CLIMATE OF MINNESOTA
Part XIII—Duration and Depth of Snow Cover

Earl L. Kuehnast
Donald G. Baker
James A. Zandlo

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Authors:

Earl L. Kuehnast is the state climatologist, Department of Natural Resources, St. Paul; Donald G. Baker is a professor in the Department of Soil Science, University of Minnesota, St. Paul; and James A Zandlo is the assistant climatologist, Department of Natural Resources.

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CLIMATE OF MINNESOTA—PART XIII

Duration and Depth of Snow Cover

I. Introduction

This study was prepared to provide a climatology of snow and to aid in solving problems related to snow depth and duration throughout Minnesota. A brief climatology of snow is contained in a chapter of the Climate of Minnesota, Part V (1), and a detailed analysis of snow cover and soil freezing at St. Paul is found in another bulletin (2). These two bulletins represent the limited amount of information available on snow in Minnesota. Somewhat similar bulletins to this one are available for Michigan (5) and Wisconsin (13).

The first recorded temperature data in Minnesota began at Fort Snelling in 1819, followed by precipitation in 1836 (6). Daily snow depth and snowfall information were not an entry on the U.S. Weather Bureau observation forms until about 1896. At that time, snow depth and duration were observed at just a few stations and their number increased slowly with time. Only in the last 30 years have the number of observation sites and demand for snow data really increased.

Snow cover duration and depth reports are valuable for making various assessments and interpretations. For hydrologists they are of obvious importance as a major factor in spring runoff and flood forecasting. Such information is of particular importance in the case of agricultural soils where most snowmelt is lost as runoff because the underlying soil is usually still frozen. In contrast to agricultural soils, snow is ordinarily an important source of soil water recharge in forest soils. More meltwater is usually able to enter forest soils because of more vegetative cover and less blowing of surface snow. Further, the forest soils are seldom frozen deeply, and the meltwater runs off more slowly (13).

The duration of snow cover in late winter or early spring is of extreme importance relative to forest and prairie fires. The greatest frequency of fires is in April, the period between the disappearance of snow and the greening of vegetation due to spring rains and rising temperatures. So the longer that snow lasts, the lower the fire danger because the previous year's dry and dead vegetation is exposed for a shorter period.

Snow cover or the lack of it plays a very important part in the micro- and mesoclimates of an area. A microclimate is the climate found within a very limited area, measuring at most about 0.5 mile on a side, and restricted to a very shallow depth of the atmosphere. A mesoclimate is intermediate between a micro- and the large scale or macroclimate with respect to both area and depth of the atmosphere. The climate of a city or several counties might approximate the areal limits of a mesoclimate.

In the presence of snow cover, very little solar radiation is absorbed. Depending upon the age of the snow, 50 to 90 percent of the solar radiation may be reflected. In the absence of snow, no more than 30 percent of the solar radiation is reflected from natural surfaces, with the absorbed energy used mainly in evaporation and heating the air.

Snow depth data are also useful for winter recreation activities and wildlife management. For example, a snow depth of 18 inches or greater restricts the movement of deer to the point where they can forage for food only with difficulty; after 12 weeks losses began to occur from starvation (4).

A number of local factors affect the duration and depth of snow cover. Chief among them are the local topography and vegetative cover. In Minnesota there are four major topographic features: the North Shore Ridge, Mesabi Iron Range, Alexandria Moraine, and Buffalo Ridge. These locations are shown in Figure 1. The North Shore Ridge, also known as North Shore Highlands (14), is more or less parallel to the Lake Superior shore line. The ridge is a rather abrupt increase in elevation,from the 602 feet mean sea level (msl) of Lake Superior. The crest varies from 1,400 to more than 2,000 feet msl at distances varying from 2 to 15 miles from the lake shore. The highest point in Minnesota, Eagle Mountain at 2,301 feet msl, occurs within the North Shore Ridge upland area.

The second major upland, the Iron Range, is not far west of the North Shore Ridge. The Mesabi Iron Range is referred to as the Mesabi Range and further divided into the Giant's Range by Winchell (12) and Wright (14). Winchell (12) state: "Giant's Range, the ridge which lies just to the north of the Mesabi iron bearing rocks.... This ridge is composed of granitic rocks and forms the divide between streams which flow north and northwest from those which flow south." Wright uses the name Giants (sic) Range which is described as a "highland of granite flanking the Mesabi range on the north from Hibbing to Babbitt." This range is about 200-400 feet above the plains lying to the north and south.

This low ridge of irregular hills extending from just east of Grand Rapids in Itasca County northeastward to near Ely in northeastern St. Louis County is the Iron Range as shown in Figure 1. The hills are not as pronounced as the other three highlands, but they are important relative to the nature of the snow cover regime in their immediate area.

The third upland area lies to the east of the Red River Valley in an arc that extends northward from Pope County to southern Clearwater and Beltrami Counties. This is referred to as the Alexandria Moraine by Wright (14) and as the Coteau du Grand Bois (literally, Slope of the Big Woods) by Joseph N. Nicollet (11), not to be confused with Father Jean Nicollet the priest-explorer of an earlier century. The Leaf Hills mentioned by both Winchell and Upham (11) and Wright (14) occupy the central and southern part of the Alexandria Moraine where elevations reach more than 1,700 feet mean sea level. At the northern end of the Alexandria Moraine is the Itasca Moraine which extends eastward. This was named The Height of Land by Nicollet (11). Elevations reach more than 1,800 feet mean sea level in Itasca State Park and the surrounding area. West of the Alexandria Moraine elevations drop to about 900 feet mean sea level in the Red River Valley.

The fourth major upland is located in the southwestern corner of the state. J.N. Nicollet, whose 1842 map of the Minnesota and Dakota territory is shown by Winchell and Upham (11), accepted with reservation the name Coteau des Prairies by which the upland was apparently already known. Nicollet stated in his report (11) that the word prairie, or "plain" in English, did not convey the proper image. He felt that "plateau" was much truer to describing this physiographic feature. Thus Nicollet's 1842 map (11) has this upland labeled "Plateau de Coteau des Prairies." In spite of this concern over the feature's name, most local inhabitants speak of this physical feature as Buffalo Ridge.

The main ground cover in Minnesota ranges from forest to agricultural land, and in the case of the latter it

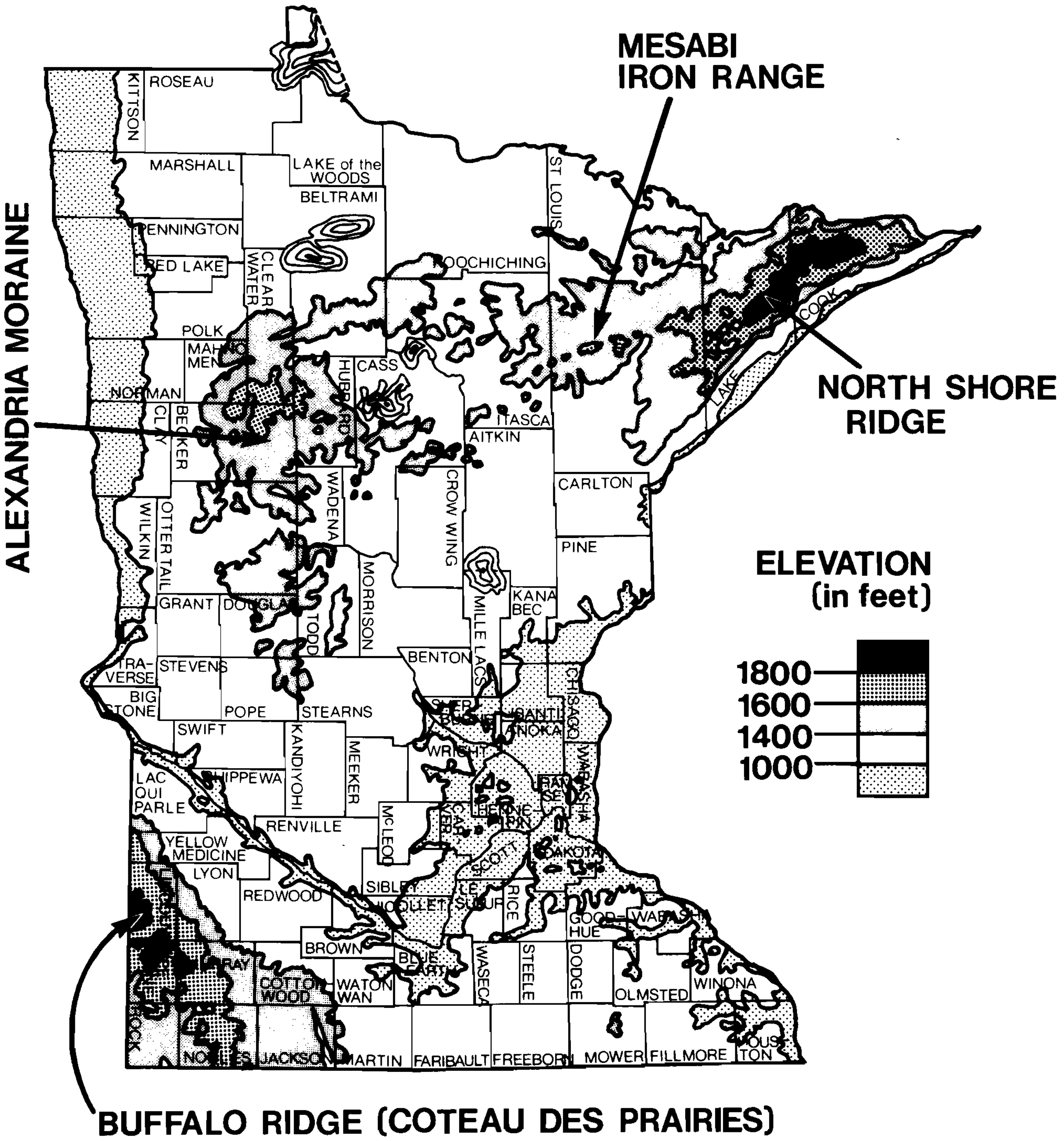

Figure 1. Topographic map of Minnesota.

is those fields with standing vegetation, such as meadows, uncut corn, or crop residues that act as effective snow traps for over-winter snow cover. Another kind of "cover" should not be overlooked, since its areal extent is ever-increasing and its effect upon snow cover is very great. This is the "urban cover" of cities and metropolitan areas where snow cover rapidly disappears.

Figure 2 shows the location of the National Weather Service (NWS) stations from which all of the snow depth and duration data used in this study were collected (7,8,9). The NWS volunteer cooperative weather observers are all trained to ensure that their observation methods are uniform. These observers are Minnesota's unsung heroes and heroines. They are truly historians of our daily weather. Their service to Minnesota dates from about 1845. No other volunteer group has been more faithful so long to their program and received less praise than Minnesota's volunteer weather observers to whom this bulletin is dedicated.

II. Snow Cover

A. SEASONAL DAYS OF SNOW COVER BY STATION

The seasonal mean number of snow cover days for five different snow depths at 52 stations for the 20 winters extending from 1959-60 through 1978-79 is

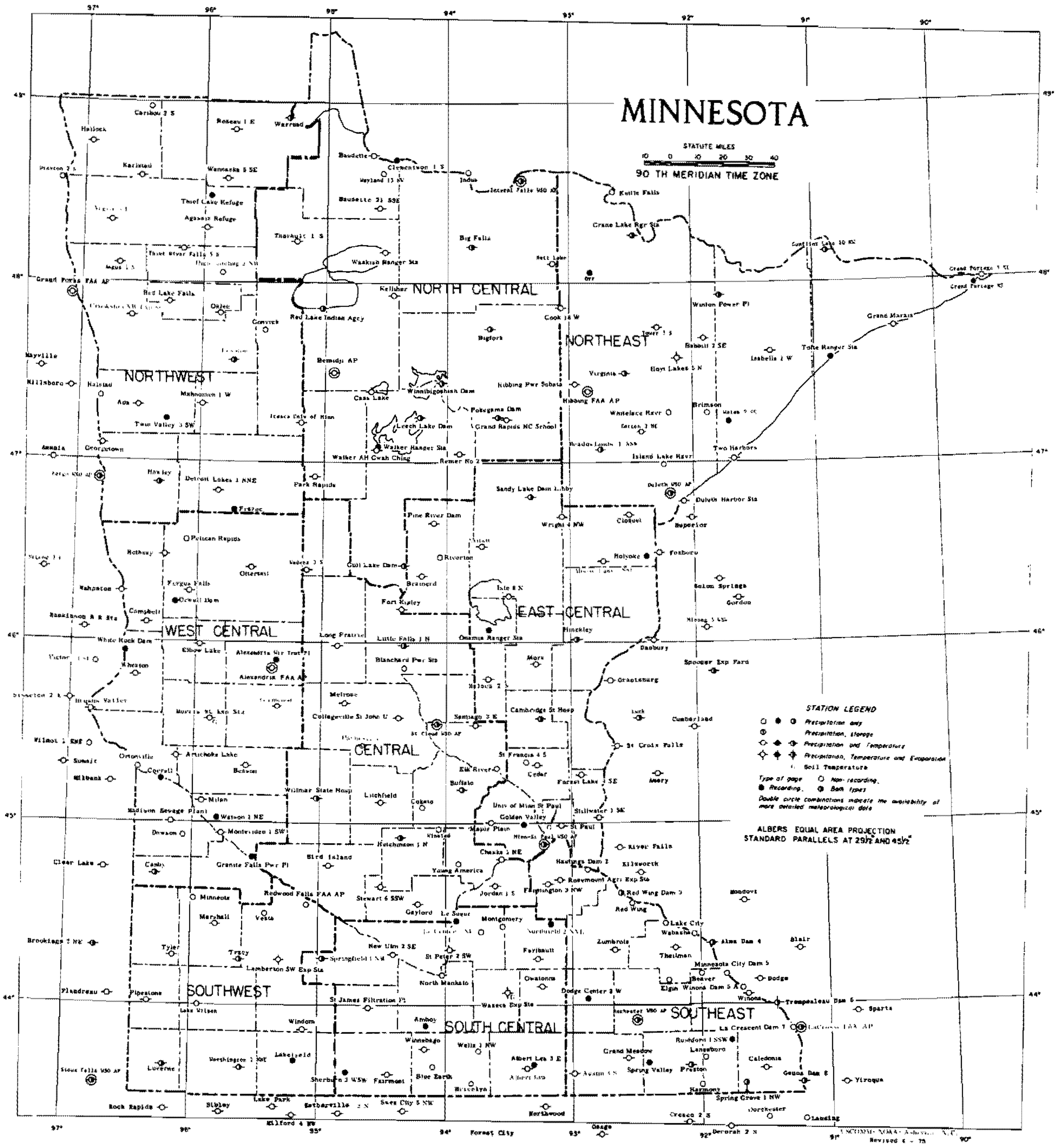

Figure 2. Name and location of the stations used in this study.

Table 1. Mean number of snow cover days for indicated depths and the first and last dates of 1-inch snow cover, October 1959-May 1979.

