VARIATION OF SNOW RESOURCES WITH CLIMATE AND VEGETATION IN CANADA[1] 530-71

By

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Introduction

Snow cover is the primary source of Canadian water supplies. It forms a vital protective blanket for plant life and small animals, and at the same time may menace grazing animals. It is a source of pleasure to countless sportsmen. It provides a road for many forms of transportation. As a consequence, information on its regional characteristics are being sought increasingly. Some broad-scale features of snow cover, as might interest regional planners, travellers, ecologists and others, are the subject of this report. Here, at attempt is made to show how commonly collected data may be used in deciding resource management procedures.

The nature of the snow cover is determined mainly by climate and therefore it is to be expected that it will vary from one climatic region to another. Igloo snow of the Arctic bears little resemblance to the wet snow cover near the Atlantic coast. Repeated thaws near the southern limit of snow cover create structures, densities and other situations which are quite different to those found in regions where snow covers remain established firmly throughout the winter. Climatic features are therefore a major factor to consider in searching for regional variations.

Physical features, such as vegetative cover, have a profound impact on climate and consequently on the associated snow cover. Within a climatic zone local topography and vegetative cover may produce major local differences in the snowpack. Over vast areas where topography is not excessively variable, it is possible to define broad zones of vegetative homogeneity. Since the nature of this vegetation is highly allied to climate, the vegetative zones serve as a logical basis for the regional analysis of snow cover.

TABLE 1

Snow Regions of Canada
(after Potter, 1965)

Region	Character	Vegetation
Arctic Archipelago	10- month winter - median maximum depth 12-15" - windswept hard snow in west - 20-30" snow in east	Tundra
Mackenzie-Keewatin	8-month winter - median maximum depth 25"	Taiga-Boreal
B. C.-Yukon	Variable duration - < 1 - 8 months - median maximum depth (valleys) 18" in north - 12" in NW B.C. <12" elsewhere - much higher values in mountains	Subalpine, Boreal, Taiga Tundra, Montane, Columbia, Coast
Prairie Provinces (incl. Peace River block of B.C.)	< 2 months in south - 3-4 months in north - median maximum depth - 12-18" in north 10" in south	Boreal, Aspen Grove, Prairie

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[2] Canadian Meteorological Service, Toronto.

Northern Ontario, Quebec and Labrador	5-7 months - median maximum depth 40-60"	Boreal, Taiga
Southern Ontario, St. Lawrence Lowlands and Atlantic Provinces	4-5 months, except 2 months near Lakes Ontario and Erie, 3 months in SW Nfld., south shore N.S. and Bay of Fundy - Median maximum depth 10-40"	Great Lakes - St. Lawrence, Acadian

The Climatic Regions of Canada

On a very broad basis Canada may be considered as having six climatic zones: (1) Pacific, (2) Cordillera, (3) Prairie, (4) Arctic, (5) Sub-arctic, and (6) Southeastern (see Fig. 1). While snow cover is common to all regions, it is much heavier as a rule in the east and along the Pacific slopes of the Cordillera. Snowfall is light in the arctic region, often termed the "polar Desert" but the shallow cover is made dense by wind compaction. The prairies are also a region of light snow cover, the pack being frequently removed from southern Alberta by mid-winter Chinooks.

Based upon the measurements of snow on the ground at climatological stations, Potter (1965) distinguished seven principal snow cover regions which are described in Table 1. These regions are essentially identical to the above-mentioned climatic regions; however, allowances are made for the differences in snowfall amounts in the boreal forests in eastern and western Canada. Because of the much heavier snowfall which occurs east of Hudson Bay it would appear desirable to also distinguish between the eastern and western climatic regions within the arctic and subarctic, as noted in Fig. 1. Although Potter's classification is based only on climatic considerations it is apparent that the regions and the snow cover distribution patterns within them bear close resemblance to the major vegetation zones.

Vegetative Cover

Snowfall tends to be more uniform than rainfall. However, because it is easily moved by the wind, snow usually accumulates on the ground in a highly heterogeneous manner, and it is, therefore, difficult to obtain representative measurements.

