

SNOW MEASUREMENT ON MARMOT CREEK
EXPERIMENTAL WATERSHED

by

D. L. Golding

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ABSTRACT

The evolution of snow measurement on Marmot Creek experimental watershed is described and problems associated with snow measurement on research basins are discussed. Analysis of data collected over a period of six years shows significant correlation between snow-water equivalent at most of the 20 snow courses on the watershed. The relationship of snow-water equivalent to elevation closely approximates a straight line of positive slope for snow courses in the same forest-cover type and having approximately the same slope and aspect.

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D. L. Golding²

INTRODUCTION

This paper describes the evolution of snow measurement on Marmot Creek experimental watershed. It is hoped that tracing the experience on Marmot will contribute, in some degree at least, to a greater awareness of the problems of snow measurement and the need for improved snow measurement techniques, especially on research basins.

MARMOT CREEK EXPERIMENTAL WATERSHED

Marmot Creek experimental watershed (Fig. 1) was established in 1961 as the first small watershed project undertaken by the East Slopes (Alberta) Watershed Research Program (now the Alberta Watershed Research Program). The main objectives are:

- (1) to determine the hydrology within the basin,
- (2) to determine the effects of commercial timber harvest and subsequent regrowth in subalpine spruce-fir forest upon the hydrology of the area.

The watershed, located in the Kananaskis River valley about 50 miles west of Calgary, has been described by Jeffrey (1965).

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² Research Scientist, Forestry Branch, Department of Fisheries and Forestry, Calgary, Alberta.

