as the field data are received, forecasts can quickly be worked out, provided an efficient, standardized system of receiving and handling data has been evolved.

Official forecasts cannot be ventured for the first 4 or 5 years, and only then provided there is a long stream-flow record at the controlling stream gauge. If both snow sampling and stream-flow records have to start from scratch, a much longer period must usually elapse before forecasts can safely be made.

FLOOD PREDICTION

The expectancy of so many acre-feet of water during the run-off period is of great value to power companies and irrigationists, but furnishes no criterion to possible flood conditions. Prolonged warm spells or abnormal rains falling on the snow early in the run-off period are the controlling factors, and often produce serious floods from quite sub-normal snow conditions.

Several samplings subsequent to April 1, when studied in relation to precipitation and recorded run-off for the intervening period, furnish data which assist in predicting the probability of floods, but such forecasts must be regarded as far less accurate than the quantitative forecast, dependent as they are on the impending vagaries of the weather.

Flood prediction from snow surveys is under investigation by several agencies, but the difficulty of projecting the occurrence of natural phenomena into the future and predicting their frequency is complicated by the fact that they are not subject to the assumptions of the theory of probability, and when plotted give an "unsymmetrical probability" curve. It is the writer's intention to try the application of the treatment of skew frequency curves to this problem.

B.C. SNOW SURVEYS

Inaugurating the system has entailed much laborious investigation and study, and many hard miles afoot in summer, and on skis and snowshoes in winter.

At present we have 15 courses, 8 of which have had 2 years' sampling; 2 have had one year, and the remaining 5 were located last summer and will be sampled for the first time this winter. Their distribution is shown on the accompanying map. Four are in the Coastal area, the balance in the Okanagan, Kootenays and Rockies, and therefore in Columbia river drainage.

At present, funds will only permit of sampling on all courses for the April 1st forecast, and beginning this winter a January 30th sampling, and perhaps one in February on the Okanagan Courses. These are to assist in the regulation of Okanagan Lake levels. The April 1st forecast is entirely quantitative; no attempt will be made at this stage to predict the incidence of flow throughout the run-off period. When April precipitation data are available, any necessary corrections will be made to the forecasts.

The results of last winter's sampling are tabulated as follows:

Course No.	Elev.	Date of Sampling	Depth of Snow Inches	Water Content Inches	Density %	% of Last Year's Water Content	
						Normal	Water
1x	4200	Mar. 23	125.6	89.1	71.1	—	—
2	1100	26	40.1	16.0	39.9	72.3	88.0
3	4700	21	25.3	6.16	24.3	100.3	64.0
3x	4300	22	28.8	7.26	25.2	111.7	71.0
4	4200	13	29.0	6.48	22.3	137.8	88.0
5	6000	18	54.2	14.75	27.2	183.5	117.0
6	4300	15	31.3	7.40	23.6	209.0	134.0
7	6000	22	65.3	14.88	22.8	87.8	88.0
8xx	4500	26	17.4	4.02	23.1	80.3	78.0
8xxx	4500	26	17.4	4.02	23.1	74.5	—
9	3000	21	17.7	3.44	19.4	—	—

x Percentages of normal are tentative only and must be regarded with caution for a year or two: they are estimated from normals of streamflow at the controlling stream-gauging station for each course.

xx Related to Kootenay river.

xxx Related to Columbia river.

This year the mechanics of forecasting were gone through for the first time, using those courses with two years of record. The results are tabulated below; as mentioned before these are not considered as an official forecast:

SNOW SURVEYS

283

Stream		Course	R.O. in		Acre-Feet	%	Remarks
Name	at	No.	Forecast	Actual	Error		
(a) Stave	Stave Falls	2	785,200	1,290,900	38.0		Weighted normals
(b) Okanagan	Penticton	3 to 6	388,100	360,100	7.8		
(Kootenay)	Wardner	8	3,045,000	2,868,000	5.8		Same basin
(c) Kootenay	Wardner	8	3,045,000	2,868,000	5.8		Contiguous basin
(d) Columbia	Nicholson	8	1,567,000	1,770,000	11.5		
(e) Duncan	Houser	7	1,551,000	1,747,000	12.2		"
(f) Lardeau	Gerrard	7	482,000	483,000	2.7		Same basin

Note: "Same basin" means course is in same basin as stream.

"Contiguous" means course is in an adjacent and apparently similar basin to the stream.

With regard to (a)—Stave river, no great hopes of immediate success were entertained; lack of precipitation data prevented preliminary studies being made; at the same time it was known that there were wide variations in precipitation in comparatively short distances over the high and rugged watershed. Funds would not permit of the location of numerous experimental courses, the ideal method of approach. One carefully chosen course was, therefore, located and a new precipitation station established up the lake. From the information indicated by these, two more courses were laid out this fall, and it is hoped to eventually achieve success; precipitation-during-run-off will probably upset the forecasts in many years however, as it is a large factor in this area. Last year it was 147% of the 22-year normal and probably accounts in some part for the disparity between forecast and actual run-off.

(b) Okanagan, offered many complications. Forecasting was from Courses 3, 3A, 4, 5 and 6, which involved the use of weighted normals. Okanagan lake is subject to regulation, so that it was necessary to compute a theoretical unregulated flow.

(d), Columbia, was experimentally forecast from Course 8, the Upper Kootenay course. The new courses 11 and 12 will now be used for this forecast.

(e), Duncan river, was forecast experimentally from the course in an adjacent basin. Where conditions in contiguous basins are similar, this is often possible with fair results.

I believe this is the first large scale official system of snow surveys in Canada, and for any measure of success which we are achieving thanks are due to various U.S.A. authorities and agencies to whom we turned for guidance and advice, and to the co-operation of the Meteorological Service of Canada, the Dominion Hydrometric Bureau and the British Columbia Electric Railway.