Station	Average seasonal snow cover days					Average date of first 1" snow cover in the fall	Average date of last 1" snow cover in the spring
	1"	3"	6"	12"	24"		
Albert Lea	81	64	52	27	10	Dec. 1	Mar. 26
Alexandria	117	91	61	27	6	Nov. 12	Apr. 11
Angus	122	104	72	31	4	Nov. 16	Apr. 7
Austin	87	67	44	21	1	Nov. 30	Mar. 25
Babbitt	144	132	114	72	17	Nov. 15	Apr. 21
Bird Island	101	82	58	27	9	Nov. 19	Apr. 1
Cambridge	111	94	72	42	13	Nov. 22	Apr. 3
Canby	102	77	48	17	7	Nov. 12	Apr. 8
Caribou	140	124	103	60	7	Nov. 2	Apr. 22
Crane Lake	150	138	121	90	25	Oct. 30	Apr. 19
Crookston	115	94	59	14	1	Nov. 12	Apr. 6
Duluth	138	125	109	74	17	Nov. 7	Apr. 13
Fairmont	94	70	45	22	6	Nov. 21	Mar. 28
Fargo, ND	109	81	41	8	0	Nov. 12	Apr. 9
Faribault	92	74	50	22	4	Nov. 24	Mar. 31
Farmington	87	71	48	24	6	Nov. 28	Mar. 27
Fergus Falls	113	87	55	20	2	Nov. 14	Apr. 9
Forest Lake	108	86	56	26	2	Nov. 21	Apr. 2
Fosston	124	108	89	49	5	Nov. 9	Apr. 8
Grand Marias	130	117	94	56	11	Nov. 17	Apr. 9
Grand Rapids	131	116	99	62	14	Nov. 13	Apr. 12
Gunflint	151	150	127	91	25	Nov. 7	Apr. 20
*Gunflint Trail	175	170	160	150	100	—	—
Hibbing	140	125	103	69	25	Nov. 11	Apr. 15
Hinckley	122	104	76	42	7	Nov. 13	Apr. 12
Hutchinson	100	82	55	27	10	Nov. 22	Apr. 2
Interntl Falls	145	131	113	75	13	Nov. 6	Apr. 17
Itasca Park	140	130	112	64	10	Nov. 7	Apr. 12
Jordan	92	71	45	19	4	Nov. 28	Mar. 26
Lamberton	83	60	32	12	0	Nov. 24	Apr. 2
Little Falls	112	100	77	44	14	Nov. 21	Apr. 6
Meadowlands	125	109	89	52	23	Nov. 22	Apr. 11
Milan	102	83	50	20	5	Nov. 14	Apr. 4
Minneapolis	100	79	54	24	1	Nov. 22	Apr. 2
Moose Lake	128	110	90	51	17	Nov. 20	Apr. 10
Morris	107	82	56	26	0	Nov. 12	Apr. 9
New Ulm	87	65	36	15	0	Nov. 24	Mar. 27
Pine River	124	111	91	48	8	Nov. 17	Apr. 15
Pipestone	94	66	38	17	4	Nov. 15	Mar. 31
Rochester	94	70	46	15	0	Nov. 24	Apr. 5
St. Cloud	103	84	56	24	3	Nov. 21	Apr. 4
St. James	91	68	46	25	6	Nov. 22	Mar. 27
Sandy Lake	130	115	99	62	15	Nov. 19	Apr. 12
Sioux Falls, SD	81	56	29	9	3	Nov. 22	Mar. 24
Spring Grove	102	79	57	20	0	Nov. 23	Apr. 2
Thorhult	140	126	100	55	11	Nov. 7	Apr. 14
Wadena	113	103	76	34	4	Nov. 11	Apr. 11
Warroad	133	120	98	63	10	Nov. 13	Apr. 13
Willmar	103	81	57	29	4	Nov. 24	Mar. 30
Winnie Dam	138	128	112	68	14	Nov. 9	Apr. 12
Winona	89	65	43	20	3	Nov. 22	Mar. 26
Worthington	96	72	37	12	2	Nov. 10	Apr. 3
Zumbrota	95	76	54	23	2	Nov. 24	Mar. 27

*Estimated values

shown in Table 1. The five depths are 1,3,6,12, and 24-inches. Also shown are the average date of the first occurrence of a measured 1-inch snow depth in the fall or early winter and the last date of a 1-inch snow depth in the spring or late winter at each station.

Gunflint Trail, Gunflint, and Crane Lake in the extreme northeast have the longest snow cover season with 175, 151, and 150 days, respectively (Table 1). Albert Lea and Lamberton generally have the shortest seasonal snow cover with 81 and 83 days, respectively. Sioux Falls, South Dakota, also has only 81 days.

In the fall, Crane Lake has the earliest mean date with 1 inch of snow on the ground by October 30. The latest mean date occurs at Albert Lea on December 1. In the spring, the earliest mean date for the disappearance of the 1-inch snow cover is March 25 at Austin. The latest date is April 22 at Caribou.

There is one station to which special attention should be given. It is located along the Gunflint Trail 8 miles northeast of Grand Marais in extreme northeastern Minnesota. This station is important because it is the only one located within the heaviest snow area of the state. Observations of snow depth were made weekly by the Minnesota Department of Natural Resources personnel for the 15-year period 1966-1979 at the Gunflint Trail station. However, no first or last dates of snow cover observations were made at the site. An estimate of the first date of 1-inch snow cover is November 1 and the estimated last date in spring is May 5. These weekly snow depth observations, defined in terms of seasonal snow cover days, show that the Gunflint Trail station has the longest season of snow cover days of any station on the average.

B. SNOW COVER DAYS

The mean duration of snow on the ground averaged over 20 winter seasons from the fall of 1959 through the spring of 1979 is shown in Figures 3-7. These five figures depict the average number of snow cover days for depths of 1,3,6,12, and 24 inches, respectively. The maps do not necessarily represent consecutive days with snow cover for each depth because it is rare that the first snow in the fall remains all winter or that late spring snowfalls do not occur after the over-winter snow has melted.

It has been determined that when there are fewer than about 20 days within the record period for any depth, the median serves as a better predictor than the mean. In such cases the calculated mean numbers of days shows a value that is deceiving because in more than half the years there may be no occurrence of that particular depth. An example can be cited. During the 20-year period at Warroad, a depth of 24 inches or greater occurred in six of the years, a total of 200 days. The calculated average duration for the 24-inch or greater depth is therefore 10 days per year; yet in 14 of the 20 years, or 70 percent of the time, such a depth was not reached at all. Therefore, a more realistic statistic to use is the median as a predictor rather than the mean. Due to the skewed distribution of the data, only the median divides the population into two equal parts.

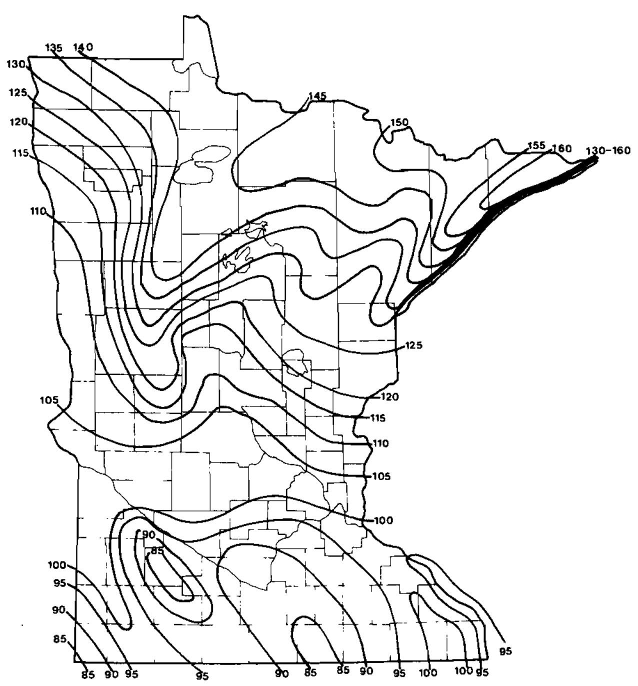

Figure 3. Mean duration of 1-inch or greater snow cover in days, 1959-1979.

Days of 1-inch or greater snow cover: Figure 3 shows iso-lines of mean number of days of 1-inch snow cover for a winter season. There is a considerable length of time in which the entire state is under a 1-inch or more blanket of snow. The range is from less than 85 days in the south and southwest to more than 160 days in the northeast. The five maps of days of snow cover indicate a relationship between snow cover and topography. The closest relationship exists between the map of 1-inch snow cover days, Figure 3, and topography, Figure 1. The most extreme gradient of snow cover days lies along the north shore of Lake Superior. This is caused by the topographic effect of the North Shore ridge. This effect begins early in the winter season when the lake is free of ice and winds are from the east through south. The moist air from the lake is forced over the highlands on the North Shore. This lifting cools the air, causing it to condense and precipitate as snow. The greatest amounts fall about 5 to 7 miles inland (3,5,1).

In the northwestern part of the state the large gradient in the number of days with 1-inch or more snow cover closely parallels the contours from the Red River Valley into the Alexandria Moraine. Another gradient shows up in the southwest. The sharp rise southwestward from the upper Minnesota River Basin is a reflection of Buffalo Ridge on which snow cover persists considerably longer than in the area 30 to 40 miles to the northeast. The upper Minnesota River basin characteristically has little snow cover due to a combination of windy conditions in the open prairie and higher temperatures in the lower levels because of adiabatic heating.[1] The Mesabi Iron Range has the smallest gradient in snow cover days, but the topo-

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[1] Adiabatic heating refers to the warming of air due to the compression of air as it descends.

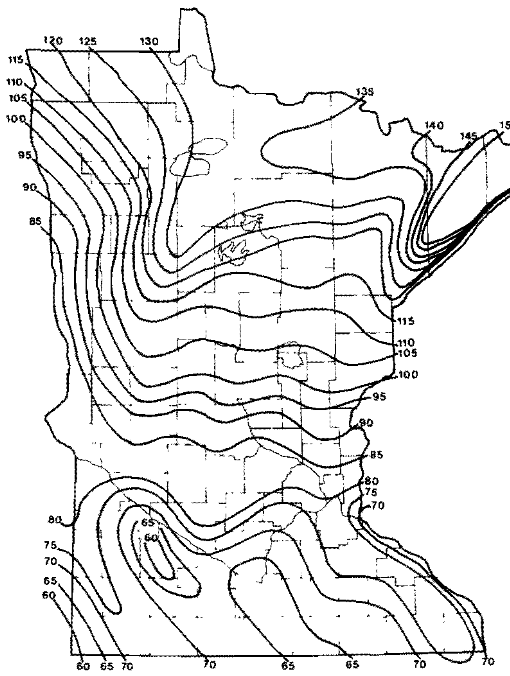

Figure 4. Mean duration of 3-inch or greater snow cover in days, 1959-1979.

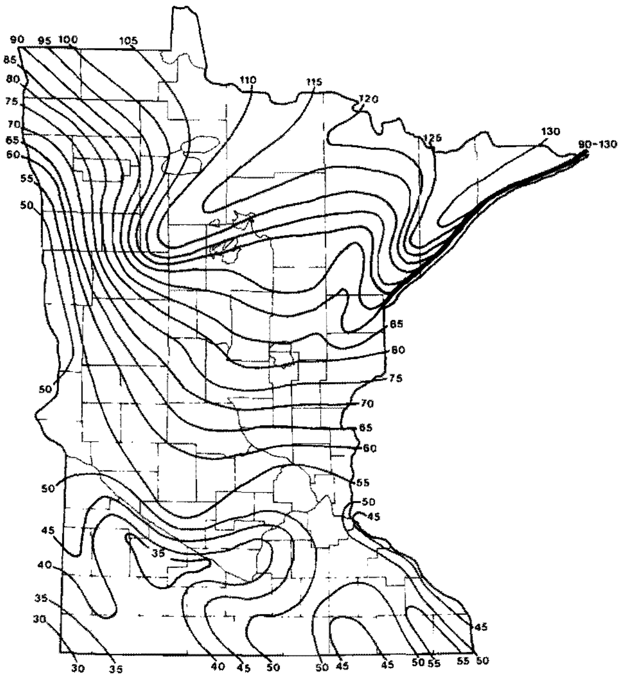

Figure 5. Mean duration of 6-inch or greater snow cover in days, 1959-1979.

graphic effects, particularly to the north of the Range, are evident.

Mean days of 3-inches or greater snow cover: All of the patterns outlined on the 1-inch map (Figure 3) show up here with a change in values only. The 3-inch iso-line map of snow cover days (Figure 4) shows ranges that vary from more than 150 days in the Arrowhead country to 60 days in the southwest. The large area in central and eastern Minnesota where isolines are oriented in an east-west fashion is noteworthy. This is the only area where such a pattern is so well developed. It is also the part of the state which is not affected by significant topographic differences. The pattern that develops in the area represents the overall direct relationship of latitude and snow cover.

Mean days of 6-inches or greater snow cover: The 6-inch isoline map (Figure 5) shows the major patterns still persisting on the ridge lines. The gradient in the northwest has tightened considerably, while the area of less cover in the southwest is expanding. For cross-country skiing and snowmobiling, which requires a cover of 6-inches or more for best results, there is slightly more than one month of 6-inch cover days available in the south, while the entire north from Duluth west to Park Rapids to the northwest corner of the state, has at least 90 days. The northeast has 130 days or four times as many days of 6 inches or more as the southwest.

Mean days of 12 inches or greater snow cover: Figure 6 shows that the patterns remain virtually unchanged with minimum values averaging less than 15 days in the southwest and a maximum of 100 days or more dominating the Arrowhead country in the northeast. The relatively large and varying values which appear in the south-central part of the state are difficult to explain. They could be a reflection of observing sites; those sites where the presence of shrubs, trees, and buildings are subject to greater drifting than those sites that are more exposed to the effects of wind and sun. It must be remembered that the south central and western sites are located in the prairie where frequent strong winds shift the snow around, thus making possible large differences in the observations.

Mean days of 24 inches or greater snow cover: This isoline map (Figure 7) shows significant differences from the previous snow cover maps. The western and the southern third of the state vary from zero to about five snow cover days, while more than 30 days are found in the narrow highland strip along the north shore of Lake Superior.

III. Snow Depth

A. DATE WITH FIRST 1-INCH SNOW DEPTH

The isoline map of the average date of the first 1-inch snow depth on the ground (Figure 8) shows that those dates span the whole month of November, resulting in a gradient which is quite large between the Canadian and the Iowa borders. The snow line moves southward 360 miles in about 30 days, an average of 12 miles per day. Mean dates of the first 1-inch snow depth at Crane Lake and Albert Lea are October 30 and December 1, respectively.

The orientation of the isolines follows a mean storm track for November that is generally oriented from southwest to northeast. As low pressure systems track to the northeast through central Minnesota, cold air dominates the northern and western sectors where precipitation occurs as snow. While in the warmer air,

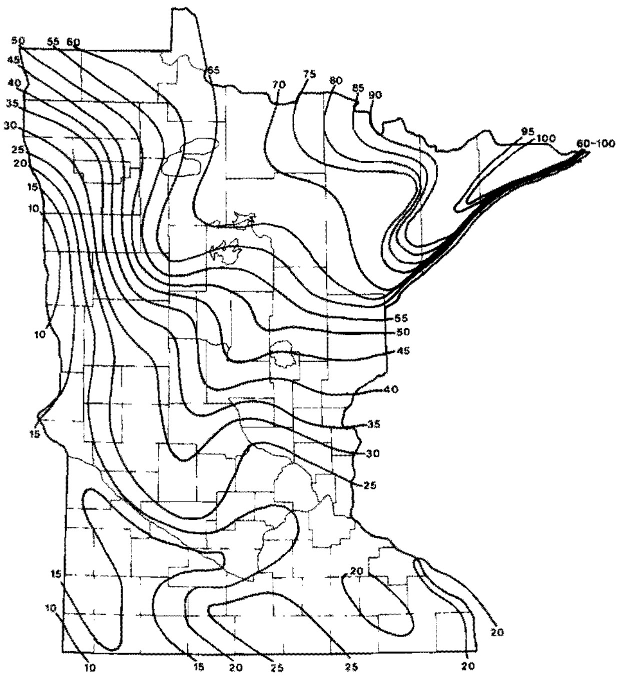

Figure 6. Mean duration of 12-inch or greater snow cover in days, 1959-1979.

