SNOW COVER PATTERNS IN THE NASHWAAK EXPERIMENTAL WATERSHED, NEW BRUNSWICK[1]

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The Nashwaak Experimental Watershed Project, located in central New Brunswick, was initiated in 1970 to carry out research on the impacts of certain forest management practices on environmental quality. Initial research began within the Environmental Studies Group of the University of New Brunswick Faculty of Forestry, but the Project has since expanded to involve other university, Provincial and federal agencies.

One of the first experimental treatments to be imposed is a commercially-designed clearcut harvest, tentatively scheduled for early 1976. This treatment is expected to alter the water balance of the watershed system, particularly during spring when exposure to solar radiation and convective-condensation influences will accelerate snowmelt runoff. Distribution patterns of snow cover are also expected to be altered, as a result of wind effects during the accumulation period and differential melt during the ablation period.

With respect to snow as a water balance component the study will use an experimental and a control watershed in the "paired watershed" approach, with three phases -- the calibration phase, the treatment phase, and the recovery phase. The spatial distribution of snow cover will be related to topographic and forest cover variables in order to estimate untreated conditions for the experimental watershed following removal of the forest cover. The snow cover study began in 1972-73, so that four seasons of data will be accumulated during the calibration phase.

The site is located in a totally forested area of the central New Brunswick highlands (figure 1), elevations ranging from about 700 to 1400 feet. The experimental basins are underlain mostly by argillite, and blanketed by thin glacial till except for areas of deeper deposits on lower shallow slopes. Forest cover -- principally maples, beech, balsam fir and red spruce -- is about equally hardwood and softwood, with the latter predominant on lower slopes.

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[1] This research was supported in 1973 and 1974 by a research contract from the Maritimes Forest Research Centre, Canadian Forestry Service, Environment Canada, Fredericton, N.B., and in 1975 by a research subvention from the Canadian Forestry Service, Environment Canada, Ottawa, Ont.

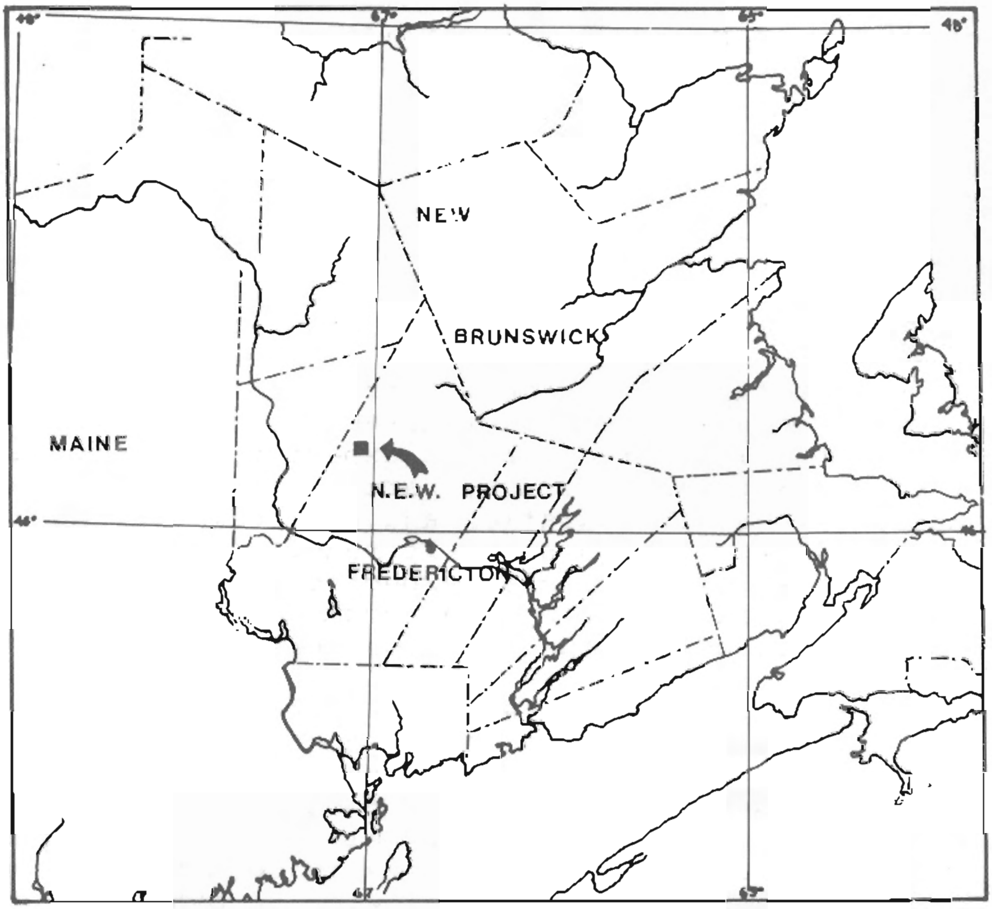

FIGURE I. LOCATION OF THE NASHWAAK EXPERIMENTAL WATERSHED PROJECT IN CENTRAL NEW BRUNSWICK.

The climate is significantly cooler and wetter than nearby settled areas, with the mean temperature estimated to be about 3°C and total precipitation about 51 inches. Average runoff is estimated to be about 35 inches annually.

The experimental watersheds drain into the Nashwaak River, one of the Province's major salmon-fishing streams, at a location about 30 miles northwest of Fredericton. The watershed to be clearcut, Middle Brook[1] (figure 2), drains an area of about 990 acres; the control watershed, Hayden Brook, has a drainage area of about 1790 acres. The streams drain into opposing sides of the Nashwaak but their general aspects are not greatly different, Hayden basin facing 170° and Middle facing 120°.

METHODS OF DATA COLLECTION

Snow cover data were obtained by periodic surveys--five during the winter of 1973, three during 1974, and one completed this season. A Mount Rose type of snow sampler was used to measure depths and water equivalents of the snow pack along four transects of each basin (figure 3). The transects are spaced at about 300 metre intervals; they correspond to transects used in a forest growth study, thereby assuring the availability of forest cover data to relate to the snow cover data. Along each transect, five measurements of depth were taken every 100 metres, and at intervals of about 300 metres -- at each forest growth plot along the transect -- measurements of water equivalent were also taken. A total survey consisted of 190 measurements of water equivalent and about 500 of snow depth, requiring about 8 man-days per survey to complete. The upper two lines of Hayden Brook were not included in the 1973 surveys, as the forest growth network was not completed.

Nine surveys have been carried out, beginning on the following dates:

1973	January 16	Middle Brook Basin only.
	February 14	Upper two survey lines in Hayden Brook Basin not included.
	March 7	
	March 27	
	April 18	
1974	February 25	
	March 25	
	April 22	
1975	January 15	

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[1] The official name of this stream was changed from Middle Brook to Narrows Mountain Brook on March 6, 1975, by a decision of the Canadian Permanent Committee on Geographical Names.