For example, the general prairie snowpack is fairly uniform, but local variations in topography and vegetative cover cause major departures from the average. Shelter belts and buildings cause massive, deep drifts, whereas nearby fields may be fairly free of snow. Well eroded gullies and deep drainage ditches act as "sediment traps" collecting snow which blows or drifts off adjacent fields. For example, a check of snow accumulation in gullies near Regina in the spring of 1966 showed them to contain about 3½ acre-feet of water (as snow) per 1000 feet of channel - when the fields were free of snow, and before significant runoff had occurred.

Within the forest, accumulations vary according to the type of tree, density of forest, number of clearings, and proximity to exposed snowfields. A solid evergreen forest is effective in intercepting snowfall which may evaporate and not contribute directly to runoff. A deciduous forest, lacking leaves, permits snow to accumulate on the forest floor, but arrests drifting such as would occur on the prairie. Clearings in coniferous forests act as traps and accumulate more snow than mixed or deciduous forest. Such clearings are frequently favoured as snow-survey sites.

Snow cover within the mountains tends to be highly variable because of the combined effects of high winds and rugged topography. Slides and unusual deposition caused by local topography may result in remarkable accumulations, far exceeding the annual snowfall. Most available measurements which are suitable for statistical treatment are for valley locations, whereas the major accumulation areas are often at high elevations.

The effects of topography and vegetative cover have been observed by Kuz'min (1960) as follows:

TABLE 2

Snow Retention Coefficients

(Virgin Soil Equals 1.0)

Open ice	0.4 to 0.5
Arable land	0.9
Virgin soil	1.0
Hilly districts	1.2
Large Forest tracts	1.3 to 1.4
River beds	3.0
Rush growth near lakes	3.0
Forest cuttings of a radius of 100 to 200 m, and edges of forests	3.2 to 3.3

Kuz'min noted that strong winds may completely remove the snow cover from ice, the coefficient then dropping to zero. Extremely strong winds may also denude farm lands, depending on the character of the snow cover. These values are regional averages - the coefficient in an individual instance being dependent on wind speed and other factors. Allowances must be made for the different catch and retention capacities of sites when treating snowfall and depth measurements.

Within Canada it is possible to define many vegetative zones; however, for regional purposes these must be considered on a broad scale. The forest classification given in the Atlas of Canada (1957) was used in selecting the following eleven regions:

1) Boreal Forest
2) Subalpine Forest
3) Columbia Forest
4) Montane Forest
5) Coastal Forest
6) Taiga
7) Tundra
8) Aspen Grove
9) Prairie
10) Great Lakes Forest
11) Acadian Forest

In Table 3 and Fig. 2 the broad characteristics of these zones, their size and distribution are outlined. Particular attention is given to the forest morphology, the closeness and type of trees, some climatic anomolies, for these are important determinants of the efficiency of snow retention and melt.

Variation of Snow Cover with Vegetation Regions

The main features of snow cover amenable to national-scale analysis are depth and density. These do not provide all the desired information, but they are pertinent to many regional planning problems. The close relationship existing between snow cover depth and density and vegetation on the local scale persists even in regional patterns. In Fig. 3 the remarkable coincidence of the spatial gradients of average snow densities in southern Manitoba to the boundaries of vegetation zones is readily apparent. Such a correspondence is re-emphasized by comparing national climatic, snow depth and vegetation maps. Snow cover varies also with topography, but local details are so complicated that regional analysis is difficult.

Snow courses are maintained by several agencies, but the records are published annually by the Canadian Meteorological Service in "Snow Cover Data". For this report supplementary records were obtained from the Provinces of British Columbia, Manitoba and Quebec. For reasons of simplicity, and the exploratory nature of the study, but also in order to have an even distribution of snow courses across the country, this report relates largely to the period 1961-70 (1965-70 in the arctic).

The snow survey data were used primarily to obtain time-curves of density (Fig. 4), but also to amplify on the store of information available from climatological measurements