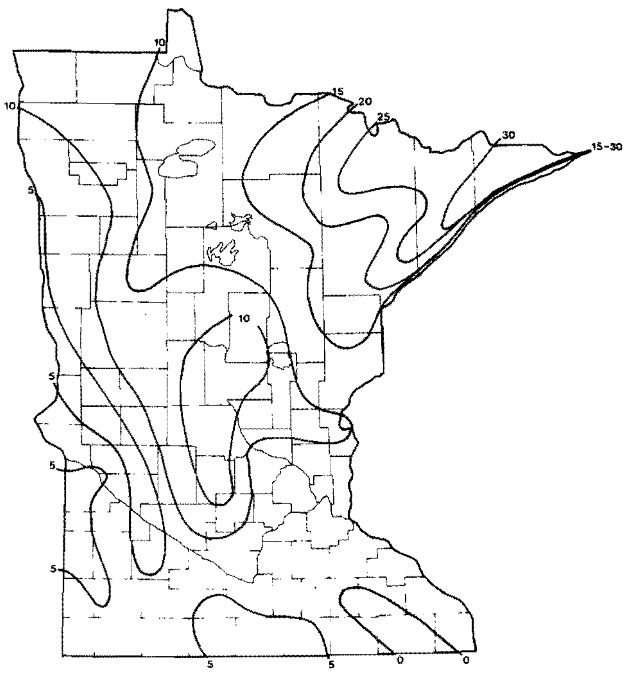

Figure 7. Mean duration of 24-inch or greater snow cover in days, 1959-1979.

which is prevalent in the southern and eastern sectors, most of the precipitation occurs in the form of rain.

The areas in the state which stand out from the general pattern are: northeast, northwest, southwest corners, and an area south of the Iron Range in St. Louis County. The strips with the earlier snowfalls in the northeast, northwest and southwest correspond to the higher elevations of the North Shore Ridge, Alexandria Moraine and Buffalo Ridge, respectively. The area south of the Iron Range, which shows much later dates for snowfall than its surroundings, is not as easily explained, although part of this phenomenon could be topographically induced. The northeast wind, which almost always accompanies significant snowfalls, must first pass over highlands rimming this area to the north and east, thus forcing a descent of the air with its attendant warming and drying as it flows west and southwestward over this area. This effect decreases condensation and precipitation.

B. SNOW DEPTH FOR 10-DAY INTERVALS

The median depth of snow for specific days at 106 stations and 20 seasons for the period, October 1959-May 1979, is shown in Table 2. The specific days of the month tabulated were the 10th, 20th, and the last day of the month (7,8,9). The intervals began on November 10 and ended on April 20. December 25 was included in the table because there is much interest in Christmas-day snow cover.

Median depths are given rather than mean depths because they may be the more suitable statistics, particularly in the fall and spring as noted earlier.

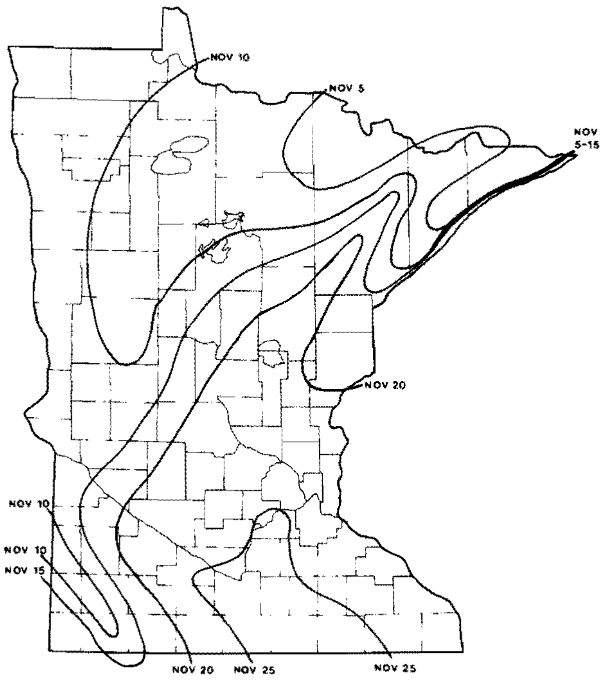

Figure 8. Average date of occurrence of the first 1-inch snow depth, 1959-1979.

Table 2 shows that on November 10 the median snow depth is 1-inch at International Falls. This table also shows that at the latest spring observation period, April 20, Isabella has a median snow depth of 2 inches. However, Gunflint Trail Station located 8 miles northeast of Grand Marais and with only 15 years of data, records a median depth of 7 inches as late as April 30 (not shown in Table 2). Snow cover and depth data received from Gunflint Trail Station and several loca-

Table 2. Median snow depth in inches at 10-day intervals at various locations, October 1959-May 1979.

Station	Nov 10	Nov 20	Nov 30	Dec 10	Dec 20	Dec 25	Dec 31	Jan 10	Jan 20	Jan 31	Feb 10	Feb 20	Feb 28	Mar 10	Mar 20	Mar 31	Apr 10	Apr 20
Ada	0	0	0	4	7	8	8	9	11	11	12	10	10	7	4	0	0	0
Albert Lea	0	0	0	1	3	4	4	6	7	5	6	8	5	5	2	0	0	0
Alexandria	0	0	0	2	3	4	4	7	7	9	9	6	5	7	5	0	0	0
Angus	0	0	2	3	5	5	6	8	8	9	9	10	9	7	3	0	0	0
Artichoke Lake	0	0	0	2	2	2	2	4	7	7	7	5	3	3	2	0	0	0
Austin	0	0	0	1	2	2	4	5	5	5	3	6	4	3	3	0	0	0
Babbitt	0	1	4	6	8	10	11	12	13	15	16	15	17	18	15	10	0	0
Bemidji	0	0	2	4	6	6	8	9	11	14	14	14	13	14	9	4	0	0
Benson	0	0	1	3	3	3	4	5	6	6	6	5	5	4	2	0	0	0
Bird Island-Olivia	0	0	0	3	3	3	4	7	7	7	8	7	8	5	4	0	0	0
Caledonia	0	0	0	1	3	4	5	7	7	6	8	9	5	6	4	0	0	0
Cambridge	0	0	1	5	5	6	6	10	12	14	13	9	9	9	4	0	0	0
Canby	0	0	0	3	3	3	4	4	5	4	6	6	4	4	3	0	0	0
Caribou	0	1	2	5	6	8	9	10	12	13	13	13	14	15	13	7	0	0
Chaska	0	0	0	2	3	2	3	5	7	7	5	6	4	4	1	0	0	0
Cloquet	0	1	3	7	10	10	12	14	16	20	19	19	19	21	20	15	5	0
Cook	0	1	5	6	10	12	12	15	16	18	18	18	17	19	13	7	2	0
Cotton	0	1	3	7	8	9	11	14	14	16	15	15	14	13	13	2	0	0
Crane Lake	0	3	5	7	9	11	12	14	16	18	20	23	21	21	17	12	8	0
Crookston	0	0	1	2	4	5	6	7	7	8	7	6	6	5	3	0	0	0
Dawson	0	0	0	3	2	1	3	4	4	4	4	4	3	2	1	0	0	0
Duluth	0	1	3	7	10	10	12	12	15	17	16	18	17	19	17	9	2	0
Elgin	0	0	0	2	3	3	5	7	7	9	6	8	6	6	4	0	0	0
Fairmont	0	0	0	1	3	3	3	6	4	4	5	5	4	3	3	0	0	0
Fargo, ND	0	0	0	2	3	3	4	6	6	5	5	4	3	2	2	0	0	0
Fairbault	0	0	0	2	2	3	4	6	6	7	7	8	7	5	2	0	0	0
Farmington	0	0	0	2	3	3	4	6	7	7	6	8	7	4	3	0	0	0
Fergus Falls	0	0	0	2	4	4	5	6	7	8	8	8	6	4	2	0	0	0
Forest Lake	0	0	1	3	3	3	5	6	8	8	9	7	5	4	3	0	0	0
Fort Ripley	0	0	2	5	6	7	8	9	12	12	13	12	11	14	8	2	0	0
Fosston	0	0	0	4	6	7	9	10	11	14	14	14	13	13	7	0	0	0
Gaylord	0	0	0	3	4	3	4	5	6	6	5	5	3	4	3	0	0	0
Glenwood	0	0	1	3	4	4	4	6	6	9	9	10	7	6	4	0	0	0
Grand Marais	0	0	1	4	6	7	8	11	11	12	15	19	18	15	13	7	1	0
Grand Meadow	0	0	0	1	2	3	3	6	9	9	5	8	4	8	4	0	0	0
Grand Rapids	0	0	3	6	9	10	11	12	13	14	15	13	15	15	12	4	0	0
Gull Lake Dam	0	0	2	5	6	7	8	10	13	14	12	11	12	12	11	3	0	0
Gunflint	0	4	7	9	10	14	15	18	16	19	19	20	21	21	23	17	13	0
*Gunflint Trail	—	—	11	14	19	23	23	29	30	33	32	34	35	36	36	31	30	17
Hastings Dam	0	0	0	2	3	3	5	7	7	9	9	9	8	6	4	0	0	0
Hibbing	0	1	3	7	9	10	11	14	15	18	18	17	18	17	13	5	1	0
Hinckley	0	0	2	4	6	6	7	10	10	12	13	11	11	9	7	1	0	0
Hoyt Lakes	0	2	3	5	8	9	9	11	11	12	12	13	12	11	6	0	0	0
Hutchinson	0	0	0	3	3	3	4	7	8	8	8	6	5	6	3	0	0	0
International Falls	1	2	4	5	8	11	11	13	14	16	18	18	18	18	14	9	4	0
Isabella	0	3	8	11	13	14	16	17	19	21	23	25	26	26	24	23	16	2
Island Lake	0	1	2	6	9	11	11	12	14	17	13	15	16	18	17	5	2	0
Itasca Park School	0	0	2	5	7	9	10	12	13	15	13	13	15	15	11	9	2	0
Jordan	0	0	0	2	3	2	4	5	6	6	5	7	4	4	2	0	0	0
La Crescent Dam	0	0	0	0	3	4	4	5	4	6	4	4	3	3	1	0	0	0
Lake City	0	0	0	1	1	3	5	6	7	8	8	11	7	8	3	0	0	0
Lake Wilson-Slayton	0	0	0	3	2	3	4	5	5	4	4	3	2	3	1	0	0	0
Lamberton	0	0	0	2	2	3	3	4	5	3	3	3	0	3	0	0	0	0
Lanesboro	0	0	0	1	3	4	5	6	6	6	3	5	3	4	2	0	0	0
Leech Lake	0	0	2	6	8	8	8	12	13	15	17	16	15	16	11	4	0	0
Little Falls	0	0	2	4	6	6	7	10	12	15	14	12	9	11	6	2	0	0
Long Prairie	0	0	1	4	5	6	7	8	11	13	14	11	11	11	8	0	0	0
Luverne	0	0	1	2	3	3	5	8	6	5	5	4	3	3	3	0	0	0
Madison	0	0	0	3	3	2	4	4	6	5	6	3	3	4	1	0	0	0
Maple Plain	0	0	0	3	3	3	4	7	9	10	9	7	7	5	3	0	0	0
Marshall	0	0	0	2	2	3	5	5	6	5	5	4	2	3	0	0	0	0
Meadowlands	0	0	3	7	8	9	10	13	15	12	13	13	13	9	7	1	0	0
Milaca	0	0	1	5	5	5	6	9	8	10	10	9	9	7	3	0	0	0
Milan	0	0	0	4	3	3	3	6	8	7	6	5	4	4	1	0	0	0

Table 2. Median snow depth in inches at 10-day intervals at various locations, October 1959-May 1979.

Station	Nov 10	Nov 20	Nov 30	Dec 10	Dec 20	Dec 25	Dec 31	Jan 10	Jan 20	Jan 31	Feb 10	Feb 20	Feb 28	Mar 10	Mar 20	Mar 31	Apr 10	Apr 20
Mpls.-St. Paul Airport	0	0	0	3	3	3	3	7	8	7	7	8	6	6	3	0	0	0
Minnesota City Dam	0	0	0	1	3	5	5	6	6	6	6	7	4	5	2	0	0	0
Minneota	0	0	0	2	1	2	3	3	4	3	2	4	1	2	1	0	0	0
Moose Lake	0	0	1	5	6	7	8	11	10	14	16	16	17	16	14	3	0	0
Mora	0	0	1	4	6	7	7	9	10	12	14	12	11	8	7	0	0	0
Morris	0	0	1	2	4	3	4	7	7	9	10	9	6	4	2	0	0	0
New Ulm	0	0	0	1	3	2	2	5	5	4	5	5	3	3	0	0	0	0
North Mankato	0	0	0	1	3	3	5	7	7	7	7	7	6	6	2	0	0	0
Oklee	0	0	1	4	5	6	7	9	10	12	12	13	13	12	7	3	0	0
Ottertail	0	0	1	2	5	6	7	10	9	10	8	7	7	7	3	0	0	0
Park Rapids	0	0	2	5	7	8	8	10	12	13	12	13	13	12	8	2	0	0
Pine River Dam	0	0	2	5	6	8	8	11	13	14	14	12	11	14	10	4	0	0
Pipestone	0	0	0	1	1	2	4	4	4	4	6	5	2	2	2	0	0	0
Red Lake Falls	0	1	2	3	7	9	10	12	12	15	15	12	11	10	6	1	0	0
Red Wing City	0	0	0	1	3	3	4	6	7	7	10	10	10	6	3	0	0	0
Redwood Falls	0	0	0	2	2	2	3	3	4	3	4	5	3	4	1	0	0	0
Rochester	0	0	0	2	2	3	3	6	6	5	2	7	5	6	4	0	0	0
Rosemount	0	0	0	2	3	3	4	6	7	7	6	8	7	4	4	0	0	0
St. Cloud	0	0	1	4	3	3	4	6	6	7	8	8	7	6	4	0	0	0
St. James	0	0	0	1	2	2	4	7	5	6	6	3	4	8	1	0	0	0
St. Paul	0	0	1	3	4	4	5	7	6	7	8	9	7	7	4	0	0	0
St. Peter	0	0	0	2	2	2	3	5	7	6	5	7	3	5	2	0	0	0
Sandy Lake Dam	0	1	2	5	8	8	9	13	15	17	16	15	16	15	12	4	0	0
Santiago	0	0	2	5	6	5	7	8	10	12	11	11	11	10	5	0	0	0
Springfield	0	0	0	1	2	2	3	3	3	3	3	3	3	3	0	0	0	0
Spring Grove	0	0	0	2	3	5	5	7	7	7	7	8	6	5	4	0	0	0
Thorhult	0	1	2	5	7	8	9	12	12	14	14	13	14	12	10	6	1	0
Tower	0	1	4	6	8	9	11	13	15	18	21	21	20	20	18	13	3	0
Tyler	0	0	0	1	1	2	4	3	3	3	4	3	1	1	0	0	0	0
Wadena	0	0	2	4	6	7	7	8	11	12	12	11	10	8	5	1	0	0
Walker	0	0	2	4	7	7	8	12	12	14	13	13	13	12	8	4	0	0
Warroad	0	0	2	4	7	8	9	11	13	16	15	15	16	15	12	5	0	0
Wells	0	0	1	3	3	4	4	6	6	6	4	5	4	4	4	0	0	0
Whiteface Reservoir	0	1	4	7	8	9	11	14	15	17	18	17	18	17	16	8	4	0
Willmar Hospital	0	0	0	3	3	3	4	5	7	8	5	5	5	6	5	0	0	0
Winnebago	0	0	0	2	4	4	6	6	5	7	7	9	6	5	4	0	0	0
Winnie Dam	0	1	3	6	9	10	9	12	15	17	17	16	17	19	16	9	0	0
Winona	0	0	0	1	3	4	5	6	6	6	4	4	2	4	1	0	0	0
Winton Power Plant	0	2	5	7	9	11	12	13	14	16	18	18	17	19	20	11	4	0
Worthington	0	0	0	2	2	3	4	6	5	4	5	4	3	2	1	0	0	0
Young America	0	0	0	3	3	3	3	6	7	8	8	7	6	6	2	0	0	0
Zumbrota	0	0	0	3	3	3	4	7	7	8	9	9	5	7	2	0	0	0

*15 years of data, 1966-1979.

tions 5 to 10 miles inland from the Lake Superior north shore during three winter seasons, 1978-79 through 1980-81, indicate that this snow band along Lake Superior is the last area to lose its snow cover. This loss of snow cover takes place about 10 days after stations which are located farther inland and about 20 days after stations located along the immediate shore line. From Table 2 several items of immediate interest can be noted:.