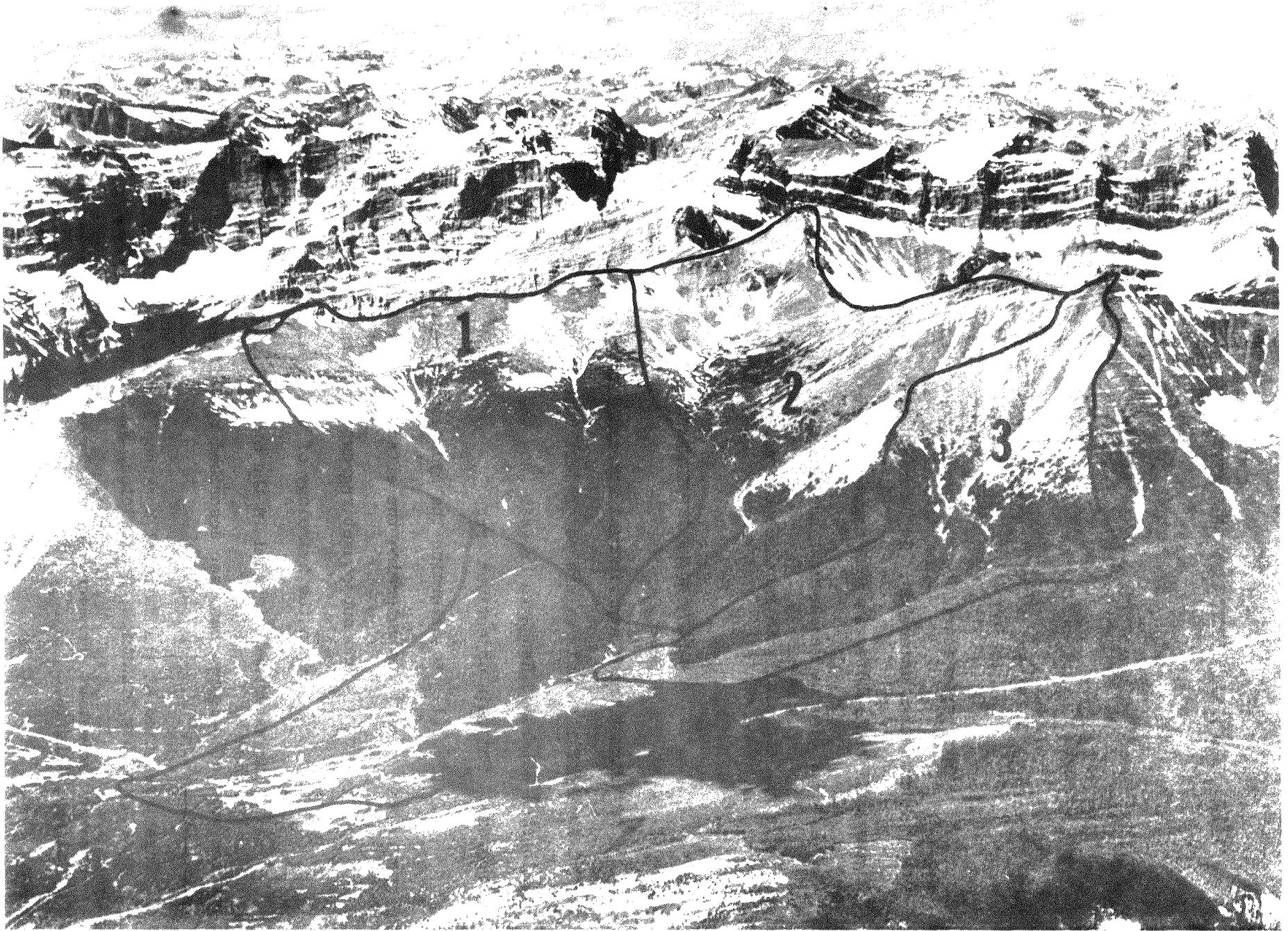


FIG. 1 Marmot Creek experimental watershed showing Twin Creek sub-basin(1), Middle Creek sub -basin(2), Cabin Creek sub-basin(3), and the confluence area(4).

SNOW MEASUREMENT

Sampling

Ideally, each hydrometeorologically-homogeneous or unit-source zone on a research basin should be sampled sufficiently to estimate, at the 95 per cent confidence level, the water equivalent of the snowpack to within 15 per cent of the true mean (I. H. D. 1966). This is especially true where most of the input to the system is in the form of snow. The difficulty here is in defining hydrometeorologically-distinct zones. In mountainous watersheds the area of each such zone approaches zero because of the great influence of topography and elevation on precipitation at a given point. Theoretically, random sampling for snow accumulation should be employed, although there are advantages to systematic sampling. As knowledge of the snow-accumulation pattern is gained, greater efficiency may be achieved with stratified sampling.

Where research objectives do not warrant sampling to the intensity described above, or where resources are presently not available, sampling should be distributed so that at least an index of snowfall is obtained, especially where snowpack is great.

Snow Measurement on Marmot Basin

Snow accounts for 70-75 per cent of annual precipitation on Marmot basin (Storr 1967). Snow measurement should therefore have high priority to provide data not only on total input to the system but also for some of the companion studies envisioned at the start of the program (Jeffrey 1961), e.g.,

- (1) the relation of snow accumulation and melt to forest

- cover, ground vegetation, and timber harvesting methods,
- (2) forecasting of snow-melt runoff,
 - (3) relation of snow accumulation and melt to such watershed variables as elevation and aspect.

The main problem associated with obtaining adequate data on snow-fall in the basin has been one of access. One of the first snow-measurement methods tried was snow stakes consisting of vertical poles with cross-bars at fixed intervals. The stakes were established in bare areas above timber-line and depth of snow was read by telescope from accessible vantage points or from helicopter. Field sampling was necessary to obtain measurements of density or water equivalent of the snowpack. Throughout the season, snow density may range from 20 to 50 per cent, and on any given day may vary by as much as 25 per cent over the basin. Because of this variation as well as improved access to the upper elevations the use of snow stakes was discontinued.

Near the beginning of the research program, consideration was given to measuring snow intensively on permanent plots established throughout the basin. Instead, line transects, or snow courses, were taken of snow depth and water equivalent. The advantage seen for line transects was that a greater area could be sampled with the same effort, although less intensively than on plots. In 1961, two 10-point snow courses were established and the number has gradually increased to the present 20. The highest elevation sampled is 7,840 feet. Supplementing snow-course data are 10 Sacramento storage-precipitation gauges which are measured four times a year, and one recording precipitation gauge.

A test was carried out in 1964 to determine areal extent and depth

of snowpack by photogrammetric techniques (Pollock 1965). Aerial photographs of the snowpack, taken in April 1964, were used in conjunction with 1963 summer photos. The test indicated apparent vertical errors in the order of two feet. However, the accuracy may have been better than the two feet indicated because the photogrammetrically-determined depth was averaged over a five-foot diameter circle whereas the ground check, or control, was a single-point measurement within that circle. This level of accuracy may be acceptable in areas of deep snowpack, but few areas on Marmot basin accumulate more than eight feet of snow.