TABLE 3

Characteristics of Vegetation Regions

Vegetation Region	Approx. Area $mi^2 x 10^3$	Location	Nature of Vegetation	Principal Plant Species
Boreal Forest	876	East-west band through central Canada. Dry, sunny western and moist eastern climates.	Close coniferous trees, more open on boundaries. Deciduous species in burnt-over areas - varying topography and large muskeg areas.	White and black spruces, tamarack, broadleaf poplars, birches. Balsam fir and jackpine in east - alpine fir and lodgepole pine in west.
Subalpine Forest	88	Central and south B.C. east of Coast Range on mountain slopes 3000-7000 ft. MSL.	Close coniferous trees in lower elevations, becomes more open in higher and drier areas - similarities with Boreal Forest in north.	Engelmann spruce, alpine fir, lodgepole pine.
Montane Forest	50	South central B. C.	Relatively open forest, particularly in drier rain-shadow areas in the south.	Douglas fir, Ponderosa pine in south, Englemann spruce and alpine fir in north.
Coast Forest	50	West coast B. C.	Luxuriant, coniferous rain forest. Close canopy usually but where open - a well developed understorey.	Western red cedar, western hemlock, Douglas fir (south), Sitka spruce (north), Amabilis fir, yellow cedar.
Columbia	17	Columbia Mountains region, especially windward lower slopes.	Similar to Coast Forest, but smaller trees. Strong Subalpine influence.	Coast and Subalpine types.
Taiga	450	East-west band through north-central Canada.	Transitional zone between Boreal Forest and tundra. Very open, often devoid of trees on higher areas. Tundra vegetation on ground level.	Black and white spruces, often lichen lower storey (Cladonia spp).

(Cont'd)

Vegetation Region	Approx. Area $mi^2 \times 10^3$	Location	Nature of Vegetation	Principal Plant Species
Tundra	1,125	Northern one-third of Canada. Areas above 7,000 feet in Cordillera (lower in north).	Devoid of trees except in some sheltered valleys in south. Extensive plains of lichens, mosses, sedges, etc. Extensive bare rock surfaces with limited plant colonization. Surface is often very wet.	Varying groups of lichens, mosses, sedges, dwarf woody plants and flowering plants.
Aspen Grove	81	South-central Alberta, Saskatchewan, southern Manitoba.	Transition from Prairie grassland to Boreal Forest or Great Lakes Forest. Clumps or groves of trees where soil moisture is greatest in south becoming open forest in north.	Aspen and grasses.
Prairie	102	Southern parts of Prairie Provinces.	Grassland 3 ft. high in north and east, 1 ft. high in southwest. Relief generally level. Much of area is cultivated.	Grasses.
Great Lakes - St. Lawrence Forest	148	Great Lakes - St. Lawrence River Valley	Mixed forest, predominantly coniferous. Sporadic clearings and settlements.	White and red pines, eastern hemlock, sugar and red maples, red oak, basswood, white elm, eastern white cedar, aspen.
Acadian Forest	50	Atlantic Provinces except Newfoundland.	Similar to Great Lakes and Boreal Forests. Topography somewhat variable but generally low relief.	Boreal species plus red spruce, balsam fir, yellow birch and sugar maple.