1. The earliest median date of 6 inches is November 30, at three stations in the northeast: Isabella, Gunflint, and Gunflint Trail Station.
2. The earliest median date of 18 inches of snow cover occurs on January 10 at Gunflint. However, if the Gunflint Trail station data were used, it would be December 20.
3. There are four stations in southwestern Minnesota that show a median snow depth of less than 5 inches for any of the 10-day observation periods during the winter.
4. The greatest depth occurs at many stations on February 20, but for southwestern stations, it occurs generally in January and at northeastern stations in March.

C. SNOW DEPTH LAST OF EACH MONTH

Isoline maps of snow depths analyzed for the end of each winter month are shown in Figures 9-13. The snow depths are median values and represent the 50 percent probability depth at the end of each month.

November 30 isolines of median snow depth (Figure 9) show no snow cover in the southern third of the state and the western counties north to Crookston. The zero isoline can also be interpreted as indicating that in at

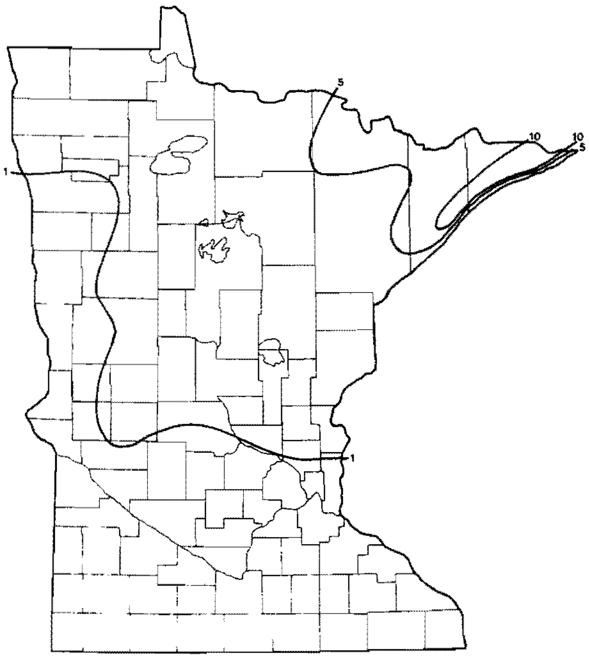

Figure 9. Median snow depth on November 30, for the years 1959-1979.

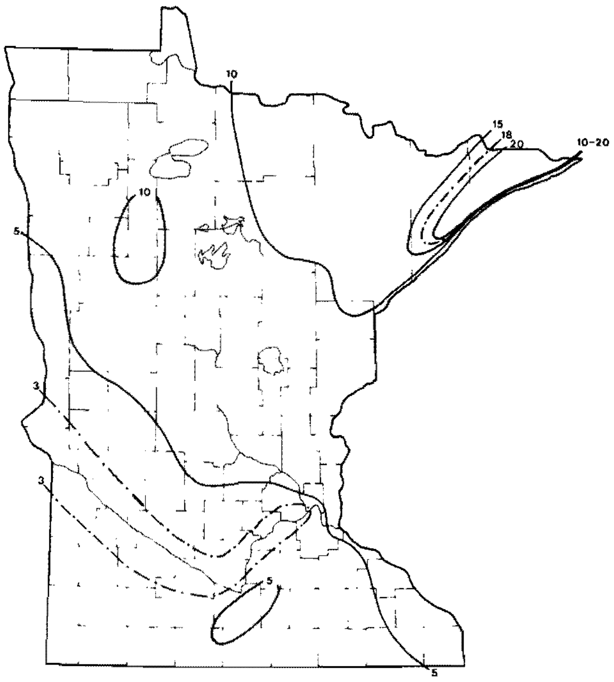

Figure 10. Median snow depth on December 31, for the years 1959-1979.

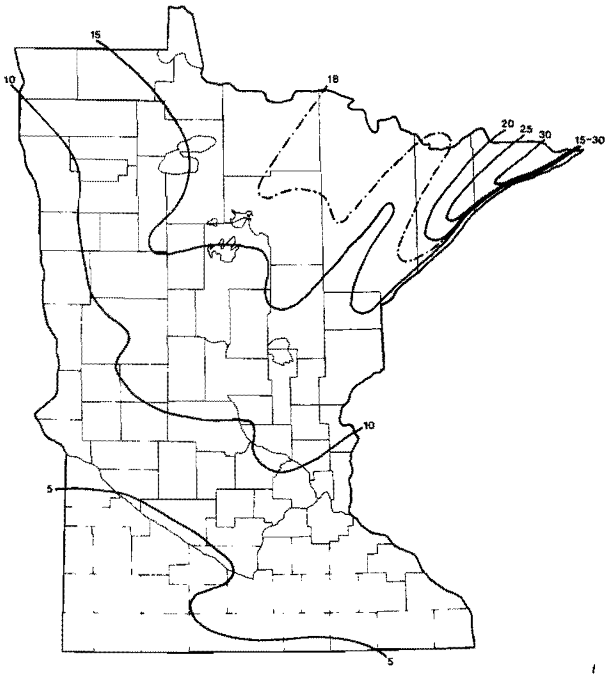

Figure 11. Median snow depth on January 31, for the years 1959-1979.

least 50 percent of the years there will be no measurable snow depth on November 30 in areas to the south and west of this line.

Snow depth medians vary from 5 to 10 inches in the northeast to more than 10 inches in a narrow strip along the north shore of Lake Superior. The increased snow depth in this narrow strip is a result of snow showers originating over Lake Superior. Air crossing the open lake absorbs moisture, which may be precipitated as snow when the moist air from a southerly or easterly trajectory rises over the North Shore highlands [3].

December 31 isolines of snow depth medians (Figure 10) show a similar pattern to that of November 30, but the depths have increased about 5 inches. Exceptions are the narrow strip along the north shore which now has increased to 20-inch depths, while the higher elevations around Itasca State Park have increased to 10-inch depths. Another interesting feature on the map is a 30-mile wide band with a snow depth of 3 inches or less extending on both sides of the Minnesota River Valley from Ortonville to the Twin Cities. It is difficult to explain this, though it is probably due in part to the low elevations within the river valley and strong winds shifting the snow after it has fallen. The river valley and the immediate areas are warmed by downslope adiabatic heating, particularly in the upper Minnesota River Valley, where southwest flow off Buffalo Ridge descends into the Minnesota River Valley 1,000 to 1,200 feet below. This descent and associated compression of the air is capable of warming the air about 5 to 6°F. Northwest winds have a funneling effect between Buffalo Ridge and Alexandria Moraine causing increased surface winds along the upper Minnesota River Valley. Evidence of the strong northwest flow between these ridge lines is shown by the cold temperatures that occur in southern and southeastern Minnesota and northern or northeastern Iowa after strong, cold Polar air mass outbreaks. In addition, a cursory study of maximum wind gusts during strong outbreaks of Polar air masses shows the higher velocities to be in the center of the Minnesota Valley rather than in areas outside of the valley.

January 31 isolines of snow depth medians (Figure 11) vary from a 5-inch depth in the southwest to as much as a 30-inch depth in the northeast. Three areas

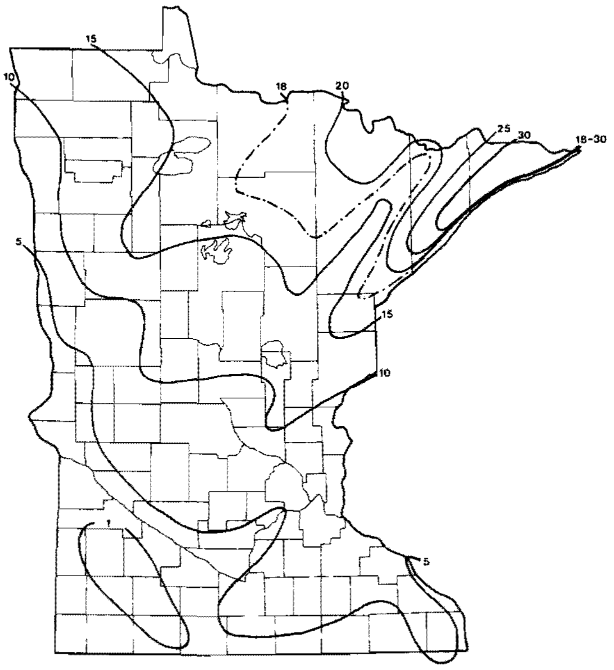

Figure 12. Median snow depth on February 28, for the years 1959-1979.

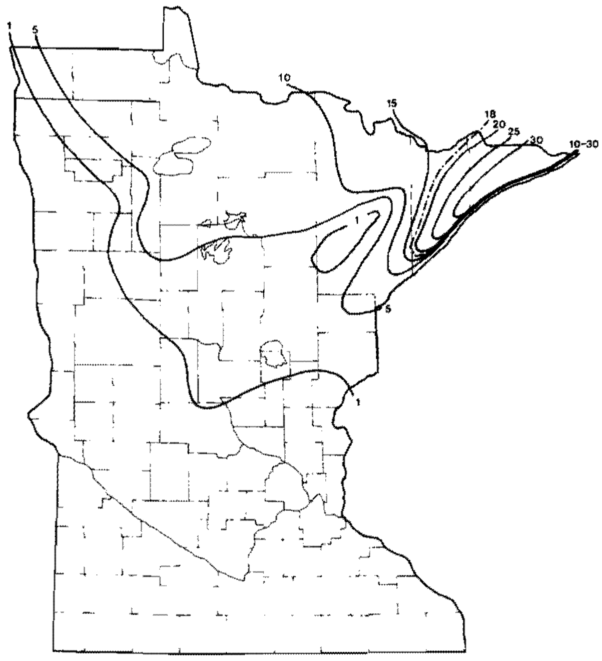

Figure 13. Median snow depth on March 31, for the years 1959-1979.

are noteworthy: first, the narrow strip along the North Shore that now shows more than 30-inch snow depths; second, a strip with decreased snow depths from southwest St. Louis County extending northeast to Babbitt between the Mesabi Iron Range and the North Shore Ridge; and third an 18-inch snow depth that now extends from Cook and Lake counties across northern St. Louis County into east central Koochiching County.

February 28 isolines of snow depth medians shown in Figure 12 vary from about 2-inch depths in the southwest to more than 30 inches in northeast. Basically there is little change from the January 31 map, except for the small increase in the northeast and a decrease to less than 2 inches in a small area to the northeast of Buffalo Ridge. Also the 18-inch area in Koochiching County has now expanded into most of northeastern Itasca County. As a rough rule, 20 percent of the snow depth measured on February 28 represents the inches of water in the snow.

March 31 isolines of snow depth (Figure 13) show a marked decrease of 10 inches or even to no-snow cover from February 28. This holds except in the extreme northeast where very little loss is indicated. The agricultural areas in both the western and the southern half of Minnesota have now lost all of their snow cover.

A very interesting meteorological phenomena has occurred over winter within the narrow strip along the North Shore Ridge, and particularly in Cook and Lake counties, which should be noted. During November, December, and January, the snow depths increased about 10 inches each month to a total of approximately 30-35 inches, compared to a 5-inch per month increase for the rest of the state. However, during February and March very little additional snow was added to this strip. Since snow showers originating primarily from moist air off of Lake Superior are the cause of this band of deeper snow, a question can be raised as to why there is an abrupt end to the snow showers at the end of January. The answer is that the snow showers abate as the western part of Lake Superior freezes over around this time almost every year. The ice breaks up on Lake Superior generally in April and by that time air temperatures are equal to or above the lake surface temperature which deters the formation of snow showers. By the end of April the snow depth medians are at zero across the entire state except for the narrow strip in the northeast along Lake Superior. Because of the longer duration and greater depth of snow and the effect these have upon forest fires, this area is sometimes referred to as the "asbestos belt" (3).

D. DATE OF LAST 1-INCH SNOW DEPTH

The average last date of 1 inch of snow on the ground is approximately March 25 along the Iowa border and April 30 in the extreme northeast (Figure 14). In almost all cases the dates shown in Figure 14 do not equal the last date of the presence of a continuous over-winter snow cover. The map is actually more indicative of the average date of the last occurrence of a 1-inch or greater snowfall in the spring. This is because the snow which accumulated during the winter ordinarily melts and completely disappears in most years before the snowfall season had ended. Some measurable snowfalls still occur after the over-winter snow cover has gone.

Because the ridge lines are colder than surrounding areas they also have the latest snow cover, thus the isolines delineate all of the ridge lines and higher elevations. Again the North Shore Ridge is well defined, with the snow remaining there until April 30.

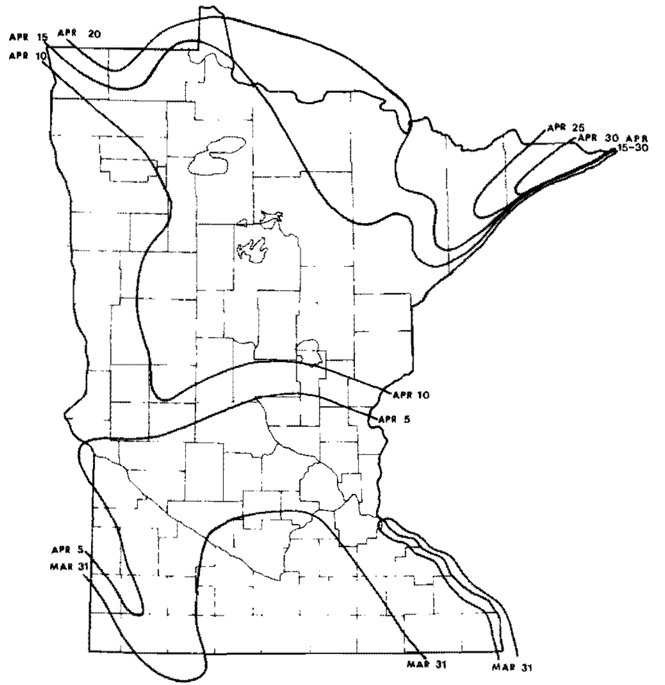

Figure 14. Average date of occurrence of the last 1-inch snow depth, 1959-1979.