The test showed the feasibility of photogrammetric measurement of snowpacks although serious problems were encountered. One of the difficulties was in reading or "seeing" snow surface elevations. Pancromatic film was used in this test and appears to be the film best suited for this type of work. However, the possibilities of the method warrant trials of other films as well as filters to improve snow surface definition. Darker prints than would be normally used for interpretation might also be helpful in this regard, so that experimentation with film developing may be worthwhile.

The photos used in this test of the photogrammetric method were approximately 1:8,000 scale taken with a 6-inch focal length camera. A camera of 12-inch focal length, used at the same altitude, will produce photos at twice the scale. This is relevant because the accuracy of elevations measured on a stereomodel using a photogrammetric plotter varies inversely with photo scale, and stereo plotters are available for use with photos taken with various focal length cameras. Although the method has

its limitations, e.g., it cannot be used in forested areas and it requires considerable horizontal and vertical ground control, in areas such as Marmot Creek it may provide data that can be obtained only with great difficulty any other way.

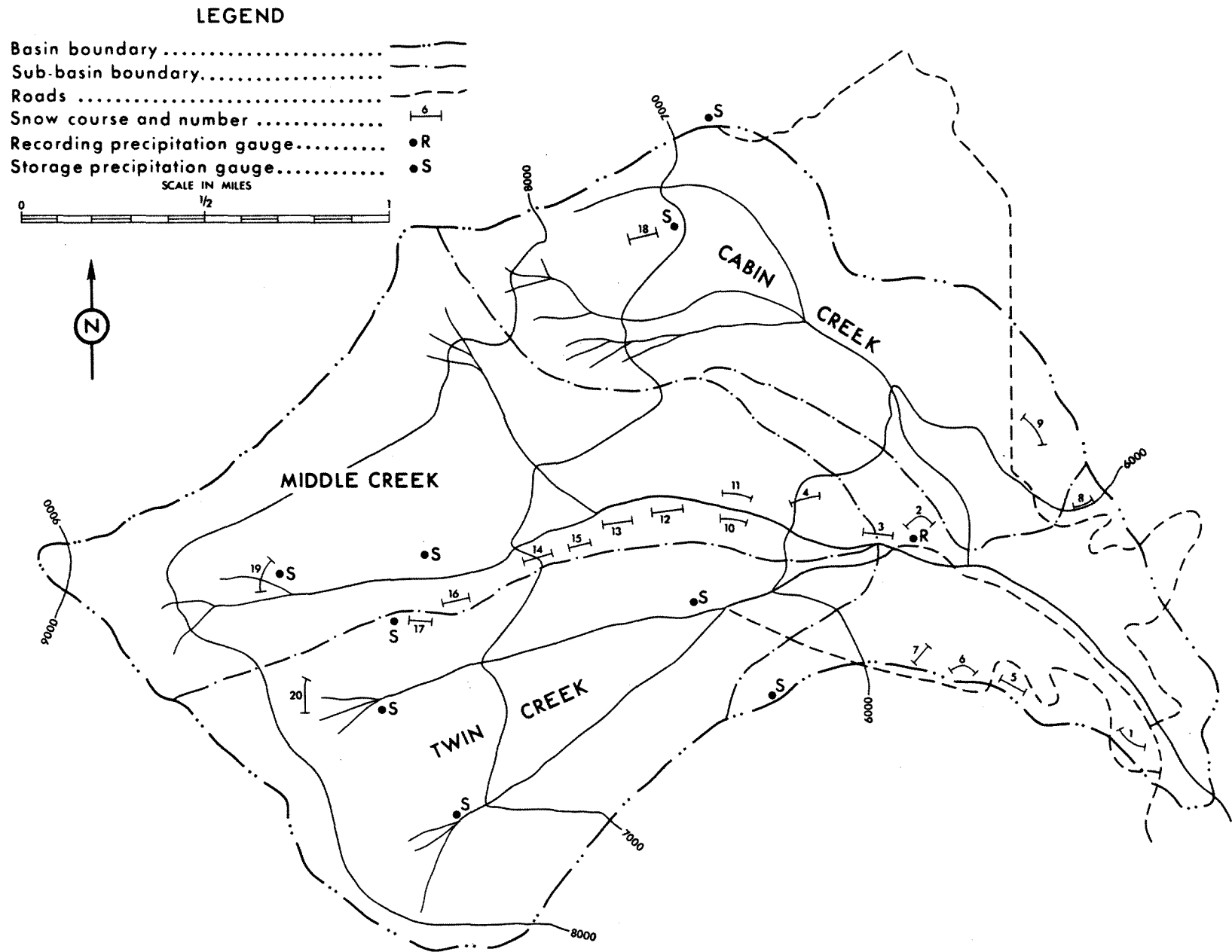
The present snow-measurement network on Marmot basin is shown in Fig. 2. The snow-courses were established to sample snow accumulation at different elevations and aspects and under different forest cover, as well as to provide information on total precipitation on the watershed. Middle Creek sub-basin and the confluence area have eight and seven courses, respectively. However, the number of snow courses, two, in each of Twin and Cabin sub-basins, and their location indicate that these sub-basins are inadequately sampled to satisfy the minimum need, i.e., an index of snow accumulation.