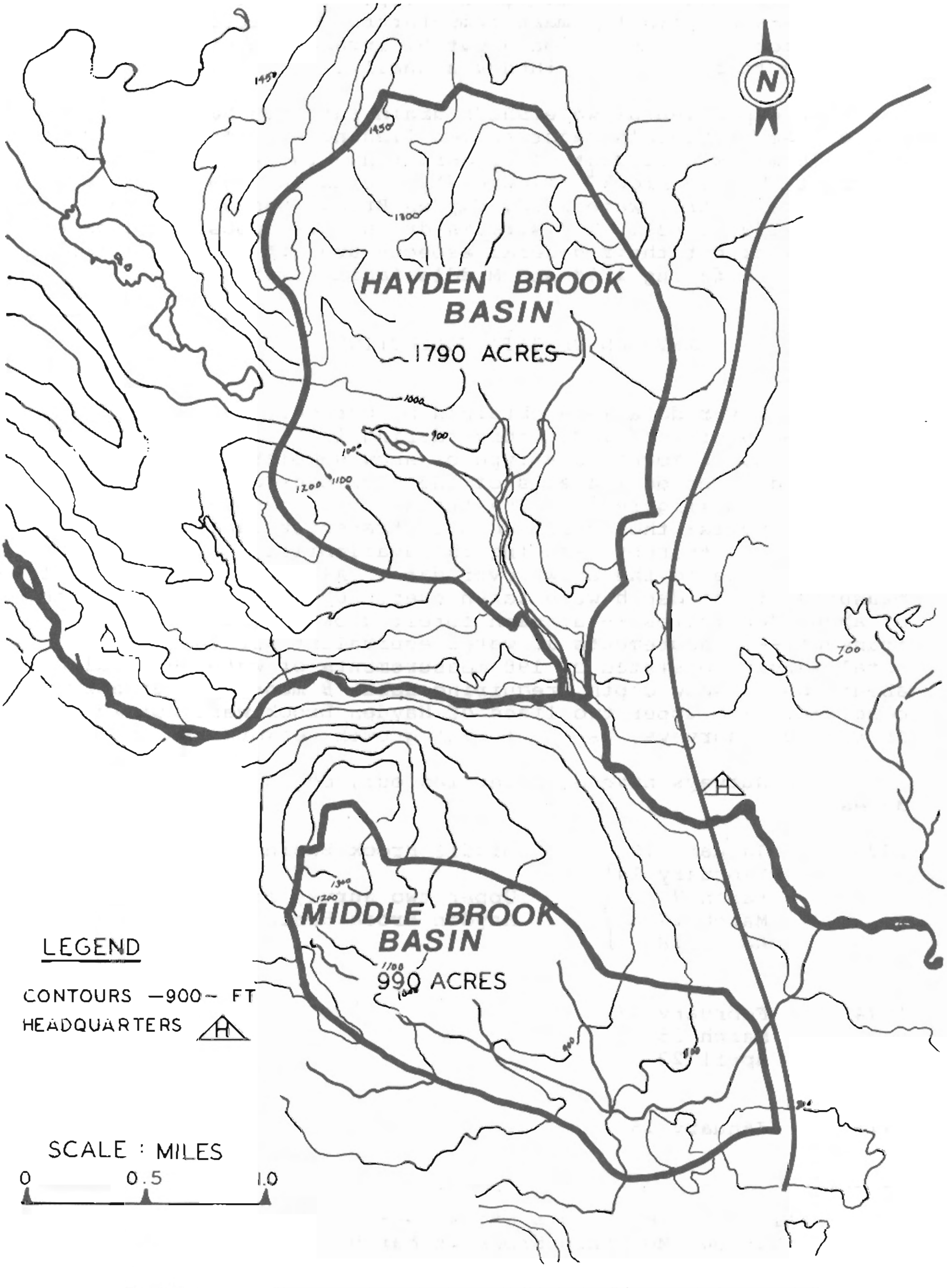

FIGURE 2: THE NASHWAAK EXPERIMENTAL WATERSHED PROJECT AREA

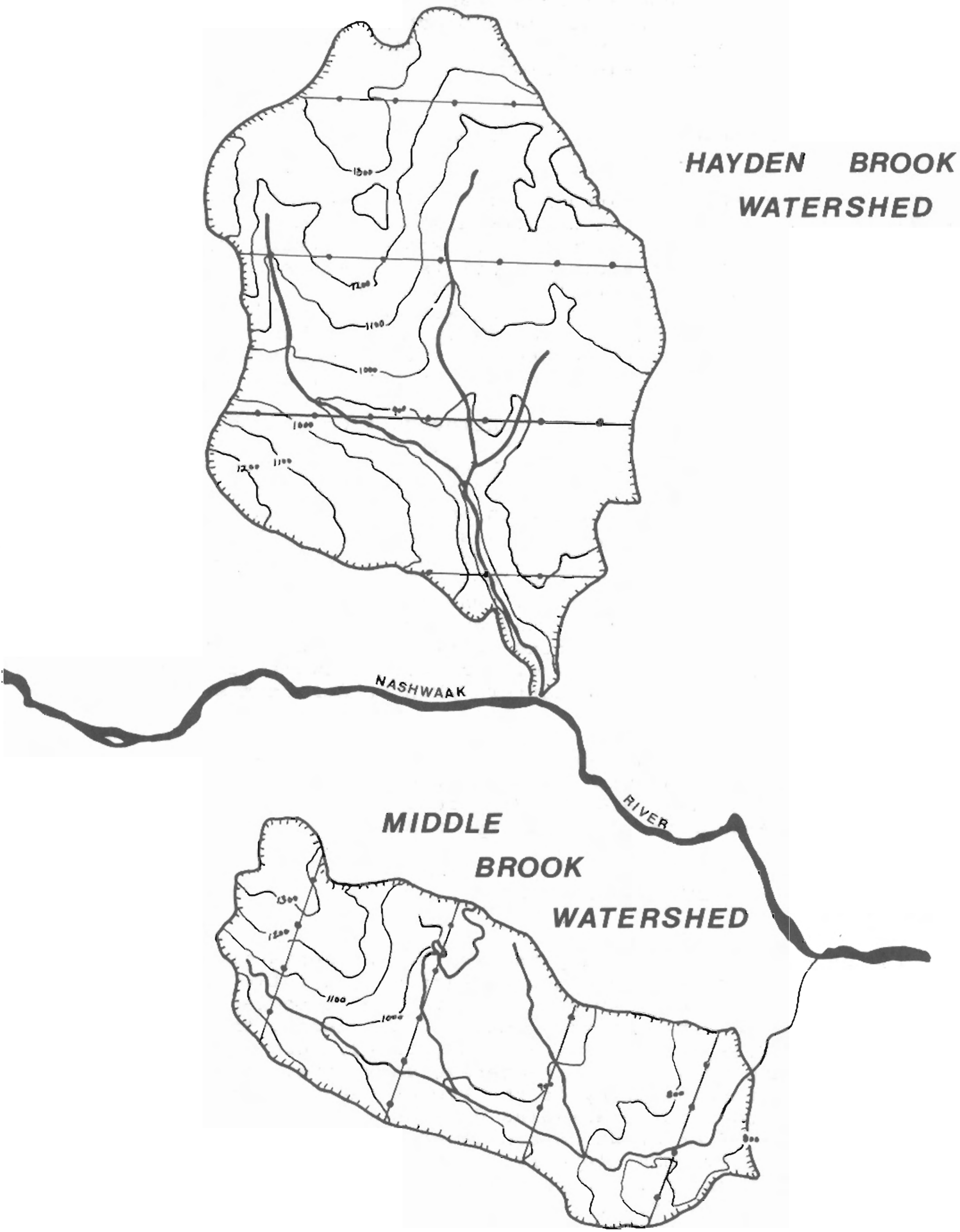

FIGURE 3 : LOCATION OF SNOW SURVEY AND FOREST GROWTH STUDY PLOTS.