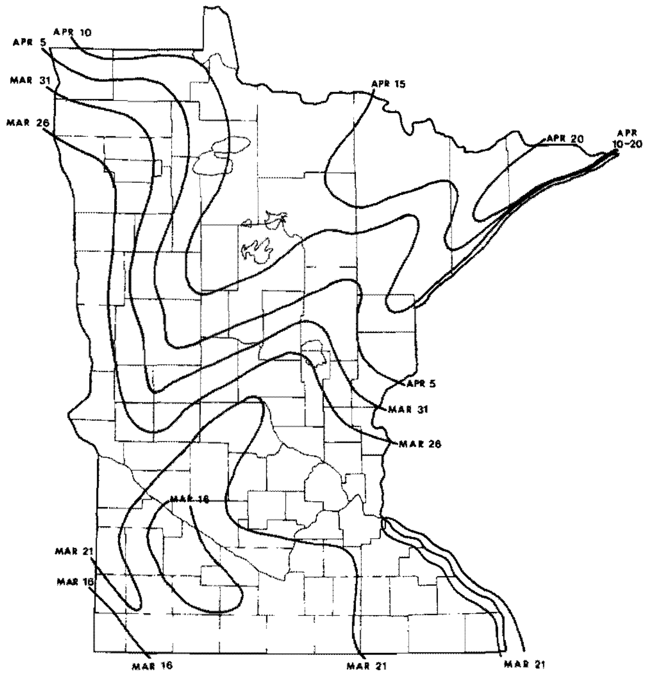

Figure 15. Average date of occurrence of the last 3-inch snow depth, 1959-1979.

E. DATE OF LAST 3-INCH SNOW DEPTH

Isolines of the average date of the last 3-inch snow depth, (Figure 15) are oriented northwest-southeast. The areas which are free of snow first are in the extreme southwest and in the upper Minnesota River Basin between the Minnesota River and Buffalo Ridge. This area is favored for losing snow cover rapidly because snowfall here is usually accompanied by strong winds, which tend to drift the snow, thus allowing little accumulation over large open areas. This in turn favors a faster removal of snow, except in the isolated drifts, due to increased absorption of available solar radiation. This area is also relatively low in elevation, so with wind flow from the southwest off the Buffalo Ridge there is an increase in temperature due to adiabatic warming. The general orientation of the isolines reflects the presence of forested areas to the north and northeast, which decrease the amount of solar energy reaching the snow surface, as well as the increasing latitude that is indicative of lower sun angles, shorter days, and lower mean temperatures.

Several attempts were made to determine the date of the "winter snow melt," defined as the time when the over-winter snow cover has completely disappeared. It should be noted that this date is not the time of the last snow cover, since in most years late winter or early spring snowfalls do occur at least once after this date. The determination of the date is very subjective because in years with little snow cover, it is difficult to determine the exact date of melt of the winter snow cover. This is particularly true for the prairie regions where many seasons have had no snow cover for much of the winter, but end with late winter or early spring snows. However, it was found that the average date of the last day with a 3-inch snow cover is a reasonable approximation of the "winter snow melt." The "winter snow melt" date is important because in Minnesota it has been found to affect many seasonal operations and, indeed may be used as a predictor for the arrival of spring. For example, the last day of snow cover in Minnesota is in effect the first day of the spring grassland and forest fire season. In the interval between the disappearance of the snow cover and the greening of the vegetation, there is a peak in the frequency of grass, brush, and forest fires. In fact, statistics show that each day earlier or later than the mean disappearance date of winter snow cover is equivalent to 20 fires more and 20 fires less, respectively. In addition the last day of the winter snow cover is related to the date when soils have completely thawed and when the lake ice has melted. These last two dates in turn approximate the date field work can be started in the spring. That is, by the time the soil profile has completely thawed, the topsoil is at a temperature where it can be worked and small grains seeded if the soil is dry enough.

F. SNOW DEPTHS DURING WINTER AT SELECTED STATIONS

Figures 16, 17, and 18 depict median snow depths at selected stations for 20-seasons, 1959-1960 through 1978-1979, in the western, central, and eastern thirds of Minnesota.

The west (Figure 16), which is essentially treeless except in the far north, shows relatively little increase in snow cover from south to north thorughout the entire 350 miles length of the state until reaching the far northwest around Caribou on the Canadian border. Here the increase can be attributed to an increase in forested areas as well as the higher latitude.

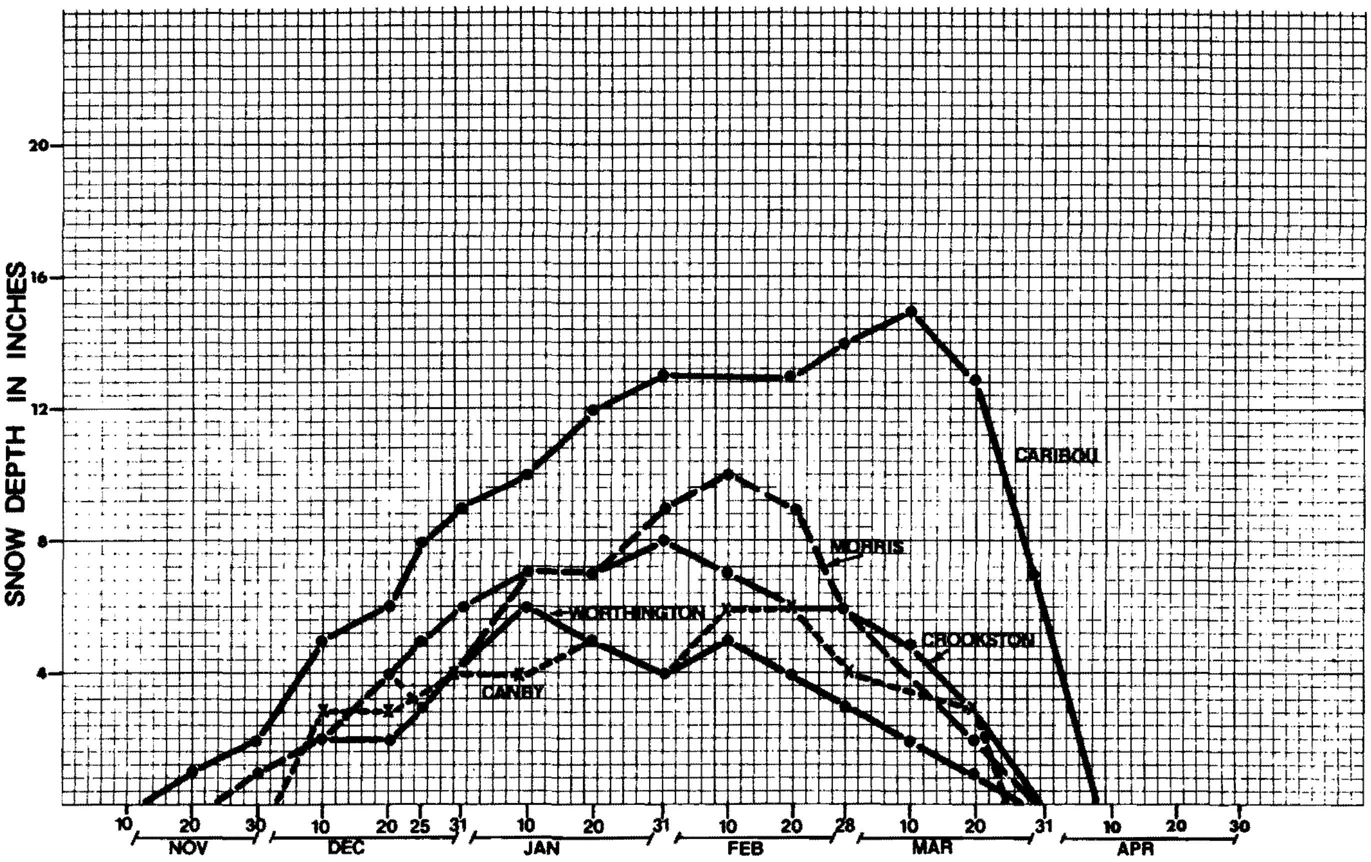

Figure 16. Median snow depths for five selected stations in western Minnesota, 1959-1979.

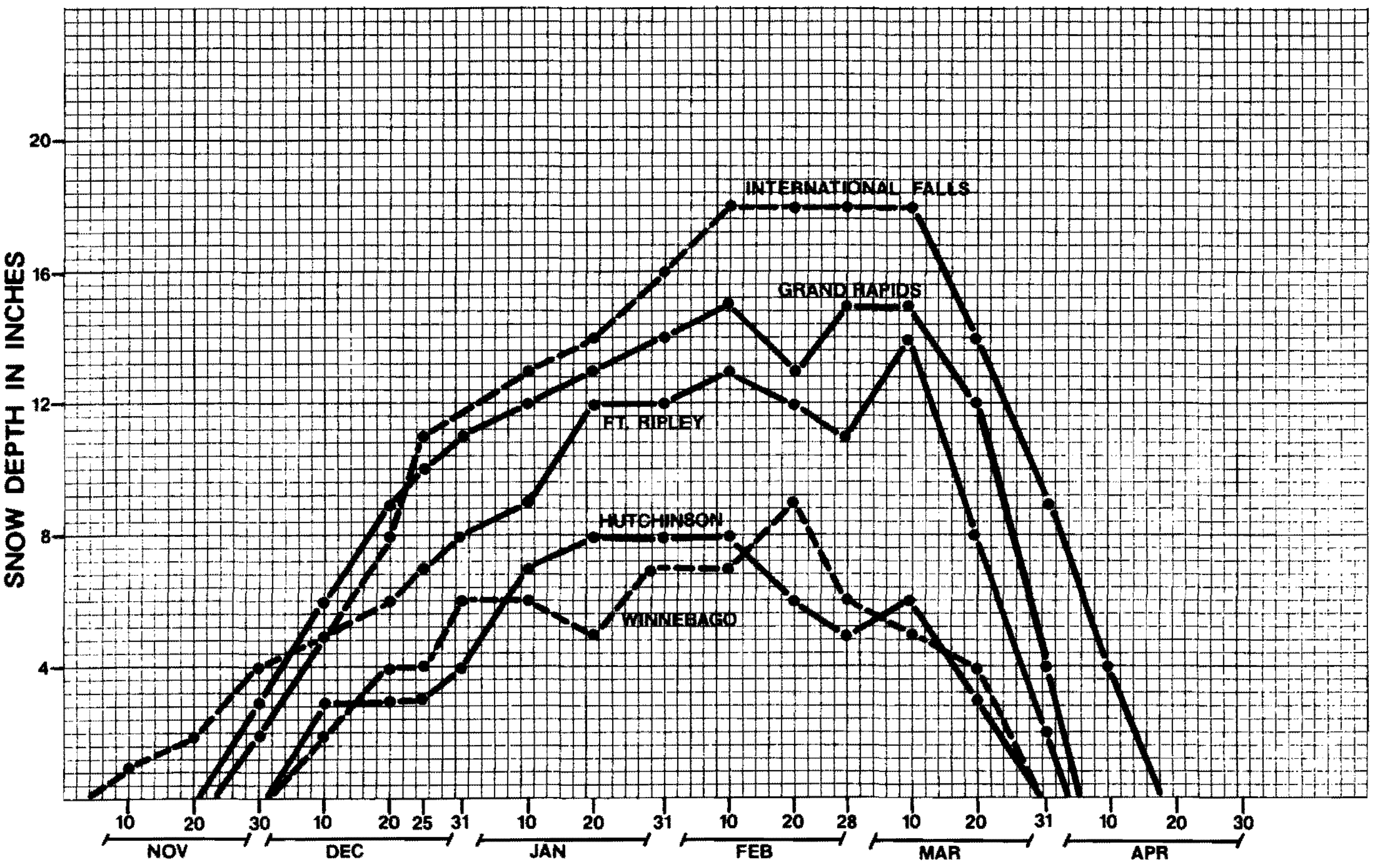

Figure 17. Median snow depths for five selected stations in central Minnesota, 1959-1979.

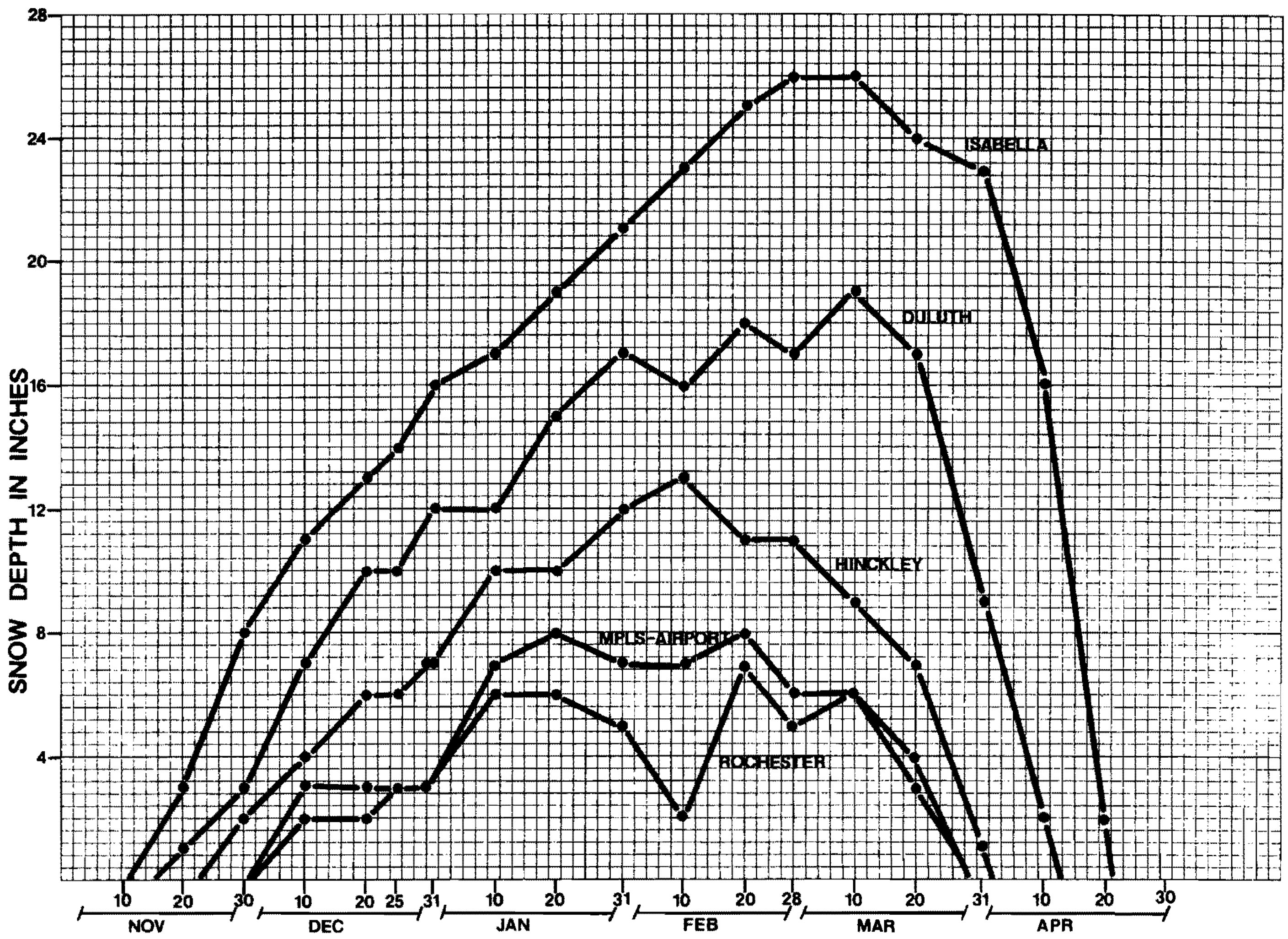

Figure 18. Median snow depths for five selected stations in eastern Minnesota, 1959-1979.