Data Analysis

Preliminary analysis of data has shown significant correlations between most of the 20 snow courses. The relation of each snow course to each of the other snow courses was determined by regression and correlation analysis. Most of the snow courses have been measured monthly from January through April, and weekly during the snow-melt season. Increments between measurements of snow-water equivalent, either positive or negative, were used in the analysis, eliminating the effect of serial correlation that would have resulted from using total accumulation at each time of measurement.

The analysis was limited to those courses on which there were nine or more comparable measurements, and was carried out for every com-

FIG. 2 Snow measurement network on Marmot Creek experimental watershed.



bination of two snow courses. Of the 119 combinations, 87 were significant at the one per cent level of probability, 21 were significant at the five per cent, and 11 were non-significant.

Correlation coefficients fell in two obvious groups - those associated with lower snow courses (No. 1-9) and those of the higher elevation courses (No. 10 - 17). Within each of these two groups all correlation coefficients were highly significant (Table 1). This close correlation and the fact that other analyses are presently being carried out relating snow accumulation to forest cover, aspect, and elevation will permit dropping some of these courses.

The equations produced by the regression analyses were of little predictive value, however, because of the large standard errors of estimate. For example, the 95 per cent confidence interval of the mean value of snow course No. 2 from the regression of snow course No. 2 on snow course No. 1 is equal to the mean \pm 56 per cent of the mean. The variation between measurement points within a snow course is indicated by the standard deviations which vary between one and five times the means of the 20 courses. This variation is to be expected using increments of snow-water equivalent between monthly measurements. Use of a single yearly measurement, e.g., at the time of maximum accumulation, would reduce the variation within and between snow courses that is exhibited by single storms. However, this will require several more years of record.

The relationship of water equivalent of the upper snow courses (No. 12 - 16) to elevation is shown in Fig. 3 and 4. Water equivalent of the snowpack on the date of measurement was used in this part of the study