In addition to these extensive basin surveys, measurements were taken at a snow course at the Project Headquarters during regular twice-monthly visits. This periodic record has been maintained over a three-year period.

THE GENERAL SNOWFALL CLIMATE

Although the Project area is within 30 miles of Fredericton, the higher elevation and the greater distance from the modifying effect of the Bay of Fundy create a snowcover climate remarkably different from that of the city. Snow is a distressingly capricious element of New Brunswick climate, and three seasons of measurements are not adequate to define its nature with any confidence. The 1972-73 season was, perhaps, more nearly normal than the others and will be used to illustrate the greater severity of the climate of the experimental area compared to that of Fredericton (figure 4).

Fredericton's snowcover was continuous from December 1, 1972 to March 12, 1973, as determined from daily observations at the nearby airport, elevation 67 feet above msl. This continuous period of 114 days, plus another 14 days with temporary snow cover, is close to the median 121 days with snowcover determined by Potter (1965). By contrast, there was a continuous snowcover period of about 175 days at the Project Headquarters, in a cleared area at an elevation of about 650 feet. The maximum depth at Fredericton, reached on January 21, was only 25 inches, while at the Project Headquarters it reached an estimated 36 inches at the beginning of March. The difference between the two locations was particularly marked during late winter, with a two-foot snowcover remaining at the Project Headquarters when Fredericton's cover disappeared on March 25.

Within the watershed area, the snow surveys under forest cover showed snow depths about six inches greater than the Headquarters clearing in mid-January, and the difference increased to about 12 inches at the date of the last survey on April 18.

ANALYSIS METHODS

The objective of the analysis for this presentation was to derive a preliminary assessment of relationships between snow depth and water equivalent and several parameters of topography and forest cover. Two circumstances lead to considering the assessment "preliminary"; first of all, as already stated, more than two or three seasons are needed to characterize snow cover; furthermore, a detailed topographic survey of the Project area has not yet been obtained, and topographic variables derived from existing maps are a present source of error which can later be screened from the data. Nevertheless, some clear relationships do emerge from the analysis, and lessons may be learned which will be helpful in the future conduct of the Project.

SNOW COVER VARIABLES

Snow depth (SD) and snow water equivalent (SWE) were measured

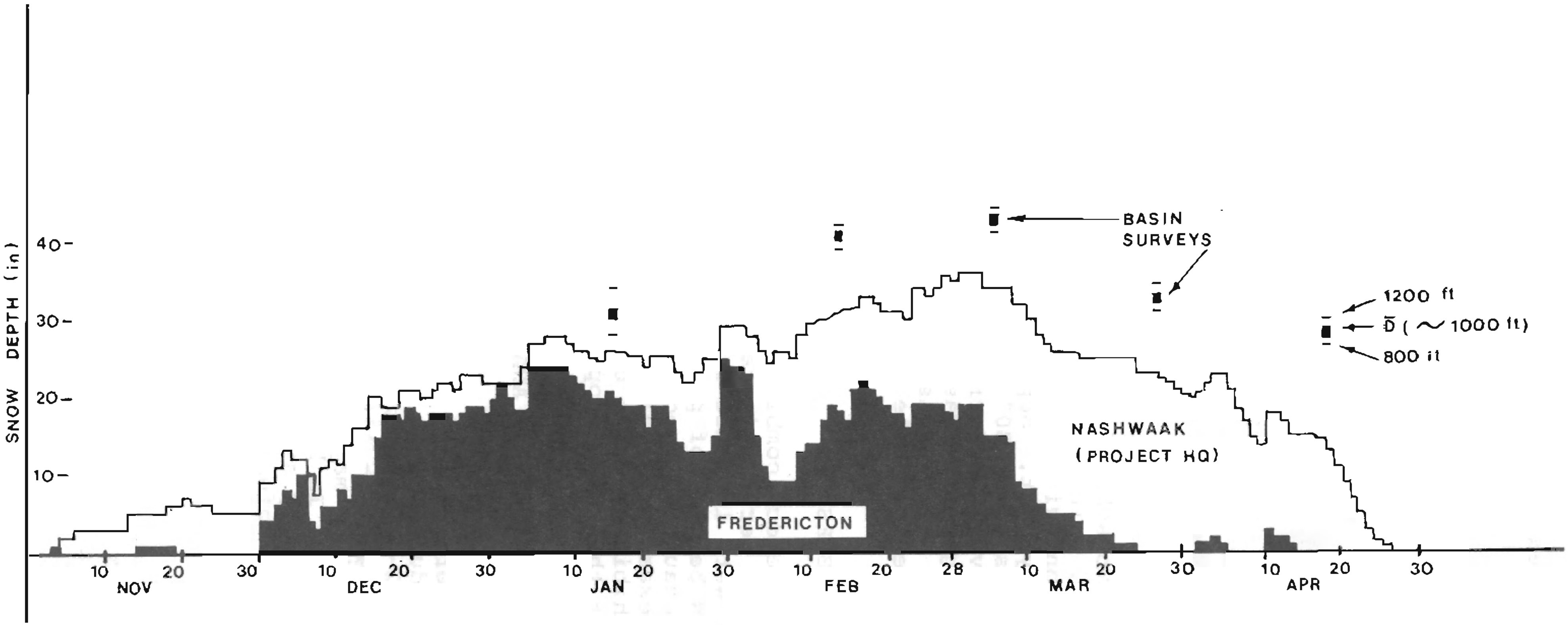

FIGURE 4 COMPARATIVE SNOW COVER RELATIONSHIPS AT FREDERICTON AND THE NASHWAAK EXPERIMENTAL WATERSHED PROJECT, 1972-73

in inches to the nearest 0.1 inch. The value used for analysis was the average at each site of five observations spaced at intervals of about six feet.

TOPOGRAPHIC VARIABLES

Elevation (El) in feet was estimated to the nearest 10 feet at each site from 50-foot contours taken from a 1:50,000 topographic map. Aspect angle (Θ) was determined within each forest growth study plot, as the direction of maximum downward slope from the centre of the plot, expressed to the nearest of eight points of the compass. Slope and topographic position were also determined, but have not been included in the analysis.

FOREST COVER VARIABLES

Vertical canopy density (CD), expressed in percent, was measured with a "Moosehorn" (Robinson, 1947) at a height of six feet above ground, using the average of five systematically determined locations within five metres of the center of each forest growth study plot. Separate measurements were made of oblique canopy density at 30° above the true south horizon. The canopy density survey was carried out May 2, 1974, prior to the emergence of foliage, thus was representative of winter conditions. Other forest cover data -- basal area, stem density, and proportion of hardwood -- were available from the original forest growth study survey.

SELECTION OF VARIABLES

In order to select combinations of variables for further analysis, the data were subjected to covariance matrix analysis. Other variables were included at this stage, but rejected for further analysis because of poor correlation with the dependent variables, or because of a poorer correlation than a substitute variable. For example, basal area and sten density were rejected because they exhibited poorer correlations with snow depth and water equivalent than did canopy density.

RESULTS OF ANALYSES

The snow cover data are summarized by survey date in table 1. The snowpack during last winter, 1973-74, was unusually light. The winter of 1972-73 was more characteristic of conditions to be expected in the region -- although the sudden termination of the snow cover season in a major flood event (Hudson, 1974) was far from characteristic. In both seasons, the water equivalent of the snowpack was fairly stable throughout much of the winter. Changes in density conformed reasonably well with those expected for the region (McKay and Findlay, 1971), rising gradually from about 0.20-0.25 to about 0.30 at the end of the season.