This is in contrast to the eastern two-thirds of the state (Figures 17 and 18), which show progressive increases in snow cover with increasing latitude. This is a reflection in large part of the increasing area of forest which serves to trap and protect snow. Note the rapid increase in snow depth between the farm land areas of Winnebago-Hutchinson into the forested area of Fort Ripley and then the progressive increase into the forested north. The same is true from Minneapolis-St. Paul to Hinckley and north. The tree cover allows snow to persist and accumulate over much longer periods than in open areas where the wind and sun continually act to reduce it. Another important fact is that the eastern portion of the state receives greater amounts of Gulf of Mexico moisture than the western part. Thus, what is shown in Figure 18 is evidence not only of persistence of snow but of greater precipitation as well.

On the average, the state experiences greater snowfall amounts from winter storms in November and early December than in January and February. The stations that have November snowcover all show rapid increases in the latter half of the month and into early December, only to level off somewhat in late December and mid-winter when storminess and moisture availability tend to decrease as the major storm tracks are now south of the state. The proverbial "January thaw" (or simply a settling or aging of the snow) is most evident at the southern stations—Worthington, Winnebago, Rochester, Canby, and the Twin Cities, while the reduction of snow depth tends to be absent in central and northern Minnesota.

Every station except Crookston shows an increase in snow cover sometime during the month of February. The March snowfall amounts are greater than for February. This is evidenced by either no change or an increase in snow depths through March 10 at the southeastern, central, and northern stations. The main reason for the increase before March 10 is that storms now yield more snow due to increased moisture from the Gulf which adds to the snow depth. After March 10 longer days with increasing radiation from the higher sun tend to condense and reduce the depth of the winter snow pack (a process known as "aging") faster than the snowfalls add to it. The aging process of the snow appears to occur prior to March 10 in the southern and western parts of the state. The early peak in snow depth at the Hinckley station on February 10 cannot be explained, as Hinckley is the only northern station to show a maximum snow depth occurring this early.

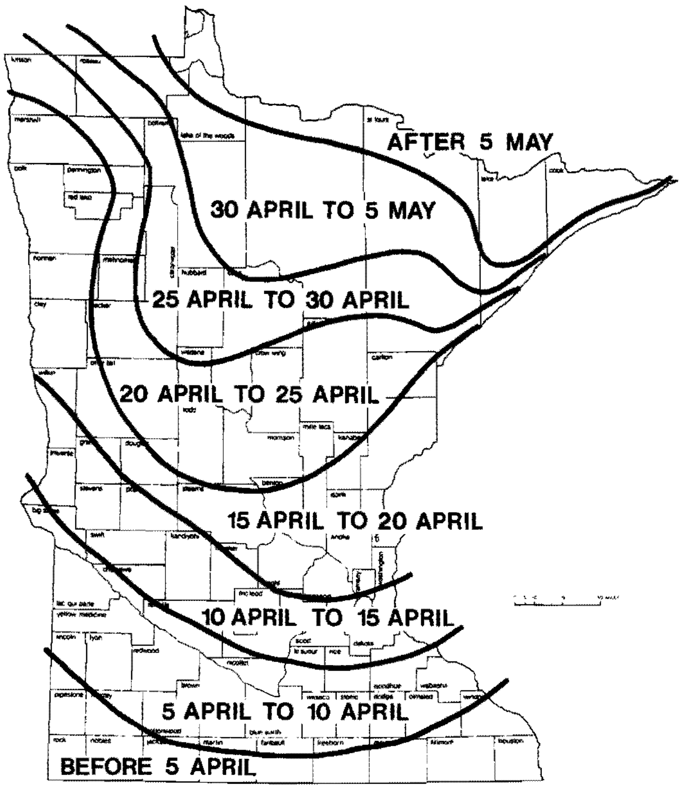

Figure 19. Mean lake ice-out date, 1960-1979.

IV. Ice-Out

A. ICE-OUT DATES OF LAKES

The end of freezing atmospheric conditions in the spring results in dramatic changes at the earth's surface. Warmer air temperatures together with the increasing length of day and the attendant increase in available solar energy, eventually eliminate the snow cover. Once that stage is reached, soils and lake ice surface no longer have the insulative cover that snow provides. Thus snow-end date, ice-out day, and end of frozen soil have an expected correlation. However, the exact juxtaposition of these events in time, along with other factors such as total winter snow and soil moisture amounts, can produce widely varying consequences for residents of Minnesota. This complex of events has impact on spring runoff and lake recharge as well as on soil and surface moisture and temperature conditions as related to agriculture and forestry. An iso-line map of "mean lake ice-out date" for a 20-year period, 1960-1979, is shown in Figure 19. The "ice-out date" was collected from 19 lakes generally with depths greater than 20 feet. These 19 lakes are distributed across the state and listed in Table 3. Lake ice-out data were in the most part collected by the Department of Natural Resources fisheries staff and field personnel and in general procured from reports in local newspapers. The observation of the "ice-out date" is subject to some error, probably of a day or so, due to the various methods of observing ice-out. For example, some observers wait until all of the ice has disappeared, others look for no ice between two pre-selected points of land, and some use a percentage of the ice melted, such as 90 percent, as the criterion.

Table 3. Mean ice-out dates at selected lakes, 1959-1979.

Lake	County	Mean Ice-Out Date
Big Stone Lake	Big Stone	10 April
Clear Lake	Waseca	8 April
Crane Lake	St. Louis	*5 May
Detroit Lake	Becker	24 April
Gull Lake	Cass-Crow Wing	23 April
Gunflint Lake	Cook	9 May
Leech Lake	Cass	29 April
Mille Lacs Lake	Mille Lacs	*25 April
Lake Minnetonka	Hennepin	15 April
Lake of the Woods	Lake of the Woods	*9 May
Lake Minnewaska	Pope	15 April
Lake Osakis	Todd-Douglas	22 April
Ox Lake (big)	Crow Wing	23 April
Shetek	Murray	8 April
Sandy Lake	Aitkin	21 April
Sissaton	Martin	5 April
Vermilion	St. Louis	2 May
Waconia	Carver	14 April
White Bear	Ramsey	16 April

*Estimated by local residents when less than 20 years of data were available.

The mean ice-out date of lakes moves progressively northward. Beginning on April 15 it is in the Twin Cities area and by May 5 it has moved into Canada. From this it can be calculated that "spring" moves northward from the Twin Cities at a rate of about 13 to 14 miles per day.

The movement of "spring" may also be monitored by examining the progression of isotherms northward. The mean daily air temperature on the mean date of ice-out for the Minneapolis-St. Paul area is 45°F. This mean 45°F isotherm can be found in Springfield, Missouri, on March 22 and in International Falls on May 2, which is close in time to the ice-out date there. Thus "spring" moves northward from Springfield to Minneapolis-St. Paul at a rate of 22 miles per day (525 miles in 24 days) and then northward from Minneapolis-St. Paul at a rate of about 16 miles per day (266 miles in 17 days). The decrease in the northward rate of movement of the 45°F air temperature line from Missouri to the Canadian border is most probably due to the additional energy needed to melt the heavier snow cover in the forested area of central and northern Minnesota.

Five lakes—Minnetonka, Minnewaska, Osakis, Detroit and Vermillion—all with more than 70 years of ice-out information, show 1950 as the year with latest ice-out date and 1965 as the next latest. The years with the earliest ice-out dates were 1910, 1945, and 1981. However, old Fort Snelling temperature records dating back to 1819 show the winter of 1877-1878 as the warmest to date. The 1878 newspapers of that spring recorded Lake Minnetonka ice-out on March 11. The average range in dates between the earliest and latest ice-out date is approximately 40 days. The southern Minnesota lakes do not follow these ice-out patterns as well because the lakes are small and shallow, the area is

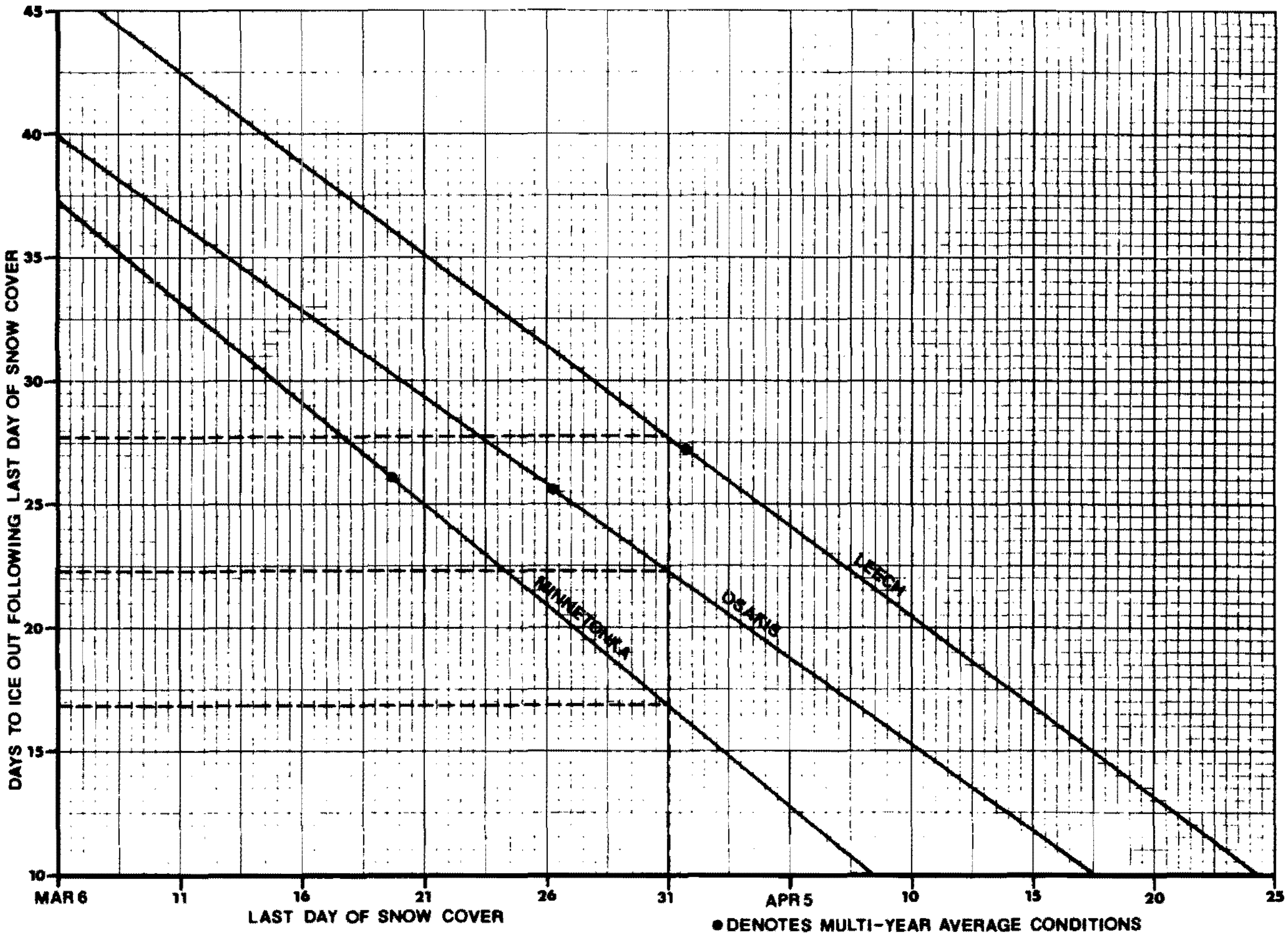

Figure 20. Lake ice-out for three lakes (Leech, Minnewaska, and Minnetonka) compared to the last day of snow cover, 1960-1979.

subject to more southerly warm air advection, and the area has less snow cover. All of these factors permit the absorption of more radiative and sensible heat energy than where there is a heavier snow cover to the north.

B. LAST DAY OF SNOW COVER COMPARED TO LAKE ICE-OUT DATE

The relationship of the date when all ice has melted (ice-out) on three lakes compared to the last day of winter snow cover at nearby locations is shown in Figure 20[2]. The method of determination of the date of ice-out has been previously defined. The last day of snow cover was derived from data collected at the snow depth observation station closest to each of the three lakes. The derived date is when the accumulated "winter snows" have melted to less than a 1-inch snow depth. Snow may occur after this date, but it generally melts quickly and does not represent the persistent snow cover of the winter season.

The three lakes studied were, from south to north, Minnetonka, Osakis, and Leech, and their mean ice-out dates are April 15, 21, and 28, respectively, for the period 1941 through 1980. The three corresponding weather stations which have snow depth data were from south to north, Maple Plain, Long Prairie, and Leech Lake Dam. The mean dates of the last day of winter snow cover for the period 1941 through 1980 at these weather stations were March 20, 26, and April 1, respectively. The lines shown in Figure 20 are intended to serve as guides or estimates of the number of days that lake ice goes out following the last day of snow cover. For best results, the curves can be applied along with the long range National Weather Service (NWS) 30-day temperature outlooks. For example, for each degree Fahrenheit the temperature is forecasted below normal add one day to the lake ice-out date and each degree above normal subtract one day. These are approximate and forecasts should be used accordingly. It is important to remember that these estimates are for the deeper lakes, while the

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[2] The modelled linear relationships were formed by minimizing the squared differences of the actual observations of both variables from the fitted line. This method of finding estimates for the true relationship was chosen over the usual approach of minimizing the squared differences of just the dependent variable from the fitted line, because that type of fit seemed to be very sensitive to possible outlying (non-representative) observations. Further, the usual model for fitting one variable to another assumes that only the dependent variable (ice-out date) has a random (unknown) component; thus only those differences from the fit are usually minimized. In this situation, no physical reason is apparent which would indicate that the snow-end date would be completely representative (no random component) of the current climate situation which would eventually cause lake-ice to go out. Thus the resulting curves were formed on the basis of their association rather than an implied causal relationship.

ice melts in the small and shallow lakes as a general rule about one week earlier than deeper lakes in the same area. For example, if the last day of winter snow cover for each of the three sites occurred on March 31, Figure 20 shows the ice to go out at Minnetonka, Osakis, and Leech Lakes April 17, 22, and 28, respectively. From the curves for a given date of the local end of snow cover, Osakis ice-out can be expected five to seven days sooner than a Leech Lake ice-out. Similarly, Minnetonka ice-out would be expected in three to six days less time than the time required for Osakis. Thus, the time to ice-out following the last day of snow cover increases roughly with latitude. Thicker ice cover to the north, corresponding to lower mean winter temperatures along with the decrease in solar radiation amounts at higher latitudes, could explain much of the delay.

