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Douglas L. Golding (1972)

SNOW ACCUMULATION AS INFLUENCED BY TOPOGRAPHY, AND ITS CORRELATION WITH ANNUAL AND SEASONAL STREAMFLOW ON MARMOT BASIN, ALBERTA.

(Presented at the Sixth Annual Congress of the Canadian Meteorological Society, May-June 1972; Edmonton, Alberta)

Northern Forest Research Centre
Environment Canada
Edmonton

SNOW ACCUMULATION AS INFLUENCED BY TOPOGRAPHY, AND ITS CORRELATION WITH ANNUAL AND SEASONAL STREAMFLOW ON MARMOT BASIN,[1] ALBERTA

by

Douglas L. Golding[2]

Abstract

In a regression model relating snow accumulation to 16 topographic and stand variables on Marmot Creek experimental watershed, 36 per cent of the variance was accounted for. Addition of variables indexing the primary and secondary location of snow-measurement points relative to major topographic features of the basin improved the model only slightly, although of the four most significant variables, two were combinations of primary and secondary position.

To determine how well snow courses that have been measured for the past 10 years indexed actual snow accumulation on the basin, snow course data were correlated with mean snow-water equivalent measured in 1969, 1970, and 1971 at 1200 points on a 1 x 10-chain grid across the basin. Correlation coefficients ranged from 0.80 to 1.00 with particular snow courses consistently having the highest values, indicating that these courses provide a good index of basin snow accumulation.

Annual and seasonal streamflow from Marmot basin and three sub-basins were correlated with both snow course and the 1 x 10-chain grid data. In both cases, highest correlations were obtained for May-June runoff (correlation coefficients of 0.73 to 1.00), followed by May-July runoff, and lastly annual flow. Higher correlations were obtained for the relation of runoff with snow course data than with grid data.

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[2] Research Scientist, Northern Forest Research Centre, Edmonton, Alberta.

INTRODUCTION

In 1961, Marmot Creek experimental watershed was established. One of the objectives is to determine the effect of commercial timber harvest on basin hydrology. The intention was to learn how to manage the forest for water along with the other products of the forest. The main hydrologic effect of manipulating forest cover is on snow accumulation and melt.

Objectives

The objectives of this study are (1) to determine what topographic and forest variables affect snow accumulation, (2) to determine how well the snow courses index snow accumulation on the basin, and (3) to relate runoff from the basin during snowmelt to snow accumulation.

Study Area

Marmot Creek experimental watershed is a 3 $mi.^2$ basin in the Kananaskis River Valley, about 25 miles south-east of Banff, Alberta. Topography is steep and elevation ranges from 5,000 to 9,000 ft. a.s.l. Forest cover is mainly Engelmann spruce (*Picea engelmanni*), alpine fir (*Abies lasiocarpa*), and lodgepole pine (*Pinus contorta*), with timberline about 7,500 ft.

REVIEW

Snow Accumulation Model

Snow accumulation has been related to topographic and forest variables in other studies. The variables that exhibit the strongest relationship to snow accumulation vary from one situation to another. Packer (1962) constructed a model in which the independent variables of elevation, aspect, and forest cover accounted for over 90% of the variance in snow accumulation. A model constructed by Anderson (1967) explained 82% of the variance using only storm characteristics such as precipitation at index station and wind.

Ffolliott and Hansen (1968) related snow accumulation to forest density, elevation, and potential insolation. Forty-six per cent of the variance was accounted for.

High correlations were shown between snow w.e. (water equivalent) and elevation at five snow courses on Marmot basin (Golding, 1969). The snow courses were on a central ridge with similar slope, aspect, and forest conditions. Snow w.e. at the 50 points on these snow courses was significantly correlated with forest density (Harlan and Golding, 1970). I correlated snow w.e. with elevation and weighted stand density, where the weight was determined for each tree by size and proximity to the snow-sampling point. Highly significant correlations were obtained. For example for April 1966 the correlation coefficient was 0.91 (Golding, 1970a). For the same date, the correlation of snow w.e. with elevation alone was 0.81, and with elevation and a single, unweighted measure of stand density, 0.87.