Fig. 2

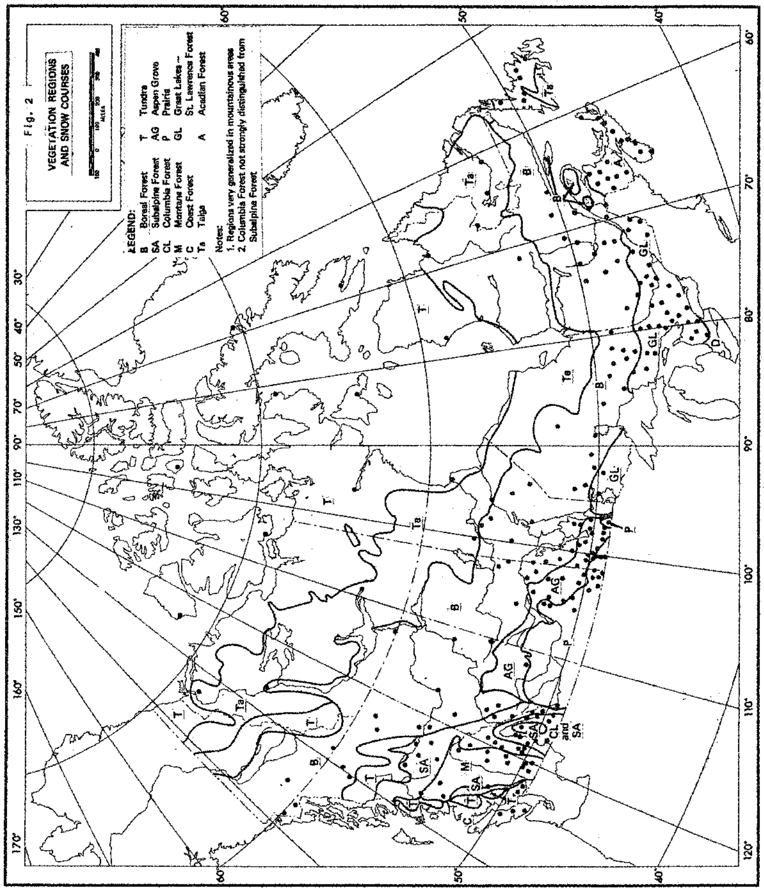
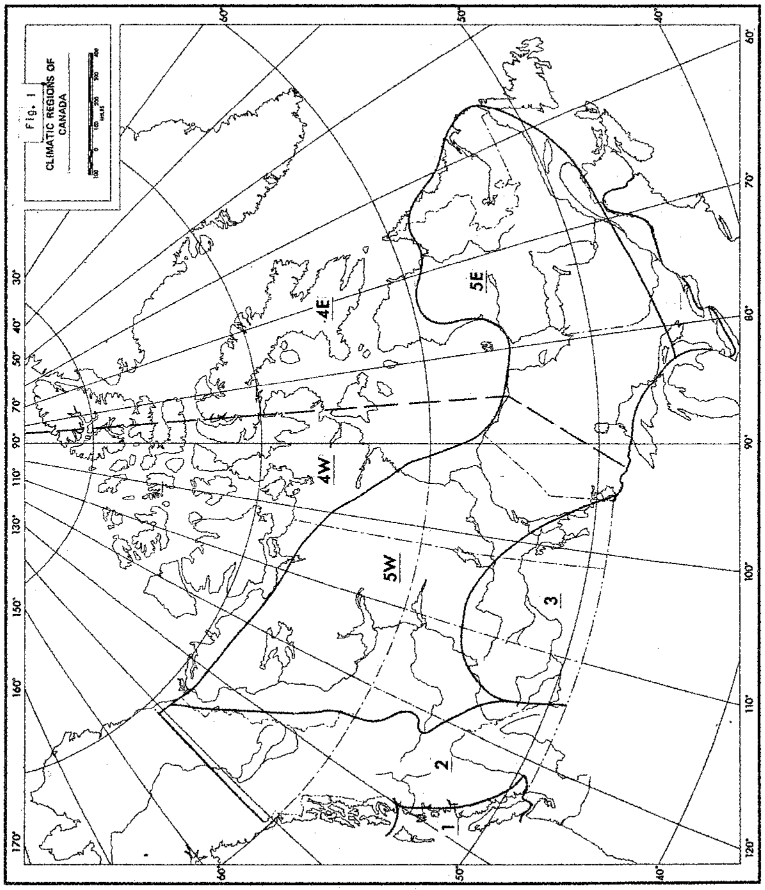


Fig. 1



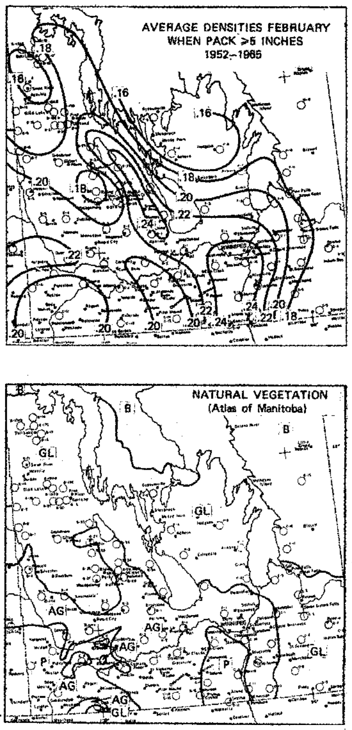
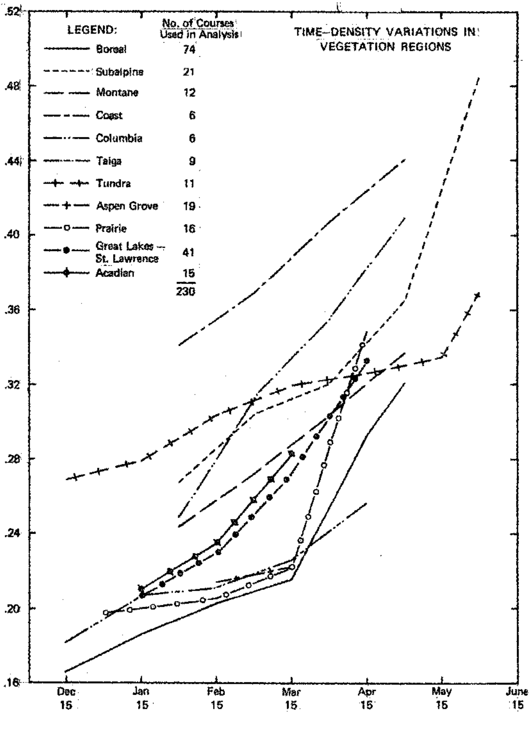