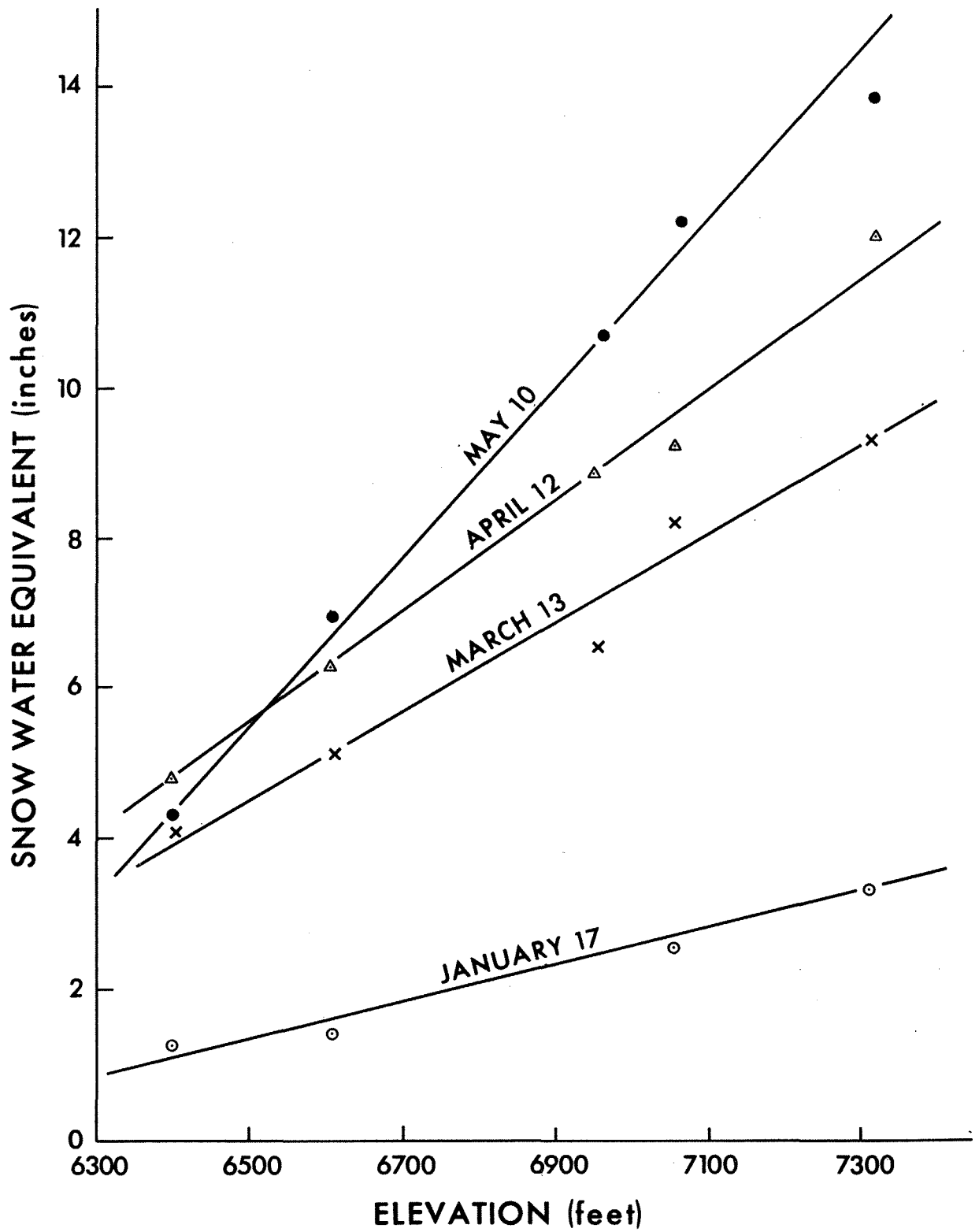


FIG.3 Snow water equivalent by elevation, Marmot Creek experimental watershed, 1965.