Snow w.e. at maximum pack (approximately March 20) at 200 points on Marmot basin was correlated with 14 variables of elevation, slope, aspect, and stand density. Variance accounted for was only 23% (Golding 1970b). It was thought that the model would be improved by including an independent variable to index relative topographic position on the basin.

Runoff and Snow Accumulation

The relationship between runoff and snow accumulation has often been studied to predict runoff for short periods. Garstka *et al.* (1958) related daily snowmelt runoff to temperature, radiation, humidity, wind, and accumulated antecedent runoff. Runoff has also been related to areal extent of snow cover throughout the melt season, e.g., Leaf (1971) in Colorado.

This paper deals only with total runoff during snowmelt and the maximum snowpack.

METHOD

The first snow courses on Marmot basin were established in 1961. These consist of 10 points, 50 - 100 ft. apart. The courses are intended to provide an *index* to snow accumulation on the basin. Snow depth and w.e. are measured monthly during the snow season. Data for 1969, 1970 and 1971 for snow courses 1, 3, 6, 8, 11, 14, and 19 are used in this study.

Since 1969, a much more intensive snow-sampling program has been carried out. Snow depth and w.e. are measured in late March at over 1500 points on a 1-chain (east-west) X 10-chain (north-south) grid. At every fifth point east-west, the following were recorded: elevation, aspect, slope, and stand density. On a sub-sample of 106 of these points, primary and secondary position were also recorded.

Primary and secondary position index the sample point relative to topographic features of the basin (Table 3).

Streamflow is gauged year-round by Water Survey of Canada. Stevens A-35 stage recorders are used with three concrete weirs and one H-type flume on the four streams.

For the snow-accumulation models, results for 1970 are reported here with occasional reference to 1969 and 1971 results.

RESULTS

Snow Accumulation Model

Multiple regression model. Three snow accumulation models were constructed using data from 106 sample points on Marmot basin. Model I consisted of six independent variables that had earlier been shown to be significantly related to snow w.e. (i.e., FOREST DENSITY, $SLOPE^3$, $ASPECT^2$, $ELEVATION^2$, ELEVATION X SLOPE, FOREST $DENSITY^2$). This model accounted for 36% of the variance in snow w.e.

Model II consisted of the same six variables as well as nine variables of PRIMARY POSITION, SECONDARY POSITION, and their interactions. Variance accounted for increased to 48%.

Model III included the 15 variables of Model II plus other powers of the six basic variables (i.e., $SLOPE^2$, $SLOPE^3$, ASPECT, $ASPECT^3$, ELEVATION). Also, those variables for which a numerical index was used (ASPECT, PRIMARY and SECONDARY POSITION) were re-indexed in order of increasing mean snow w.e. This model accounted for 58% of the variance (Table 1). The simple correlations with snow w.e. of the re-indexed variables increased from 0.17 to 0.34 for PRIMARY POSITION, 0.05 to 0.17 for SECONDARY POSITION, and from 0.14 to 0.27 for $ASPECT^2$ (Table 2).

Simple regression model. Regressions were run of each independent variable with snow w.e.. For every 1000 ft. increase in elevation w.e. increased by 2.2 in. Relations such as this will change from year to year depending on the snowpack. This amounts to an increase in w.e. of 0.45 in/1000 ft. elevation/inch mean snow w.e. In 1971 the increase was 4.7 in/1000 ft., but expressed on the basis of the snow accumulation in 1971 is 0.43 in./1000 ft. This is just about the same rate as 1970.

Change in snow w.e. with aspect is generally small. South-west and north-west aspects accumulated least (2.68 in. and 3.82 in. w.e. respectively, whereas west accumulated most (7.25 in. w.e.) (Table 2). However, west aspect had only two samples.

Snow w.e. decreased 0.41 in./10% slope increase. This is 0.084 in./10% slope/inch mean snow w.e. This compares to a decrease of 0.42 in./10% slope increase in 1969, or 0.064 in./10% slope/inch mean snow w.e.

As forest density increases, snow w.e. decreases. The measure of forest density is tree count as determined by the Bitterlich point sampling method. As tree count increases by one, snow w.e. decreases by 0.11 in. This is a decrease of 0.022 in. w.e./increase in tree count of one/inch mean snow w.e. The equivalent rate in 1971 was 0.015 in.