Fig. 3 Snow density and vegetation in southern Manitoba

Fig. 4



of snow depth. Each time-curve represents the average conditions for all courses within a vegetative region. The Prairie curve has been estimated prior to February 15 and after March 15. The Tundra curve has been estimated after May 15.

TABLE 4

Means and Standard Deviations of Snow Cover Density

Vegetation Region	Dec. 15		Jan. 15		Feb. 15		Mar. 15		Apr. 15		May 15	
	M.	S.D.	M.	S.D.	M.	S.D.	M.	S.D.	M.	S.D.	M.	S.D.
Boreal	.17	.01	.19	.02	.20	.03	.22	.05	.29	.04		
Subalpine*			.27	.04	.30	.03	.32	.04	.37	.05	.48	.05
Columbia*			.25	.02	.31	.03	.36	.05	.41	.05		
Montane*			.24	.03	.27	.03	.30	.03	.34	.04		
Coast*			.34	.04	.37	.03	.41	.03	.44	.05		
Taiga	.18	.03	.21	.05	.21	.03	.22	.04	.26	.04		
Tundra	.27	.03	.28	.04	.30	.03	.32	.04	.33	.03	.34	.03
Aspen Grove					.21	.02	.22	.03				
Prairie					.21	.02	.22	.03				
Great Lakes -St. Lawrence			.21	.03	.23	.05	.27	.04	.33	.05		
Acadian			.21	.04	.24	.03	.28	.03				

* Values for end of month

It is interesting to note that the standard deviations of the mean course values for each vegetation zone are small, considering the relatively few data used (Table 4). They confirm that this is regional homogeneity of snow density at a specific time of year. Each weather event may have a marked affect on the density of a stratum, and while the resulting pack stratigraphy may sometimes be complex, by and large the integrated seasonal effects on quality are remarkably similar from year to year so that it is reasonable to suggest the character of the density at a specific time in the climatic calendar. This makes it possible to make statements of value in predicting trafficability, water supplies and recreation over large areas.

The absolute values and trends demonstrated by the nature of the curves may be explained by climatic influences, principally temperature and wind but also by vegetative factors such as retention, shelter and evaporation-melt opportunities. Another factor is pack depth as illustrated in Fig. 5, a plot of density values against snow depth in a sample of B.C. snow course data. The increased densification with depth is not readily apparent in shallow cover zones.

Wind is primarily responsible for pack compaction and the high density values encountered on the prairies and in the tundra regions, both polar and alpine. For the most part these areas have low relief and few obstructions to strong winds. The effect of such winds on snow density at Regina is shown in Fig. 6. This diagram verifies that in years when winds are strong the snow will be hard and dense. The relations of wind speed and density may be further assessed for regional significance by simultaneously referring to Fig. 7 (mean daily maximum temperatures within each vegetation region). Firstly, it is apparent that since the temperatures on the Taiga and Tundra are similar, their density differences are due to the vegetative cover which affects the wind speed. Wind compaction is therefore conclusively a major influence on density. A similar pattern occurs between the open prairie and the surrounding wooded zone.

Variations in the remaining areas (Fig. 7) have a close relationship with day-time air temperatures. Particularly noticeable are the inflection points on many of the density curves, indicating rapid snow water concentration towards the "ripening" point as spring approaches. Within the Great Lakes area the inflection point is in mid-February, in the Boreal Forest mid-March, while in the Taiga, where densities are normally high and depths shallow, no inflection point is apparent. This is also true for the relatively warm deep packs near the West Coast in which there is apparently a considerable storage of free water.