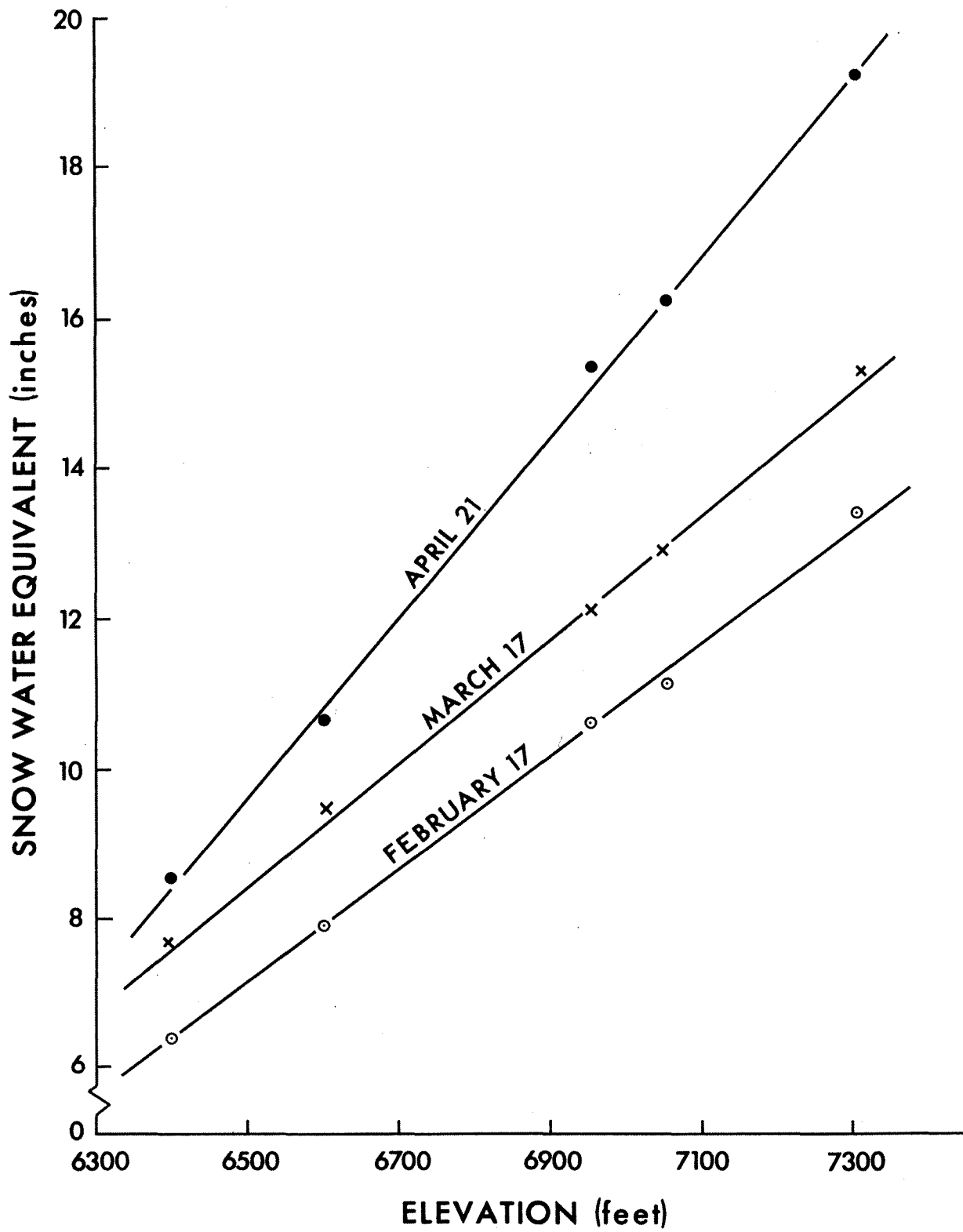


FIG. 4 Snow water equivalent by elevation, Marmot Creek experimental watershed, 1967

Table 1. Matrix Indicating Significance of Simple Correlation Coefficients
for Periodic Increments of Snow for 20 Snow Courses
on Marmot Creek Experimental Watershed

Snow course number	Significance of simple correlation coefficient by snow course ^{1,2}																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		X	X	X	X	X	X	X	X	O	X	O	N	-	-	N	N	-	-	-
2			X	X	X	X	X	X	X	X	X	X	O	-	-	O	N	-	-	-
3				X	X	X	X	X	X	O	X	N	O	-	-	N	N	-	-	-
4					X	X	X	X	X	X	X	X	X	X	-	X	X	-	-	-
5						X	X	X	X	X	X	X	O	-	-	O	O	-	-	-
6							X	X	X	O	X	N	O	-	-	O	N	-	-	-
7								X	X	X	X	O	O	-	-	O	O	-	-	-
8									X	X	X	X	O	-	-	O	N	-	-	-
9										X	X	O	O	-	-	O	N	-	-	-
10											X	X	X	X	X	X	X	-	-	-
11												X	X	X	X	X	X	-	-	-
12													X	X	X	X	X	-	-	-
13														X	X	X	X	-	-	-
14															X	X	X	-	-	-
15																X	X	-	-	-
16																	X	-	-	-
17																		-	-	-
18																			-	-
19																				-

¹ Significance is indicated by the following symbols:

X - significant at the 99 per cent level

O - significant at the 95 per cent level

N - non-significant at the 95 per cent level

² Insufficient data (fewer than 9 samples) are indicated by dash.