ELEVATION EFFECTS

The statistics from linear regression of snow depth and water equivalent against elevation are given in table 2, for data

Table 1. Summary of snow survey data

Date of Beginning of Survey		No. of Observation Sites	Depth (In)	Water Equivalent (In)	Density
16 Jan 1973	PLOT DATA	17	30.64	7.11	.232
	ALL DATA	44	30.05		
14 Feb 1973	PLOT DATA	27	40.39	9.91	.245
	ALL DATA	77	39.63		
6 Mar 1973	PLOT DATA	27	42.43	9.65	.227
	ALL DATA	77	41.84		
27 Mar 1973	PLOT DATA	27	32.34	8.19	.253
	ALL DATA	71	32.10		
18 Apr 1973	PLOT DATA	27	28.16	8.36	.297
	ALL DATA	72	27.47		
25 Feb 1974	PLOT DATA	38	20.70	4.09	.198
	ALL DATA	102	20.40		
25 Mar 1974	PLOT DATA	38	21.54	5.53	.256
	ALL DATA	103	20.80		
22 Apr 1974	PLOT DATA	38	16.11	4.88	.303
	ALL DATA	105	15.56		
15 Jan 1975	PLOT DATA	37	17.11	4.07	.238
	ALL DATA	97	16.40		

Table 2. Statistics from linear regression of snow depth and snow water equivalent against elevation

Date of Beginning of Survey		df	Snow Depth a (In)	Snow Depth b (In/100 ft)	Snow Depth r	Snow Depth $^{b}/SD_{1000}$	Snow Water Equivalent a (In)	Snow Water Equivalent b (In/100 ft)	Snow Water Equivalent r	Snow Water Equivalent $^{b}/SWE_{1000}$
16 JAN 73	PLOT DATA	15	17.49	1.36	$.694^{**}$	.438	4.34	0.29	$.391^{ns}$	.398
	ALL DATA	42	17.63	1.29	$.565^{**}$	.422				
14 FEB 73	PLOT DATA	25	30.45	1.04	$.375^{ns}$	.256	5.03	0.51	$.610^{**}$	.505
	ALL DATA	75	30.71	0.94	$.285^{*}$	.235				
6 MAR 73	PLOT DATA	25	34.65	0.82	$.315^{ns}$	.491	6.64	0.32	$.343^{ns}$	.322
	ALL DATA	75	33.76	0.85	324^{**}	201				
27 MAR 73	PLOT DATA	25	23.53	0.93	$.387^{*}$	.282	8.53	-0.03	$.041^{ns}$	-.043
	ALL DATA	69	25.36	0.71	$.282^{*}$	.220				
18 APR 73	PLOT DATA	25	19.78	0.88	$.225^{ns}$	.308	6.25	0.22	$.197^{ns}$	.262
	ALL DATA	70	21.45	0.64	$.112^{ns}$	.229				
25 FEB 74	PLOT DATA	36	15.38	0.53	$.408^{*}$	.255	3.39	0.07	$.155^{ns}$	.169
	ALL DATA	100	11.77	0.85	$.434^{**}$	.421				
25 MAR 74	PLOT DATA	36	12.32	0.91	$.321^{*}$	.425	2.52	0.30	$.424^{**}$	.542
	ALL DATA	101	7.46	1.32	$.444^{**}$	.639				
22 APR 74	PLOT DATA	36	15.73	0.04	$.015^{ns}$	.023	3.94	0.09	$.123^{ns}$	.191
	ALL DATA	103	13.68	0.19	$.067^{ns}$	.120				
15 JAN 75	PLOT DATA	35	13.60	0.35	$.152^{ns}$	.205	4.29	-0.02	$.037^{ns}$	-.054
	ALL DATA	95	9.81	0.66	$.297^{**}$	.403				

Among the significant multiple correlations with topographic variables are those for February 14 and March 27, 1973, shown in figure 7. The relationship is better and the difference between north and south slopes is greater on the late-March survey.

FOREST COVER

Although canopy density produces higher average correlation coefficients than either basal area or stem density as measures of forest cover density, the correlations are significant for depth or water equivalent for only three of the nine surveys: January 16, and March 6, 1973 and February 25, 1974.

It is recognized that the effect of canopy density reverses during the snow cover season. During the accumulation period, increasing canopy density is associated with decreased turbulence and increased interception losses, both of which lead to lower snow cover. This was reflected in the surveys on January 16, 1973, March 6, 1973 and February 25, 1974 (figure 8). Again, because of the lack of studies related to snow depth, these findings cannot be compared with others in the literature. One occasion, March 6, 1973, provided a significant relationship between canopy density and snow water equivalent, indicating a decrease of 0.20 inches for each 10% increase in canopy density (figure 9), somewhat lower than the value of about 1/3 inches found by Lull and Rushmore (1960) in their Adirondacks study. Other reported values are still higher, e.g. 0.42 inches by Packer (1962) in Idaho, about 1.5 inches by Anderson (1969) in California; Kittredge (1953) gives a range of 0.50 to 2.2 inches.

The effect of canopy density reverses during the ablation period, as increasing densities retard melt by shading the snowpack and sheltering it from convective-condensation influences. Due to the oblique angle of the solar beam at this latitude during the melt period, the degree of shading is related to canopy depth as well as vertical canopy projection. It was this consideration which led to the use of oblique densiometer measurements as a forest cover parameter. This parameter failed to achieve the 0.95 level of significance for either April survey, but the coefficients were substantially better than those for vertical canopy density.

A study of the seasonal change in the correlation coefficients for vertical and oblique canopy densities is interesting (figure 10), those for vertical density being significantly negative initially, but becoming progressively smaller with the progress of the season, whereas oblique densities change from small negative values to positive values approaching significance. Although this indicates that oblique canopy density is a better predictor of snow cover than vertical canopy density late in the season, its practical application is questionable. Vertical canopy density may be estimated from conventional aerial photography, hence relationships based on it are widely applicable.