IV. Farmington Data

The Farmington National Weather Service Cooperative Weather Station, located on a farmstead three miles northwest of Farmington, has the longest and most complete chronological weather and snow history in Minnesota (10). The site is unique in that there is not another weather station in Minnesota that has 92 years of snow depth and 85 years of snow duration data from the same site with essentially no change in the local environment. The value of the Farmington records rests with the combination of its longevity and the uniformity of the physical environment at the observing site. To add to the uniformity of the data, there have been only three observers, all from the Akin family: D.F. Akin 1888-1909, E.D. Akin 1909-1919, and Jerome Akin 1919 to date, with the father in each case passing the observing function on to the son.

Snow depth observations at Farmington from 1888 to 1896 were entered on the old U.S. Army Signal Service—U.S. Weather Bureau forms which required observations only two times a month, the 15th and the last day. Beginning in April, 1896, a new U.S. Weather Bureau form required daily snow depth observations and this practice continues today (10).

A. SNOW COVER BY SEASON, 1896-1979

Table 4 shows for each month and for each season, the number of snow cover days and the first and last date of 1-inch or greater snow cover. The expected or median seasonal number of snow cover days is 88 at Farmington. The expected date in the fall for the first 1-inch snow cover is November 25 and the last date in the spring is March 29. Those seasons with highest number of snow cover days 1-inch or greater were 1950-1951, 1896-1897, and 1898-1899 with 142, 139, and 135 days, respectively. The seasons with the lowest number of days were 1960-1961, 1967-1968, and 1980-1981 with 21, 27, and 29 days, respectively. The two earliest dates for a 1-inch snow cover to occur were September 26, 1942, and October 13, 1959, and the latest dates were April 30, 1908, and April 29, 1906. Remember, this is not snowfall but snow cover measured on the ground at the time the daily observation is made. A snowfall may have melted before the observations were taken.

B. SNOW DEPTH BY 10-DAY INTERVALS, 1888-1979

Table 5 shows snow depth on the 10th, 20th and the last day of each month for each season from October through April. The 10-day interval with the deepest average snow depth is between January 31 and February 10 with a mean of 8 inches. The deepest snow depth recorded in the 92 years was 34 inches on February 28, 1929.[3] The December through February periods with the deepest snow cover occurred in 1919-1920 and 1978-1979 with an average of 15.1 and 14.7 inches, respectively. There were several December-February periods with very little snow cover. Those considered to be the most "open winters" were 1943-1944 and 1960-1961.

C. PERCENT FREQUENCY OF SNOW DEPTHS DURING THE WINTER AT FARMINGTON

Figure 21 shows for nine different snow depths (1, 2, 3, 4, 5, 6, 8, 10, and 12 inches) the percent frequency of their occurrence based on 84 years of record. These curves have been smoothed for planning purposes. The highest frequency observed for a 1-inch or greater snow depth is 90 percent near the end of January, while the highest for a 12-inch or greater snow depth is 35 percent about mid-February. An interesting feature noted in Figure 21 is the relatively uniform increase in the curves for the first 90 days of winter, followed by the irregular decrease in the next 40 to 50 days. The irregularity in the curves occurs principally during March and is particularly noticeable in the 4 and 6-inch or greater snow depth probabilities. Figure 22, an expanded graph of percent probabilities for a 4-inch or greater snow depth on the days of March, was prepared in order to facilitate visual examination of these irregular patterns. That graph suggests that the probability alternates every three to four days between periods of slightly increasing or constant tendencies and periods of decrease with time. Figure 22 also shows mean daily temperatures at Minneapolis during March for the period 1891-1973. That snow cover is generally decreasing with the spring rise in temperature is expected. However, fluctuations of snow cover and temperature from their linear trends also appear to be highly correlated. This symmetry in detailed behavior suggests that the fluctuations about smooth tendencies are not merely artifacts of observation. However, the natural variabilities of both snow cover and temperature are so large that the fluctuations of the daily means do not appear to be significantly different from zero by the methods of analysis used.[4]

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[3] Data received after 1979 show a 40-inch snow depth, January 23, 1982.

[4] An approach to testing the significance of the anomalies in a statistical sense involves fitting the March segment of average daily snow depth (not shown) to time with a smooth curve and then testing to see if the differences (residuals) of the actual data from the fitted curve are significant at some probability level. The differences from a linear fit line in this case yielded a very low value for an F-statistic. A few important aspects of these numerical operations need to be considered, however, before assuming no significance for the anomalies. The methods of finding a "best" fit line assumes that the dependent variable (snow cover depth) is normally distributed. In fact, the lowest class interval (zero inches) increases from 29 percent of all years at the beginning of March to 86 percent of all years at the end of March. This 'non-normality,' will also affect the validity of assumptions made (or not made) based on the F-statistic which assumes differences from the fited line that are normally distributed. Conclusions by this method are thus elusive.

Table 4. Observed snow cover days of 1-inch or greater at Farmington, and the first and last occurrence of measured snow cover, 1896-1981.

Year	First date with 1" snow cover	Oct	Nov	Dec	Year	Jan	Feb	Mar	Apr	Seasonal	Last date with 1" snow cover
1896	Oct. 29	2	22	27	1897	31	28	28	1	139	Apr. 12
1897	Nov. 26	0	5	28	1898	0	14	7	1	55	Apr. 18
1898	Nov. 21	0	10	31	1899	31	25	31	7	135	Apr. 8
1899	Dec. 3	0	0	3	1900	12	23	12	0	50	Mar. 26
1900	Nov. 16	0	15	26	1901	28	28	10	0	107	Mar. 21
1901	Dec. 3	0	0	29	1902	11	23	3	0	66	Mar. 3
1902	Nov. 29	0	1	30	1903	31	28	8	0	98	Mar. 23
1903	Nov. 12	0	3	28	1904	31	29	23	2	116	Apr. 14
1904	Dec. 16	0	0	12	1905	30	27	0	0	69	Feb. 27
1905	Oct. 29	3	5	12	1906	30	20	8	0	78	Mar. 15
1906	Nov. 16	0	1	10	1907	31	28	18	3	91	Apr. 29
1907	Dec. 13	0	0	17	1908	31	22	10	3	83	Apr. 27
1908	Nov. 13	0	1	16	1909	30	28	22	3	100	Apr. 30
1909	Nov. 16	0	6	27	1910	31	28	9	1	102	Apr. 17
1910	Dec. 22	0	0	10	1911	31	6	0	2	49	Apr. 2
1911	Nov. 14	0	17	16	1912	31	29	18	0	111	Mar. 22
1912	Dec. 5	0	0	19	1913	18	22	16	1	76	Apr. 9
1913	Jan. 1	0	0	0	1914	15	22	3	0	40	Mar. 8
1914	Dec. 7	0	0	25	1915	20	28	23	0	96	Mar. 23
1915	Nov. 22	0	1	16	1916	31	29	23	0	100	Mar. 23
1916	Oct. 19	2	0	20	1917	31	28	30	0	111	Mar. 30
1917	Oct. 22	1	0	14	1918	31	28	8	0	82	Mar. 15
1918	Nov. 28	0	3	4	1919	25	26	11	2	71	Apr. 16
1919	Nov. 11	0	11	31	1920	31	29	17	2	121	Apr. 6
1920	Nov. 26	0	1	10	1921	19	13	2	0	45	Mar. 9
1921	Nov. 8	0	23	23	1922	31	28	12	2	119	Apr. 12
1922	Dec. 15	0	0	7	1923	29	24	12	3	75	Apr. 14
1923	Dec. 29	0	0	3	1924	31	29	5	3	71	Apr. 3
1924	Nov. 7	0	3	27	1925	31	28	13	0	92	Mar. 13
1925	Nov. 28	0	3	1	1926	15	15	12	3	49	Apr. 6
1926	Nov. 23	0	7	31	1927	31	23	4	0	96	Mar. 23
1927	Nov. 8	0	12	31	1928	19	23	4	9	98	Apr. 17
1928	Dec. 3	0	0	12	1929	25	28	14	5	84	Apr. 12
1929	Dec. 1	0	0	13	1930	20	19	3	0	55	Mar. 3
1930	Nov. 25	0	5	21	1931	0	2	8	0	36	Mar. 27
1931	Dec. 5	0	0	3	1932	31	29	25	0	88	Mar. 25
1932	Dec. 4	0	0	28	1933	14	22	3	0	67	Mar. 25
1933	Dec. 13	0	0	11	1934	19	0	2	0	32	Mar. 31
1934	Nov. 30	0	2	31	1935	31	28	14	1	107	Apr. 4
1935	Nov. 5	0	5	25	1936	31	29	31	9	130	Apr. 9
*1936	Dec. 3	0	0	22	1937	30	28	14	5	99	Apr. 5
*1937	Nov. 18	0	5	17	1938	14	24	12	0	72	Mar. 12
*1938	Dec. 22	0	0	10	1939	31	28	20	2	91	Apr. 18
*1939	Dec. 19	0	0	13	1940	31	29	21	0	87	Mar. 29
*1940	Nov. 12	0	19	31	1941	31	28	23	0	132	Mar. 23
*1941	Dec. 12	0	0	8	1942	12	20	4	0	44	Mar. 21
*1942	Sep. 26	0	3	31	1943	31	28	27	0	120	Mar. 24
*1943	Nov. 6	0	25	3	1944	0	6	13	0	47	Mar. 30
*1944	Nov. 26	0	5	4	1945	31	28	13	2	83	Apr. 5
*1945	Nov. 8	0	6	24	1946	31	28	6	0	95	Mar. 6
*1946	Nov. 10	0	5	14	1947	16	14	0	0	49	Feb. 14
*1947	Nov. 7	0	21	31	1948	31	20	18	0	121	Mar. 18
*1948	Dec. 5	0	0	27	1949	31	28	4	2	92	Apr. 2
*1949	Nov. 24	0	1	2	1950	29	28	20	1	81	Apr. 2
*1950	Nov. 22	0	9	31	1951	31	28	31	12	142	Apr. 12
*1951	Nov. 3	0	20	13	1952	31	29	31	9	133	Apr. 9
*1952	Nov. 25	0	6	31	1953	31	28	21	0	117	Mar. 20
*1953	Dec. 6	0	0	26	1954	17	0	4	0	47	Mar. 15
1954	Nov. 26	0	4	31	1955	31	28	10	0	104	Mar. 10
1955	Nov. 15	0	4	31	1956	31	29	25	0	119	Mar. 30
1956	Nov. 15	0	2	0	1957	6	12	7	4	31	Apr. 7
1957	Nov. 18	0	13	4	1958	6	21	6	0	50	Mar. 6

Table 4. Observed snow cover days of 1-inch or greater at Farmington, and the first and last occurrence of measured snow cover, 1896-1981.

Year	First date with 1" snow cover	Oct	Nov	Dec	Year	Jan	Feb	Mar	Apr	Seasonal	Last date with 1" snow cover
1958	Nov. 23	0	2	9	1959	8	21	1	0	41	Mar. 8
*1959	Oct. 13	1	5	2	1960	30	16	21	0	75	Mar. 26
1960	Feb. 18	0	0	0	1961	0	3	16	2	21	Apr. 17
1961	Dec. 10	0	0	22	1962	31	28	31	3	115	Apr. 15
1962	Nov. 23	0	3	0	1963	21	28	5	0	57	Mar. 21
*1963	Dec. 3	0	0	27	1964	28	0	12	0	67	Mar. 23
1964	Nov. 27	0	4	24	1965	29	27	30	7	121	Apr. 25
1965	Nov. 26	0	4	0	1966	30	19	7	0	60	Mar. 28
1966	Nov. 11	0	4	23	1967	31	28	23	0	109	Mar. 23
1967	Dec. 10	0	0	2	1968	21	2	2	0	27	Feb. 3
1968	Nov. 17	0	3	13	1969	31	28	26	0	101	Mar. 31
*1969	Nov. 14	0	4	25	1970	31	28	24	0	112	Mar. 24
*1970	Nov. 3	0	5	22	1971	31	28	25	1	112	Apr. 1
*1971	Nov. 23	0	8	31	1972	31	29	15	2	116	Apr. 21
1972	Dec. 2	0	0	26	1973	19	28	2	2	77	Apr. 10
1973	Dec. 5	0	0	18	1974	31	28	3	2	82	Apr. 4
1974	Nov. 26	0	1	17	1975	31	28	31	14	122	Apr. 14
1975	Nov. 20	0	10	19	1976	30	8	11	0	78	Mar. 12
1976	Dec. 3	0	0	17	1977	31	9	8	0	65	Mar. 18
1977	Nov. 23	0	8	13	1978	31	28	21	0	101	Mar. 21
1978	Nov. 12	0	14	31	1979	31	28	27	0	131	Mar. 27
1979	Nov. 9	0	13	15	1980	31	29	21	4	113	Apr. 11
1980	Dec. 2	0	0	8	1981	5	16	0	0	29	Feb. 23
Median	Nov. 25	0	3	18	Median	31	28	12	0	88	Mar. 29

*Some data substituted from Chaska, Jordan or Minneapolis-St. Paul Airport.

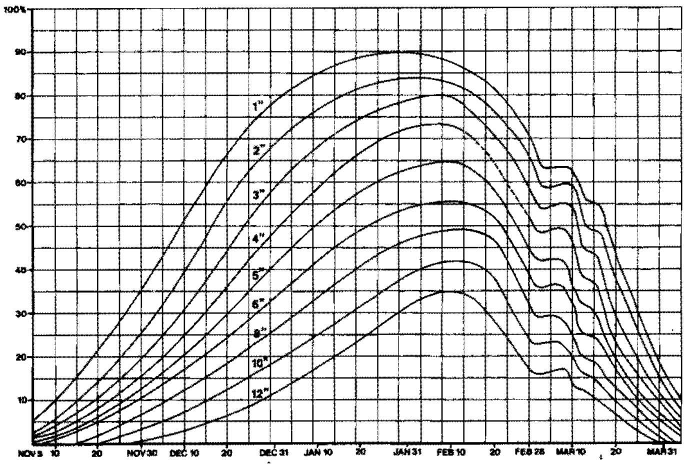

Figure 21. Frequency distribution in percent of snow depths at Farmington, 1888-1981.

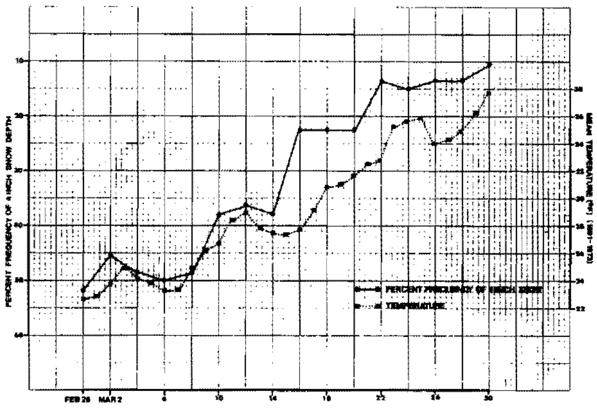

Figure 22. Frequency distributions in percent of 4-inch March snow depths at Farmington, (1897-1936 and 1954-1979) and mean daily temperature, at Minneapolis during March (1891-1973).