rather than increments between measurements as in the analysis described previously. Snow courses No. 12 - 16 are in the same forest-cover type and have approximately the same slope and aspect. On any given sampling date, snow-water equivalent plotted over elevation closely approximates a straight line. This linear relationship is consistent within each year as well as from year to year, although intercept and slope change in both cases. The two years were chosen to illustrate the relationship in a year of average snowpack (1965) and in a year of heavy snowpack (1967). Slope increases as the season progresses because each storm follows the tendency of greater snowfall with greater elevation. As the season progresses, the higher elevations accumulate proportionally more snow than lower elevations. During 1965 and 1967 snow measurements were taken only on the dates shown in Fig. 3 and 4. In the spring, melting usually occurs at the lower elevations while snow is still accumulating at the higher elevations. This may account for the intersection of the April and May, 1965, regression lines at the lower elevations (Fig. 3).

Companion Studies

Other snow studies have been carried out on the basin as well as in other areas to complement the research program on Marmot. Storr (1967), in his study of precipitation variation on the basin, dealt mainly with rainfall but included data on snowfall as measured by the Sacramento gauges. The relation of snow recession to vegetation types has been studied with a view to vegetation manipulation for watershed management. This study utilized aerial photographs taken periodically throughout the melt season in conjunction with vegetation type maps. Snow accumulation has been related

to forest density by weighting the influence of surrounding trees by size and distance from the point of snow measurement. Such a relationship is useful in computer simulation. By simulating a forest stand and various management methods the optimum method may be determined for increasing snow accumulation. Other watershed objectives may be considered as the relationship of forest density to other variables is determined.

An intensive systematic sample of snow accumulation in the alpine area of Marmot basin will be carried out in April of 1969 and the following two years. The objectives will be to obtain a measure of the total snow input to the system and to relate this to several index snow courses that can be measured in succeeding years. As well, information will be gathered on snow accumulation patterns and their consistency from year to year.

Snow studies relevant to Marmot basin have also been carried out in areas of similar forest-cover type and topography in the Crowsnest Forest, 80 miles to the south. Stanton (1966) reported greater snow accumulation in cutover areas than in adjacent forest. However, in these large cutover areas having widths of up to 16 times the average tree heights, the accumulated snow melted sooner. A study is presently underway to determine which of three widths of clear-cut strip ($1\frac{1}{2}$, 3, and 5 chains) and three orientations to the slope (parallel, perpendicular, and a combination of both) offers the optimum combination of increasing snow accumulation and retarding snow melt. The results of these studies are to be used as guidelines in the vegetative manipulation of treatment sub-basins on Marmot Creek watershed.

DISCUSSION

At the beginning of a research program the impulse is strong to gather information on all aspects of the problem so that if and when it is needed it will be available. This impulse is especially strong when dealing with annual events requiring a number of years to sample adequately. It is also common in watershed research where many of the factors of the environment may eventually be studied. Because of this and based on the experience of Marmot basin the following points seem pertinent.

In any research program, data gathering must be co-ordinated with the overall objectives of the program. Data that are collected on the chance that they may be useful later are not likely to satisfy subsequent requirements. Even though the measurement network may be far from ideal from the point of view of attaining research objectives, expansion of the network should be carried out in accordance with a comprehensive plan. Data should be analysed periodically to determine how well the objectives are being met. In this way effort can be re-directed, if necessary, early in the program.

Although 70 - 75 per cent of the annual precipitation on Marmot basin falls as snow, present sampling does not satisfy the need for reliable estimates of snowfall in unit-source areas. In two of the three sub-basins sampling is too sparse to provide valid indices of snowfall. Difficulty of measurement may have influenced such sampling to too great a degree. To remedy this, the snowcourse network will be expanded in two of the sub-basins, and some snow courses will be dropped in the third. As well, an intensive systematic sample of the alpine snowpack will be carried

out once yearly for the next three years.

With regard to snow measurement, the photogrammetric method discussed above offers distinct possibilities of measuring snow in open areas and merits more study of photo scale, films and filters, and developing and printing. Light attenuation and radar are also promising techniques of measuring snow. Better methods than those currently used can be developed and, because of the importance of snow measurement on research basins, more research must be directed to this end.

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