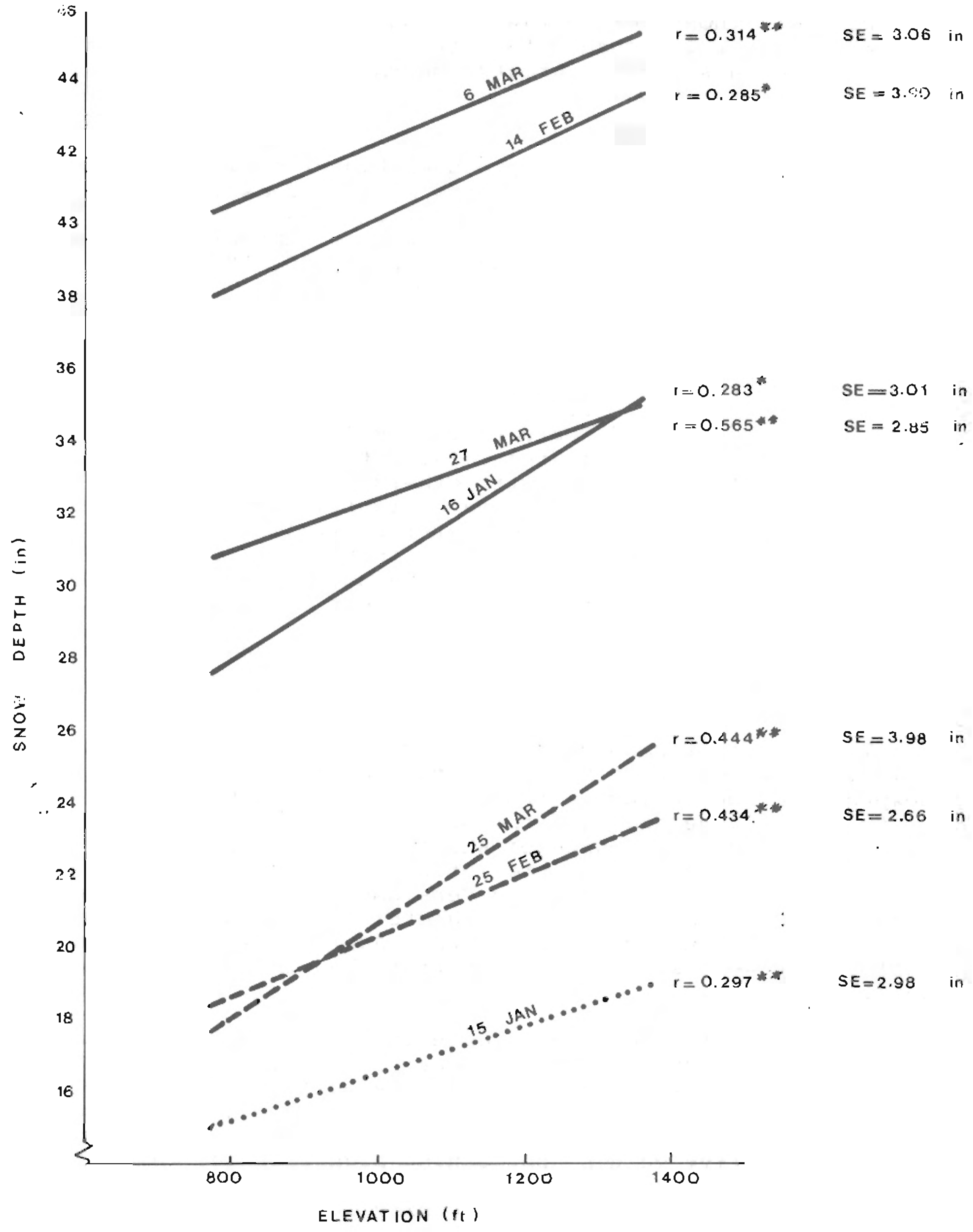

FIGURE 5 VARIATION OF SNOW DEPTH WITH ELEVATION AT ALL SITES (——— 1973 ; - - - - 1974 ; • • • • 1975).

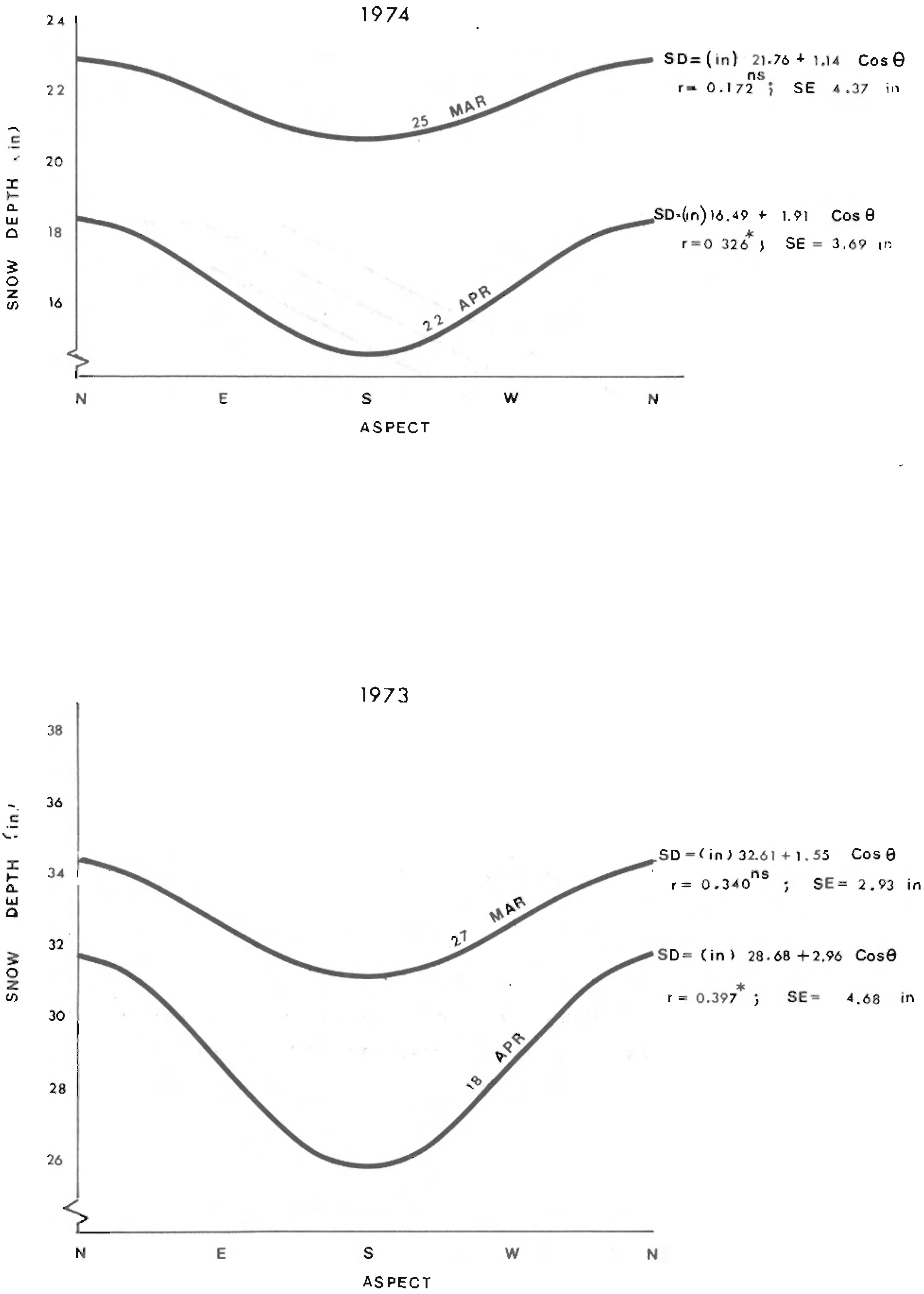

FIGURE 6 VARIATION OF SNOW DEPTH WITH ASPECT AT FOREST GROWTH STUDY PLOTS.