The distribution of sample points among the classes of PRIMARY and SECONDARY POSITION was such that only a few of the classes can be considered adequately sampled (Table 2). Snow w.e. was least for the class "hollow" (1.50 in.) in PRIMARY POSITION and greatest for "major valley" (10.17 in.) (Table 2). "Ridge top", both major and minor, rank low (3.60 in. and 3.77 in. respectively). "Valley bottoms" rank high with "major valley bottom" higher than "minor valley bottom" (10.17 in. and 6.75 in.). With SECONDARY POSITION, snow accumulation is least where the sample point is within 3 ft. of a tree (3.87 in.) and greatest along the edge of the trees but in the opening (6.83 in.).

Correlation of Snow Course and Grid w.e.

March snow w.e. at each snow course was related to mean March w.e. on each of the four areal breakdowns of the basin (Twin, Middle, and Cabin sub-basin, and Marmot basin which includes the three sub-basins and an area below their confluence). March mean w.e. was obtained from the grid sample of 1500 points.

Correlation was lowest for snow course 1 in all four basins (Table 3). For the other six courses coefficients ranged from 0.894 to 0.999. Coefficients were highest for the correlation of snow course w.e. with mean Marmot w.e., followed by those with Middle, Twin, and Cabin sub-basins. It would be expected that the best index of mean sub-basin snow accumulation would be a snow course within that basin. This is not apparent from the results (Table 3).

Highest correlations were obtained for snow course 6. This course is in the confluence area. Next highest was snow course 14 (centrally located in Middle sub-basin), and then snow course 19 (above tree line in Middle sub-basin). Of course, the differences in the correlation coefficients are not significant, having only three years' data.

Correlation of Runoff and Snow w.e.

For the correlation of runoff and snow accumulation, four runoff periods were used: water years April 1 - March 31 and May 1 - April 30, and snowmelt periods May 1 - June 30 and May 1 - July 31. Snow accumulation was for 3 measurements: March and maximum pack at the snow courses, and mean sub-basin w.e. from the March grid sampling.

For all four runoff periods, correlations were highest for runoff correlated with the March snow course w.e. This was followed by that with the maximum snow course w.e. and lastly by that with the mean sub-basin w.e. This is surprising in that mean sub-basin w.e. is the average of many points within each sub-basin and is an estimate of actual accumulation rather than an index as in the case of snow courses. Also surprising is that May 1 - June 30 runoff from each sub-basin was more highly correlated with mean Marmot w.e. than with mean w.e. on the sub-basin itself.

Of the four runoff periods, highest correlation with snow w.e. was obtained for the shortest period, May 1 - June 30 (Table 4). Although snowmelt runoff continues into July, the poorer correlation for the period May 1 - July 31 is due to factors such as rain and evapotranspiration. The two water years gave essentially the same correlation with snow w.e., none of which even approached significance at the 95% level of probability.

Only those correlations of runoff with snow w.e. associated with May 1 - June 30 runoff (Table 4) were significant at the 95% level of probability. In fact, the sign of some correlation coefficients was negative. This occurred with five snow courses for the water-year runoff correlations and indicates that factors other than snowpack account for a great deal of the variation in annual flows. However, a negative sign also occurred for the correlation of maximum snow course 19 w.e. with May 1 - July 31 runoff for all four sub-basins, and with May 1 - June 30 runoff for Cabin sub-basin. Snow course 19 is the highest course on the basin (7,800 ft.) and is in an exposed area where snow is often redistributed by wind.

Of the correlations of May 1 - June 30 runoff with snow course w.e., highest were obtained with snow courses 8, 11, and 14 (Table 4). Snow courses 11 and 14 are located in the lower half of Middle sub-basin and should provide a good index of basin snow accumulation. There is no trend to higher correlation where the snow course is in the sub-basin from which the runoff originates.

The standard errors of estimate for the best-fit regressions of May 1 - June 30 runoff on March snow course w.e. range from 3.80 ac. ft. (Middle sub-basin runoff/snow course 11) to 12.67 ac. ft. (Twin sub-basin runoff/snow course 8). That is, from 0.54 to 1.85% of the mean runoff. For example, the prediction equation for Marmot runoff on snow course 11 is:

$$Y = 454.46 + 285.66 (X)$$

where Y = May 1 - June 30 runoff from Marmot basin, in ac. ft.