Fig. 7 also suggests interesting regional features. For example, the snow season on the West Coast is short on account of the maritime climate. Although the Columbia Forest is morphologically similar to the Coast Forest, it has lower moisture reserves, being somewhat in a rain shadow; but the snow pack ripening there is fast because of the greater insolation. In subalpine areas an early accumulation of snow makes for a greater relative water content than in most other forests. However, despite the advantage of high altitude insolation, the ripening process is slow. The dry interior valleys and plateaus of the Montane Forest region have anomolously low moisture reserves. Snow dissipation is rapid possibly on account of the open nature of the forest (i.e. heat transport by turbulence is more effective), and due to the warm sunny spring. Over the Tundra a great deal of low angle solar energy is reflected from the white surface so that changes in spring are slow. Shade, shelter and a relatively "dry" snowfall give the Boreal Forest and Taiga the lowest densities and smallest changes throughout the winter. Density changes in the Acadian and Great Lakes-St. Lawrence Forests are similar, for climatic conditions as well as tree species are comparable.

It is not clear from this analysis why the Aspen Grove should have higher densities than the Prairie, particularly since this is in conflict with Fig. 7. The problem may be one of sampling. However, the snow cover is deeper in the parkland, hence total mass may be important.

Practical Applications

A knowledge of regional snow density values allows forecasting of trafficability, water resources, recreation possibilities, and may be indirectly used to suggest climatic variation from place to place a useful prelude to natural resource development and land-use planning. For example, water storage in the form of snow may be estimated over most of Canada from month to month. Table 5 illustrates this procedure where crude average snow depths estimated from Potter's (1965) data, and the monthly mean densities (Fig. 3) are used to calculate the equivalent water volume in each vegetation region. The remarkable volumes in the underveloped Tundra, Taiga and Boreal Forest regions are immediately evident. For example, in February these three regions encompass almost 84 per cent of the total national snow water supplies (excluding ice sheets). The total winter volumes are actually larger if the water which runs off during mid-winter thaws in southern and western regions is considered.

TABLE 5

Snow Water Equivalent Storage in Major Vegetation Zones

Zone	Area* (thousands of square miles)	Dec. 31		Jan. 31		Feb. 28		Mar. 31		Apr. 30	
		D	S **	D	S	D	S	D	S	D	S
Boreal	876	1.3	123.3	1.8	196.1	2.2	258.0	1.9	269.0		
Subalpine	88	1.0		1.5	22.5	1.3	21.9	0.8	14.6	0.1	5.6
Columbia	17	1.0		1.3	3.5	1.0	3.4	0.2	0.8		
Montane	50	0.7		1.2	9.3	1.3	11.2	0.7	6.7		
Coast	50	0.2		0.2	22.4	0.2	22.4	0	0		
Taiga	450	1.2	57.5	1.5	92.1	1.5	95.0	1.5	109.2		
Tundra	1,125	0.8	158.2	1.2	251.8	1.2	226.0	1.3	302.0	1.3	309.5
Aspen Grove	81	0.7		0.8	10.4	1.0	11.4	0.2			
Prairie	102	0.3		0.5	6.5	0.5	6.5	0			
Great Lakes - St. Lawrence	148	1.0		1.2	10.3	1.3	31.3	0.5	14.2		
Acadian	50	0.3		0.7	4.8	0.8	6.7	0.3			

*Areas derived from the Atlas of Canada. They are currently under review by the Canadian Forestry Service and will be modified.

** Depth in feet (D)
Storage - millions of acre-feet (S)

Another example of the useful combination of regional density and depth values is the production of national water equivalent or snow mass maps. Fig. 8 is precisely this for the late February period and is based upon space averages of climatological snow depth values and snow course density values over areas contained within five degrees of longitude and five degrees of latitude. A very striking aspect of this map is the northwest deflection of the four-inch isobath over Keewatin Territory, part of the "Polar Desert", but where the shallow snow cover is very dense due to wind compaction.

Other practical applications would include the production of trafficability maps and tables, which are very useful data for regional economic planning. However, these techniques still need considerable development and evaluation. Vegetation has been used for the basis of discussion in this paper because topographical features are difficult to evaluate on this scale. Regional relationships of snow and landform, especially factors of slope, aspect and elevation need to be derived and cannot be ignored for they are very important. At present we have inadequate knowledge of basic physical properties of snow, measured on all scales, as needed to develop sound management programs.

Steps are now being taken to permit more complete use of snow cover information through integration of climatic and survey-type records so as to provide a sound basis for policy and planning relating to this important resource.