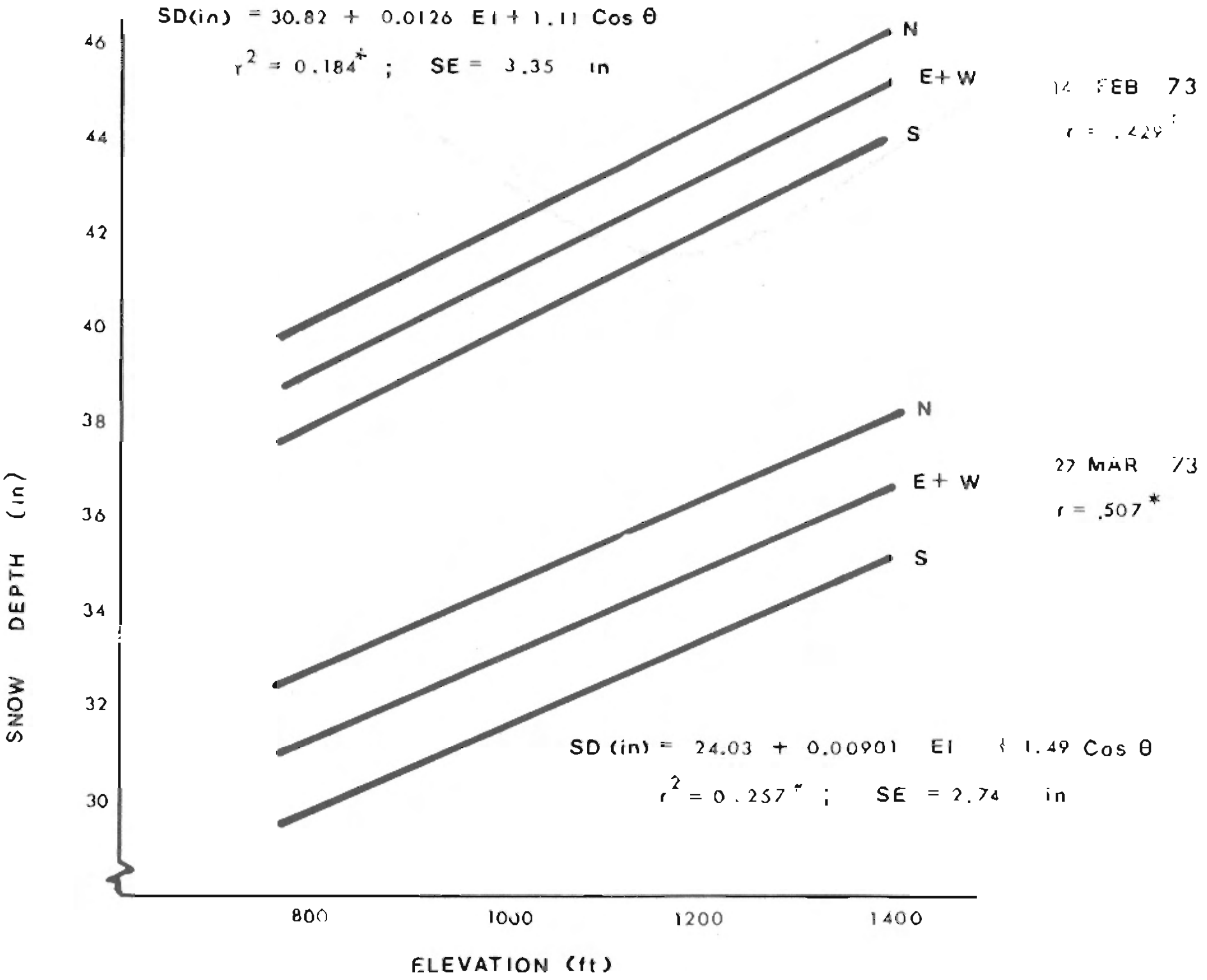

FIGURE 7 VARIATION OF SNOW DEPTH WITH ELEVATION AND ASPECT AT FOREST GROWTH STUDY PLOTS.

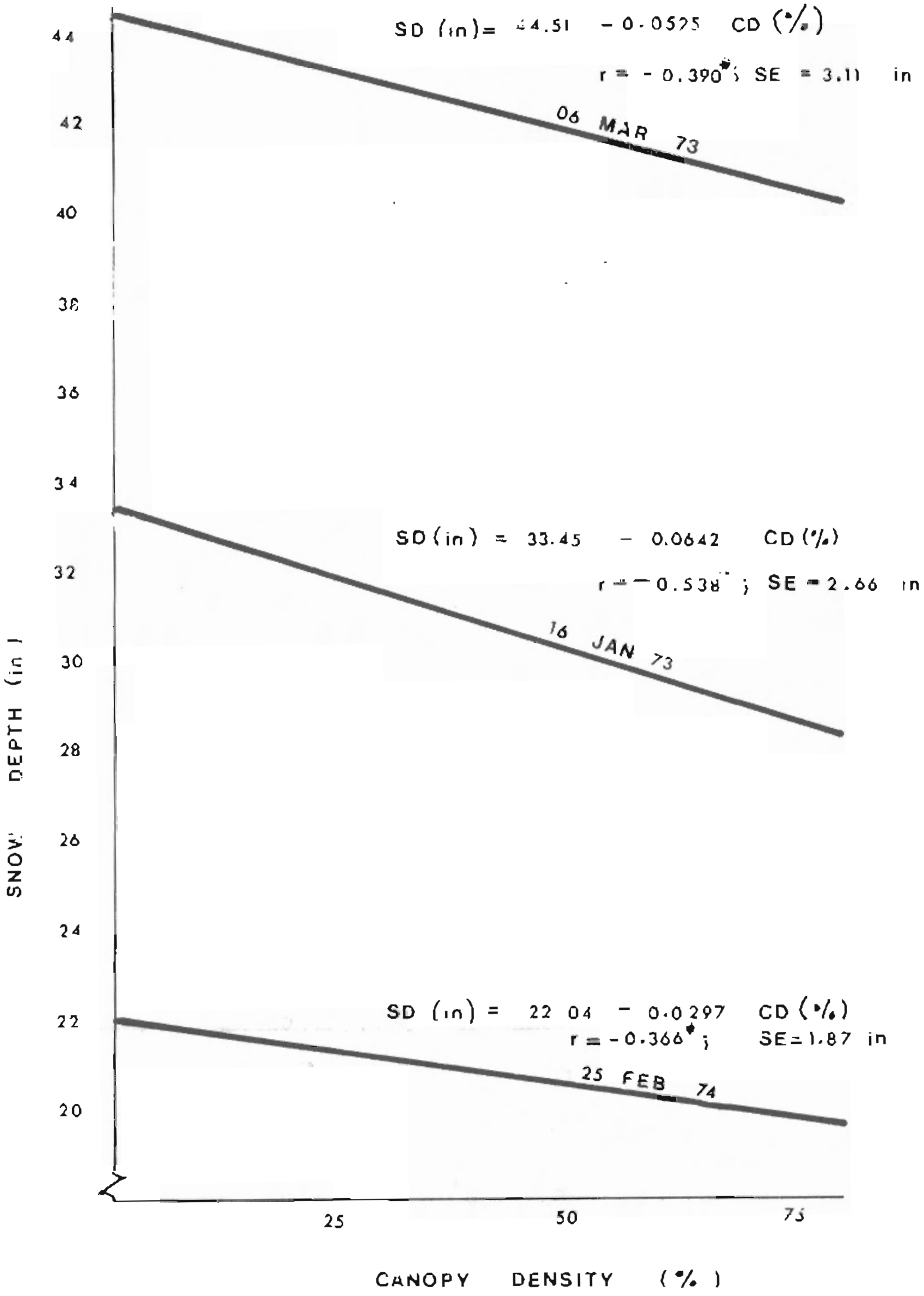

FIGURE 8. VARIATION OF SNOW WITH CANOPY DENSITY AT FOREST GROWTH STUDY PLOTS.