X = snow course 11 w.e. in late March, in inches

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Table 1. Independent variables in snow accumulation Model III

Multiple regression Model III stepwise elimination		Simple correlation coefficient of the variable with snow w.e.
Independent variables	Variance accounted for by remaining variables (R^2)	
$ASPECT^3$	0.58	0.26
SECONDARY POSITION X SLOPE	0.57	- 0.10
$SLOPE^3$	0.57	- 0.08
FOREST DENSITY	0.57	- 0.33
SECONDARY POSITION	0.56	0.17
$ELEVATION^2$	0.56	0.34
SECONDARY POSITION X ELEVATION X SLOPE	0.55	- 0.07
PRIMARY POSITION X SECONDARY POSITION	0.54	0.33
SECONDARY POSITION X ELEVATION	0.54	0.23
ELEVATION X SLOPE	0.53	- 0.21
SLOPE	0.53	- 0.23
ELEVATION	0.52	0.33
PRIMARY POSITION X SLOPE	0.49	- 0.11

Table 1. (continued)

Multiple regression Model III stepwise elimination: Independent variables	Variance accounted for by remaining variables (R^2)	Simple correlation coefficient of the variable with snow w.e.
PRIMARY POSITION	0.48	0.34
$ASPECT^2$	0.45	0.27
PRIMARY POSITION X ELEVATION X SLOPE	0.35	- 0.06
$SLOPE^2$	0.35	- 0.16
ASPECT	0.28	0.29
$FOREST DENSITY^2$	0.18	- 0.34
PRIMARY POSITION	-	- 0.34
X ELEVATION		0.43

Table 2. Mean snow w.e. by aspect, primary, and secondary position

Aspect	Number of samples	Mean snow w.e. (inches)
South-west	9	2.68
North-west	4	3.82
South	16	4.51
North	12	4.80
North-east	15	5.03
East	29	5.34
South-east	19	5.42
West	2	7.25

Primary position	Number of samples	Mean snow w.e. (inches)
Hollow	1	1.50
Major ridge top	2	3.60
Minor ridge top	3	3.77
Gentle slope	5	3.78
Mid-slope		
-minor slope	10	3.91
-major slope	78	4.92
Valley bottom		
-minor valley	4	6.75
-major valley	3	10.17

Table 2. (continued)

Secondary position	Number of samples	Mean snow w.e. (inches)
Trees within 3 ft.	6	3.87
Major valley bottom	1	4.00
Near gulley	3	4.07
Mid-slope, minor	1	4.50
Knoll	2	4.60
Mid-slope, major	8	4.62
Bench	2	4.70
Minor ridge top	2	4.80
Trees not within 3 ft.	72	5.00
Hollow	6	5.28
In open on edge of trees	3	6.83

Table 3. Correlation of mean sub-basin snow w.e. with snow course snow w.e.

Snow Course	Location	Correlation Coefficients[1] Marmot basin	Twin Sub-basin	Middle Sub-basin	Cabin Sub-basin
1	Lower confluence	0.863	0.808	0.846	0.802
3	Lower Middle	0.999	0.991	0.998	0.989
6	Confluence	0.998	0.999	0.999	0.999
8	Upper confluence	0.938	0.898	0.926	0.894
11	Middle	0.988	0.968	0.982	0.965
14	Middle	0.998	0.989	0.996	0.987
19	Upper Middle	0.987	0.998	0.992	0.999
Mean	-	0.992	0.975	0.987	0.972

[1] Correlation coefficients are significant at the 95% probability level if $\geq$ 0.997.

Table 4. Correlation of May 1 - June 30 runoff with March snow course w.e.

Snow Course	Correlation coefficients[1]			
	Marmot basin	Twin sub-basin	Middle sub-basin	Cabin sub-basin
1	0.925	0.972	0.941	0.999
3	0.994	0.967	0.989	0.848
6	0.979	0.937	0.969	0.791
8	0.977	0.998	0.986	0.972
11	1.000	0.991	1.000	0.906
14	0.996	0.971	0.991	0.856
19	0.954	0.898	0.940	0.727
Mean	1.000	0.986	0.998	0.892

[1] Correlation coefficients are significant at the 95% probability level if $\geq$ 0.997.