VI. Summary

Snow cover onset, depth, and duration vary considerably across Minnesota. Higher elevations in the state, such as the North Shore Ridge, the Alexandria Moraine, the Iron Range and Buffalo Ridge receive and retain more snow than lower elevations. Further, the sloping surfaces of these regions result in rapid changes over small distances. This effect is particularly strong along the north shore of Lake Superior where a large span of open water persists through the early winter as a moisture source.

Days with snow cover vary from an average of about 81 in the south to a 175-day maximum in the extreme northeast. The time of occurrence of the greatest snow depth shows an expected lag from south to north, with a January maximum in the south and a March maximum in the north. A marked east-west alignment of the snow depth and duration isolines occurs in Minnesota. The variations in snow cover features are associated with large scale winter horizontal temperature gradients (generally cold-north and warm-south) and with the gradient of atmospheric "gulf" moisture (generally moist-southeast and dry-northwest). Finally, though not exhaustively, local solar energy availability and its interaction with the local surface strongly affect snow cover duration. A marked difference of this type can be seen between the forest floor of the northeast and the open farmland of the southwest.

The date of ice-out for lakes and its relationship to last day of snow cover represent several meteorological parameters. Though the relationships are not exact, they do provide information in decision making. Further, the ice-out date is closely related to the northward movement of the 45°F isotherm in the spring of the year. The slowing of the northward movement of this isotherm in northern Minnesota points out the additional energy needed to melt the deeper snows there.

The Farmington snow data are used as a substitute for the metropolitan Minneapolis and St. Paul data. They give a chronological account of the winter snow conditions from 1888 to 1981 and may be used to identify anomalous as well as normal local snow cover. Figure 21 provides the probabilities of a given snow depth during the winter. Presentations of these data and their derived forms may be viewed as preliminary rather than exhaustive investigations.

The spatial and temporal variations in snow cover can be used as planning aids to facilitate decisions on a wide variety of human activities, such as skiing, snowmobiling, or other winter recreation activities which are greatly affected by the amount and duration of snow. Agriculture looks to the end of winter as a time for renewed activity. Further the disappearance of snow yields varying and sometimes severe consquences from year to year: The melting of the snow cover is often accompanied by spring flooding; newly exposed dry grasslands, not yet growing, are subject to spring fires; and the opening of lakes triggers seasonal fish spawning activities. Though the nature of a winter's snow cover will have a varying degree of impact from year to year, some tendencies within the climate can be recognized and have been depicted in map and tabular form within this publication. The average and median representations can be used to form a generally acceptable view of snow cover conditions across the state. Extreme condi-

Table 5. Observed snow depth in inches on 10-day intervals at Farmington, 1888-1981.

Year	Oct 10	Oct 20	Oct 31	Nov 10	Nov 20	Nov 30	Dec 10	Dec 20	Dec 25	Dec 31
1888	—	—	0	—	—	0	—	—	—	*
1889	—	—	0	—	—	3	—	—	—	3
1890	—	—	0	—	—	0	—	—	—	0
1891	—	—	0	—	—	6	—	—	—	5
1892	—	—	0	—	—	8	—	—	—	10
1893	—	—	0	—	—	8	—	—	—	10
1894	—	—	0	—	—	0	—	—	—	0
1895	—	—	0	—	—	3	—	—	—	0
1896	—	—	*	—	—	4	—	—	—	0
1897	0	0	0	0	0	6	1	2	2	*
1898	0	0	0	0	0	7	5	4	4	3
1899	0	0	0	0	0	0	0	0	0	*
1900	0	0	0	0	2	2	1	0	2	2
1901	0	0	0	0	0	0	3	5	2	1
1902	0	0	0	0	0	0	5	10	11	11
1903	0	0	0	0	*	0	2	3	3	4
1904	0	0	0	0	0	0	0	1	*	1
1905	0	0	2	0	0	3	*	*	1	*
1906	0	0	0	0	0	0	1	0	0	7
1907	0	0	0	0	*	*	0	1	1	5
1908	0	0	0	0	0	*	*	7	7	3
1909	0	0	0	0	2	0	3	10	11	12
1910	0	0	0	0	0	0	0	0	3	2
1911	0	0	0	0	7	3	*	*	3	16
1912	0	0	0	0	0	0	1	8	8	6
1913	0	0	*	0	0	0	0	0	*	0
1914	0	0	0	0	0	0	1	1	4	5

Year	Jan 10	Jan 20	Jan 31	Feb 10	Feb 20	Feb 28	Mar 10	Mar 20	Mar 31	Apr 10	Apr 20	Apr 30
1889	—	—	4	—	—	4	—	—	0	—	—	0
1890	—	—	10	—	—	8	—	—	4	—	—	0
1891	—	—	12	—	—	18	—	—	0	—	—	0
1892	—	—	0	—	—	2	—	—	0	—	—	0
1893	—	—	16	—	—	30	—	—	6	—	—	0
1894	—	—	14	—	—	10	—	—	0	—	—	0
1895	—	—	17	—	—	0	—	—	0	—	—	0
1896	—	—	0	—	—	0	—	—	2	—	—	0
1897	8	18	19	16	19	22	26	8	0	0	0	0
1898	0	0	0	0	5	0	0	0	1	0	0	0
1899	4	2	5	7	0	8	4	16	12	0	0	0
1900	0	0	*	4	2	1	2	0	0	0	0	0
1901	6	1	3	3	6	3	*	*	0	0	0	0
1902	0	0	4	5	3	1	0	0	0	0	0	0
1903	11	8	6	5	5	3	0	*	0	0	0	0
1904	2	5	7	10	11	7	3	2	0	0	0	0
1905	4	8	9	16	8	*	0	0	0	0	0	0
1906	10	13	4	4	1	0	*	*	0	0	0	0
1907	2	6	9	13	1	7	4	0	0	0	0	0
1908	3	2	9	12	2	0	1	0	0	0	0	0
1909	5	5	4	11	8	15	9	2	*	0	0	1
1910	16	16	18	16	17	16	*	0	0	0	0	0
1911	15	16	1	2	*	*	0	0	0	0	0	0
1912	16	16	22	24	6	4	6	*	0	0	0	0
1913	4	*	1	1	1	5	*	*	0	*	0	0
1914	*	1	1	4	5	*	*	0	0	0	0	0
1915	*	7	9	7	2	2	5	3	*	0	0	0

Table 5. Observed snow depth in inches on 10-day intervals at Farmington, 1888-1981.

Year	Oct 10	Oct 20	Oct 31	Nov 10	Nov 20	Nov 30	Dec 10	Dec 20	Dec 25	Dec 31
1915	0	0	0	0	*	0	0	4	3	3
1916	0	2	0	0	0	0	0	3	5	5
1917	0	*	*	0	0	*	3	*	*	*
1918	0	0	0	0	0	1	*	0	*	3
1919	0	0	0	*	*	8	11	14	10	7
1920	0	0	0	0	0	0	0	0	12	4
1921	0	0	0	4	9	4	3	3	4	3
1922	0	0	0	0	0	0	0	2	0	0
1923	0	0	0	0	0	0	0	0	0	8
1924	0	0	0	*	0	0	11	7	7	9
1925	0	0	0	0	0	6	2	2	5	5
1926	0	0	0	0	0	1	5	5	12	9
1927	0	0	0	*	3	0	15	27	27	11
1928	0	0	0	0	0	0	0	1	0	1
1929	0	0	0	0	*	*	*	3	3	*
1930	0	0	0	0	0	3	*	2	2	2
1931	0	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	*	0	3	7	4	5
1933	0	0	0	0	0	0	0	0	3	4
1934	0	0	0	0	*	0	22	12	14	15
1935	0	0	0	0	0	*	0	0	8	8
1936	0	0	0	0	0	0	10	2	*	*
1937	0	0	0	0	1	0	1	1	1	1
1938	0	0	0	0	0	0	0	*	4	6
1939	0	0	0	0	0	0	0	2	1	1
1940	0	0	0	0	3	7	4	6	5	5
1941	0	0	0	0	0	0	0	*	*	*
1942	0	0	0	0	0	1	1	6	5	7
1943	0	0	0	5	2	1	*	0	0	0
1944	0	0	0	0	0	2	0	*	*	*
1945	0	0	0	0	0	3	*	2	13	14
1946	0	0	0	1	0	*	0	1	0	3
1947	0	0	0	1	3	5	9	9	8	8
1948	0	0	0	0	*	*	1	2	2	2
1949	0	0	0	0	0	0	*	*	*	*
1950	0	0	0	*	0	1	10	6	10	9
1951	0	0	0	*	1	0	*	7	10	7
1952	0	0	0	0	0	8	3	4	5	4
1953	0	0	0	0	0	*	*	2	1	1
1954	0	0	0	0	0	3	3	4	3	3
1955	0	0	0	0	*	*	6	6	3	6
1956	0	0	0	0	0	0	0	0	0	0
1957	0	0	0	0	6	0	0	*	*	0
1958	0	0	0	0	0	*	2	1	*	0
1959	0	0	0	0	*	*	0	0	*	*
1960	0	0	0	0	0	0	0	1	1	*
1961	0	0	0	0	0	0	8	13	11	9
1962	0	0	0	0	0	0	*	*	1	2
1963	0	0	0	0	0	0	2	5	3	3
1964	0	0	0	0	0	3	2	3	3	4
1965	0	0	0	0	0	1	0	1	1	0
1966	0	0	0	1	0	0	3	0	1	7
1967	0	0	0	0	0	0	1	0	0	1
1968	0	0	0	0	1	0	0	8	16	21
1969	0	0	0	0	2	0	12	6	10	14
1970	0	0	0	0	0	3	1	3	6	5
1971	0	0	0	0	0	7	7	9	6	11
1972	0	0	0	0	0	0	6	4	4	2
1973	0	0	0	0	0	0	3	4	4	8
1974	0	0	0	0	0	*	0	4	4	2
1975	0	0	0	0	4	3	1	2	2	1
1976	0	0	0	0	0	*	3	*	1	2
1977	0	0	0	1	0	4	8	2	2	10
1978	0	0	0	0	10	8	12	10	10	11
1979	0	0	0	3	0	1	0	0	4	0
1980	0	0	0	0	0	0	1	0	1	0
Median	0	0	0	0	0	0	1	2	3	4
Mean	0	0	0	0	1	2	3	3	4	4

Year	Jan 10	Jan 20	Jan 31	Feb 10	Feb 20	Feb 28	Mar 10	Mar 20	Mar 31	Apr 10	Apr 20	Apr 30
1916	2	3	8	10	9	9	9	2	*	0	0	0
1917	5	9	29	29	27	26	20	25	*	*	0	0
1918	3	3	8	5	9	2	6	*	0	6	*	0
1919	7	2	*	3	2	4	5	*	0	0	0	0
1920	14	18	20	20	20	19	15	3	*	0	0	0
1921	3	*	0	5	0	0	0	0	0	0	0	0
1922	5	10	11	9	8	15	8	0	0	0	0	0
1923	1	7	11	12	12	0	0	0	0	0	0	0
1924	12	12	5	12	10	2	*	0	17	*	0	0
1925	10	10	9	4	8	6	0	0	0	0	0	0
1926	7	7	3	6	4	*	6	*	0	0	0	0
1927	12	19	15	8	7	*	0	7	0	0	0	0
1928	6	4	8	*	2	*	3	0	0	*	0	0
1929	4	9	23	26	30	34	17	*	0	2	0	0
1930	0	13	17	6	*	2	0	0	0	0	0	0
1931	0	0	0	*	0	2	0	0	0	0	0	0
1932	20	8	8	10	20	4	17	14	*	0	0	0
1933	*	0	4	11	10	*	0	2	0	0	0	0
1934	4	3	*	0	0	0	0	0	4	0	0	0
1935	5	25	25	15	12	11	11	*	0	0	0	0
1936	15	16	17	16	18	31	13	7	2	0	0	0
1937	7	9	9	15	10	8	*	0	4	0	0	0
1938	1	2	2	1	6	4	4	0	0	0	0	0
1939	1	5	4	12	9	7	6	1	0	0	0	0
1940	2	3	2	*	*	2	*	5	*	0	0	0
1941	3	4	4	3	4	6	2	2	0	0	0	0
1942	1	0	0	2	2	1	0	2	0	0	0	0
1943	10	12	14	16	11	5	6	6	0	0	0	0
1944	0	0	0	*	*	0	2	1	*	0	0	0
1945	4	8	7	9	6	6	4	0	0	0	0	0
1946	9	10	11	9	9	6	1	0	0	0	0	0
1947	1	0	3	5	*	*	0	*	0	0	0	0
1948	8	5	4	6	*	8	15	*	0	0	0	0
1949	2	1	10	11	11	4	*	0	5	0	0	0
1950	3	3	6	5	5	3	3	4	*	0	0	0
1951	12	8	10	10	8	4	13	25	5	*	0	0
1952	6	4	8	5	14	5	6	2	*	0	0	0
1953	4	5	5	5	9	9	5	0	0	0	0	0
1954	0	2	2	0	0	0	0	0	0	0	0	0
1955	4	7	9	13	10	9	3	0	0	0	0	0
1956	4	4	6	6	6	5	10	2	2	0	0	0
1957	2	*	3	*	0	0	*	0	0	1	0	0
1958	*	*	3	2	2	0	*	*	0	0	0	0
1959	1	*	1	3	3	*	0	0	0	0	0	0
1960	3	*	1	*	*	2	4	3	0	0	0	0
1961	0	1	2	0	5	*	4	*	0	0	0	0
1962	6	5	5	3	11	26	22	18	2	*	0	0
1963	*	5	5	4	4	5	4	3	0	0	0	0
1964	3	2	2	1	*	0	3	4	0	0	0	0
1965	3	3	5	5	5	3	3	16	14	2	*	0
1966	4	7	7	0	5	0	0	0	1	0	0	0
1967	16	16	14	15	23	18	9	6	0	0	0	0
1968	2	2	1	1	1	1	0	0	0	0	0	0
1969	26	16	21	18	16	12	10	6	7	0	0	0
1970	14	19	16	14	13	8	4	6	2	0	0	0
1971	7	10	16	20	8	7	6	4	0	0	0	0
1972	6	6	12	14	13	10	12	1	0	0	0	0
1973	10	3	5	6	10	8	4	0	0	0	0	0
1974	8	6	5	14	7	6	0	0	0	0	0	0
1975	11	16	21	22	20	18	15	8	13	6	0	0
1976	8	11	6	3	*	*	4	0	0	0	0	0
1977	6	11	9	4	*	*	*	0	0	0	0	0
1978	6	7	9	9	9	9	9	3	0	0	0	0
1979	11	16	23	24	18	14	18	8	1	0	0	0
1980	6	2	4	7	2	3	3	0	0	4	0	0
1981	0	1	0	8	0	0	0	0	0	0	0	0
Median	4	5	7	6	4	3	3	0	0	0	0	0
Mean	6	6	8	8	6	7	5	3	1	0	0	0

* Trace (Less than 0.5 inches).
—No observation taken.

tions may be inferred from the Farmington data. The judicious long range planner who finds his concerns linked to duration and depth of snow cover may find this information helpful in trying to be "in the right place, at the right time"; that is, one can recognize and use the expected economic effects of snow cover in the planning of operations so that the chances for success are enhanced, while the probability of disastrous results are minimized.

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