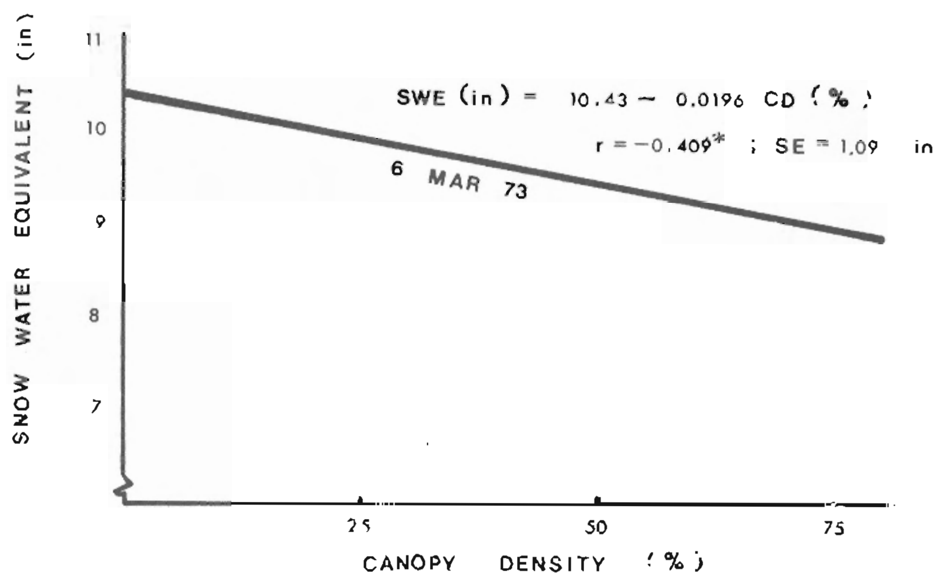

FIGURE 9 VARIATION OF SNOW WATER EQUIVALENT WITH CANOPY DENSITY AT FOREST GROWTH PLOTS.

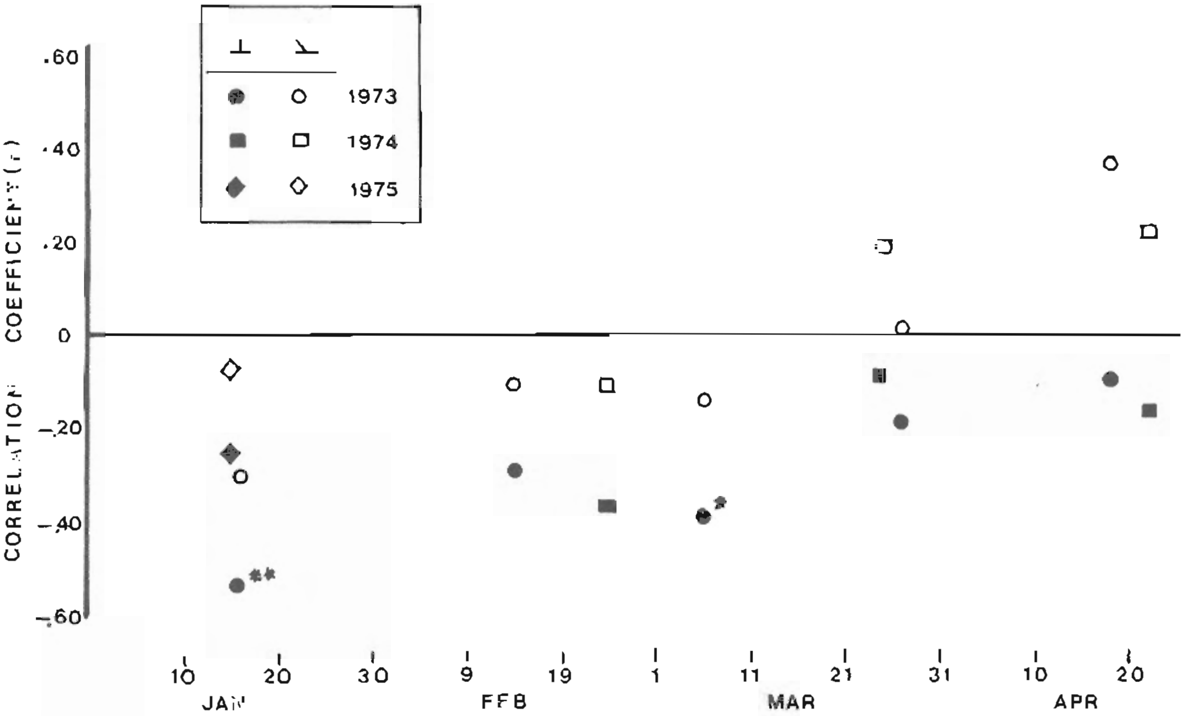

FIGURE 10 SEASONAL VARIATION OF CORRELATION COEFFICIENTS BETWEEN SNOW DEPTHS AND CANOPY DENSITY FOR BOTH VERTICAL AND OBLIQUE SOUTHERLY DENSITY.

collected at the sites within the forest growth study plots, and for all data -- which include the sites between plots where only depth measurements were taken. Depth data correlate better than snow water equivalent with elevation; snow water equivalents are significantly related for only two of the nine surveys. On those two occasions, February 14, 1973 and March 25, 1974, the snowpacks were near or at their maximum depths. The slopes of the regression relationships are 0.51 and 0.30 inches per 100 feet change of elevation, but when stanardized against the computed depths at 1000 feet become 5.0% and 5.4% per 100 feet. These standardized values relate well to those of Sartz (1957) for Hubbard Brook, New Hampshire and for several studies in California (Anderson, 1963). The gradients of 0.62 in/100 ft in New Hampshire and 1.2-2.2 in/100 ft in California each convert to about 6% gradients. How widely these relationships may vary, however, from one region to another has been illustrated in an extensive literature survey by Meiman (1968).

Snow depth data exhibit a better relationship with elevation than do the snow water equivalent data. When all depth measurements are included only the April surveys were not significant. Gradients average 0.95 in/100 ft, ranging from 0.66 to 1.32 for the significant cases; standardized gradients average 3.6%/100 ft, ranging from 2.0% to 6.4%. These relationships are shown graphically in figure 5. There are few comparisons in the literature to relate to these findings, as nearly all studies have been restricted to snow water equivalent relationships.

ASPECT

Aspect as a topographic parameter related to snow cover characteristics has been studied by many investigators, but is generally found to be less significant than elevation (Meiman, 1968). Aspect relationships were first tested by linear regression using the cosine of the aspect angle as the independent variable, based on the hypothesis that distributions were symmetric about a north-south orientation. Symmetry about the other four principal orientations was tested by successive displacement of the aspect angle by 45°, 90° and 135°. The results of this analysis are shown in table 3. All correlations with snow water equivalent are seen to be non-significant. No significant relationships for snow depth emerge until the April surveys, when northwest through northeast aspects exhibit the greatest depths. Correlation with NW-SE aspects in April 18, 1973 is -0.451, explaining over 20% of the variance, the most significant of all variables tested for that date.

Although the best relationships are in some instances offset from north-south by 45°, and except for April are non-significantly correlated, the aspect relationships as expressed by the unadjusted (N-S) cos θ correlations late in the season are of some interest and are shown in figure 6. Increasingly intense solar radiation is producing rapid melt on the more favoured south-facing slopes, and differences in residual snow depth become evident. This is demonstrated by the increasing amplitudes of the cosine relationships from 3.1 inches to 5.9 inches between March 27 and April 18, 1973 and 2.3 inches to 3.8 inches between March 25 and April 22, 1974.