REFERENCES

Bilello, M. A., 1969. "Relationships between climate and regional variations in snow-cover density in North America". U. S. Army Corps of Engrs., CRREL Research Report 267, 21 p.

Canada Dept. of Mines and Technical Surveys, 1957. Atlas of Canada, plate 39, "Forest Regions".

Canada Dept. of Transport, Meteorological Branch. Snow Cover Data, Winters 1960-61 through 1969-70.

Kuz'min, P. P., 1960. Snow Cover and Snow Reserves (translation from Russian), U. S. National Science Foundation and Dept. of Commerce (Israel Program for Scientific Translations) 1963.

Manitoba Dept. of Industry and Commerce, 1960. Economic Atlas of Manitoba, plate 10, "Natural Vegetation".

McKay, G. A., and H. A. Thompson, 1968. "Snow cover in the Prairie Provinces", Trans. of the Amer. Soc. Agric. Engrs. 11 (6), pp 812-815.

Potter, J. G., 1965. "Snow Cover", Canada Dept. of Transport, Meteorological Branch, Climatological Studies No. 3, 69 p.

United States National Academy of Sciences, 1970. "Snow research and control", Appendix C in Polar Research - A Survey, Washington, pp 97-102.

Williams, G. P., 1958. "Variability of physical characteristics of snow cover across Canada". Research Paper No. 62, Division of Building Research, National Research Council of Canada, 8 p.

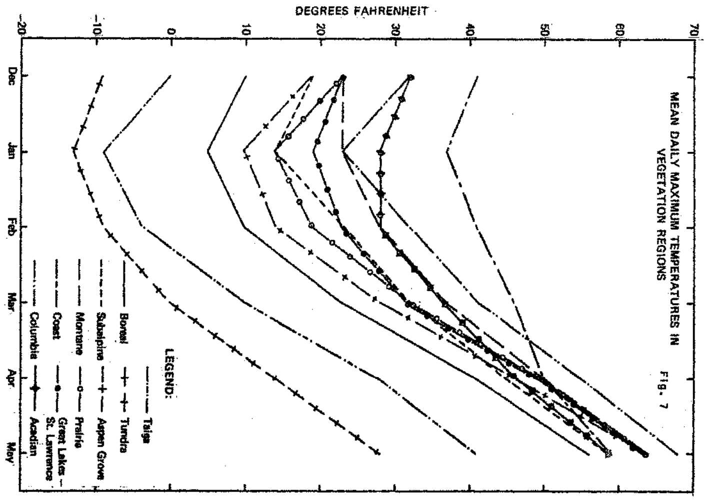


Fig. 7

MEAN DAILY MAXIMUM TEMPERATURES IN VEGETATION REGIONS

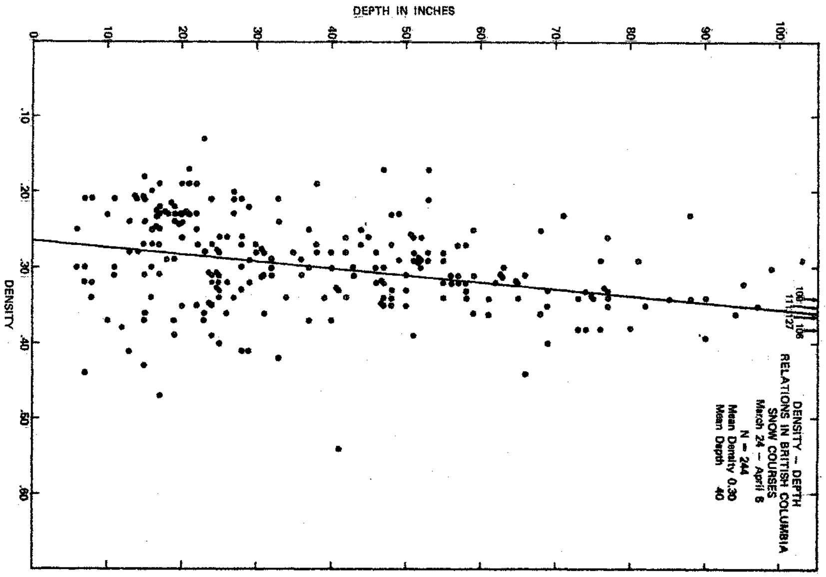


Fig. 5

DENSITY – DEPTH RELATIONS IN BRITISH COLUMBIA SNOW COURSES
March 24 – April 6
N = 244
Mean Density 0.30
Mean Depth 40

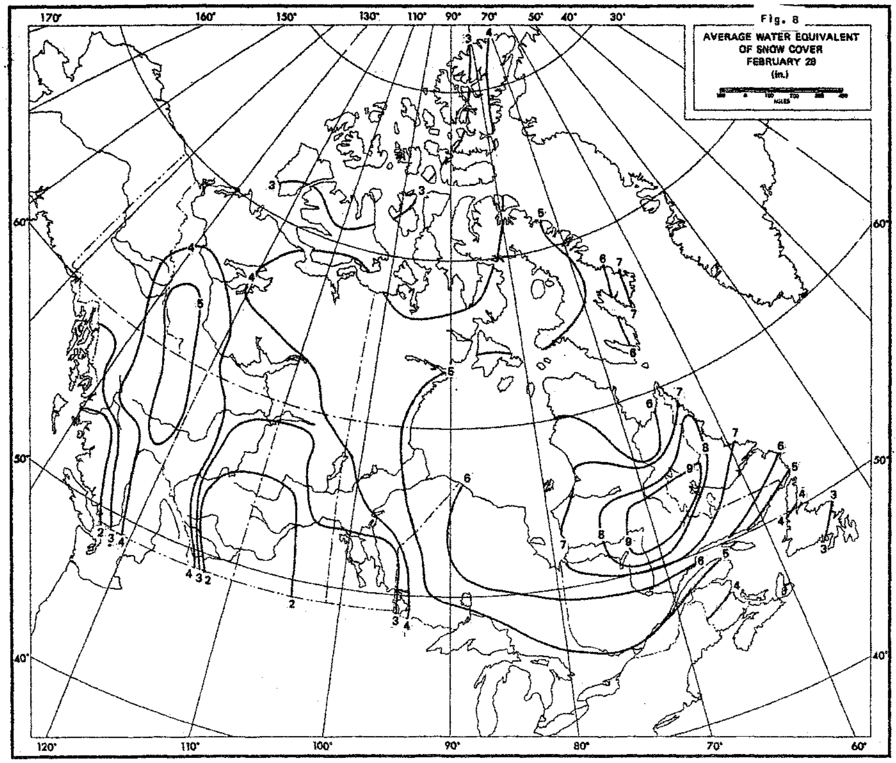


Fig. 8

AVERAGE WATER EQUIVALENT OF SNOW COVER FEBRUARY 28 (in.)

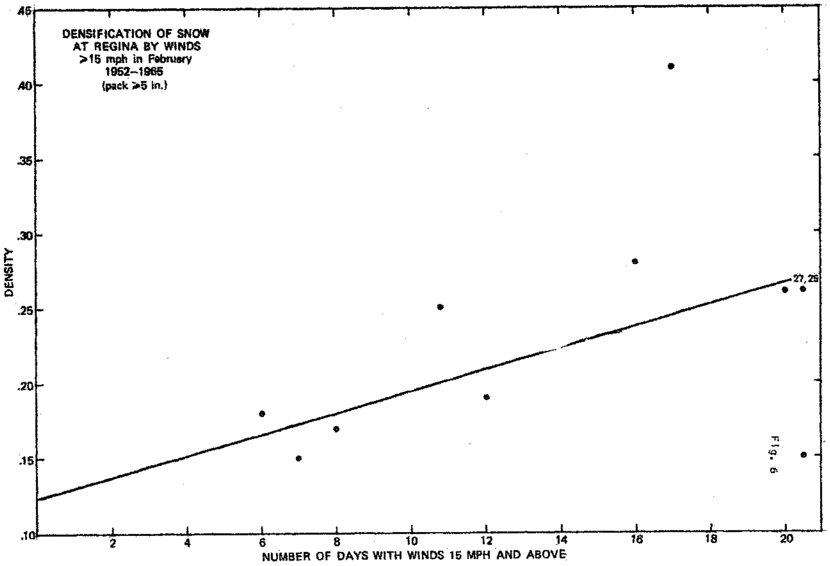


Fig. 6

DENSIFICATION OF SNOW AT REGINA BY WINDS >15 mph in February 1952–1965 (pack >5 in.)