Table 3. Relationships between snow cover and aspect

		Correlation Coefficients (r)							
			Snow Depth				Snow Water Equivalent		
Date of Beginning of Survey	df	cos Θ	cos Θ-45°	cos Θ-90°	cos Θ-135°	cos Θ	cos Θ-45°	cos Θ-90°	cos Θ-135°
15 JAN 75	35	-.036	.155	$\underline{.313}^{ns}$	.250	-.158	$-\underline{.219}^{ns}$	-.184	.008
16 JAN 73	15	.186	$\underline{.306}^{ns}$	.241	.010	$\underline{.325}^{ns}$	.318	.090	-.188
14 FEB 73	25	.221	$\underline{.252}^{ns}$	.128	-.107	-.077	-.007	.092	$\underline{.123}^{ns}$
25 FEB 74	36	-.016	.091	$\underline{.176}^{ns}$	.135	-.126	$-\underline{.131}^{ns}$	-.070	.059
6 MAR 73	25	.227	$\underline{.327}^{ns}$	.267	-.025	.003	.098	$\underline{.169}^{ns}$	.103
25 MAR 74	36	.172	$\underline{.271}^{ns}$	.253	.029	.232	$\underline{.246}^{ns}$	.136	-.103
27 MAR 73	25	$\underline{.340}^{ns}$	.282	.036	-.264	.187	.058	-.151	$-\underline{.252}^{ns}$
18 APR 73	25	$.397^{*}$	.199	-.188	$-.451^{**}$	.328	.175	-.136	$-.361^{ns}$
22 APR 74	36	$.326^{*}$	$\underline{.331}^{*}$	.164	-.164	$\underline{.226}^{ns}$	.210	.082	-.135

Highest coefficients are underlined.

DISCUSSION

This is the first detailed study of snow cover in New Brunswick to be based on data collected in forest environments. In a region which is 86% forested, a knowledge of these relationships is vital to the management of the water resource, and to coping with the annual spring flood threat. Similarly, this knowledge is needed in wildlife management and in the planning for winter recreation. It is hoped that the results of this study will serve those interests.

The use of multiple regression as an analytical tool may serve two objectives. By exploring the statistical relationships one may gain an understanding of the probability and magnitude of the physical association between snow cover and physiographic features, draw inferences about the snow cover variability within the region where the study was conducted, and compare these relationships with those found elsewhere. The objective of this paper has been to examine those relationships from preliminary data collected in the Nashwaak Experimental Watershed Project, expressed in forms whose physical interpretation is readily apparent.

The overall objective of the Project, however, is to evaluate the impact of a forest harvesting operation, which will require a prediction of the untreated condition of the experimental watershed. The accuracy of this prediction can be improved by introducing additional variables consisting of combinations of certain of the original variables and by transformations of variables. Using multiple regression in this way need not depend on any apparent logic in the physical relationships, but is merely designed to achieve optimum predictability. This is a powerful analytical tool, and its application is envisaged for the Project, but since the physical interpretations are obscure it serves no purpose to use such a complex analysis in a presentation of this nature.

ACKNOWLEDGEMENTS

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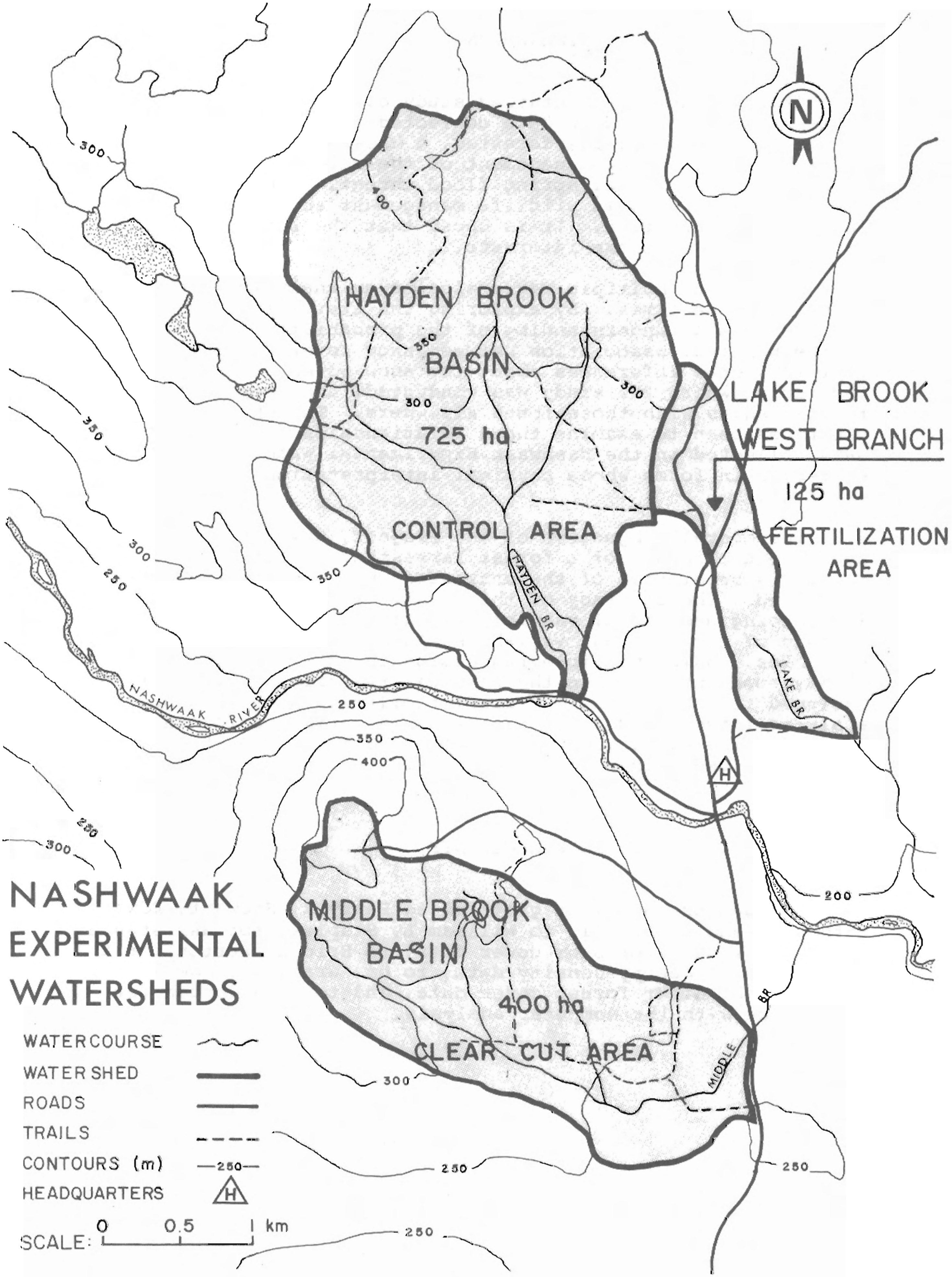
NASHWAAK
EXPERIMENTAL
WATERSHEDS
HAYDEN BROOK
BASIN
725 ha
CONTROL AREA
LAKE BROOK
WEST BRANCH
125 ha
FERTILIZATION
AREA
MIDDLE BROOK
BASIN
400 ha
CLEAR CUT AREA
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