SNOWFALL EXTREMES IN THE WESTERN UNITED STATES

By

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INTRODUCTION

About 3500 Weather Bureau observers measure various precipitation quantities along with other climatic elements in the 11 western States. During the winter season, these observers must be prepared for the possibility of snow and take steps for its proper measurement. Initially, the weather observer removes the funnel and the inner brass tube from his 8" official rain gage and if he lives in heavy snow country, he installs one or more snow stakes near the gage. For snow, the weather observer takes three measurements. First, he determines the depth of each new snow that falls in the large outer measuring can. Second, he melts the snow to determine the water content, and thirdly, he determines the depth of the total snow cover at his station. Occasionally, the weather observer may feel that the snowfall catch in the measuring can is not representative of his immediate area. In this case, instructions (1) specify that the observer should invert the can and use the rim to cut several representative samples of new snow. An average of these samples give improved estimates for snowfall and water content for his station.

These measurements of snowfall and snow depth are not only quite difficult but also lack certain scientific precision. Snowflakes, as they fall, respond quite readily to variations in temperature and wind. In addition, the time factor presents another variable. That is, for a snowfall ending at 7 am, the measurements at this time are not likely to agree with similar measurements taken at 5 pm. With high winds, the conscientious observer may experience some difficulty to determine representative sampling points. In this case, two equally experienced observers may estimate different results although the differences are not likely to be large or too significant.

Snowfall statistics have other inherent problems. In the first place, there are insufficient stations in the mountainous areas to give completely representative snowfall figures. The current distribution of precipitation stations over the eleven western States is shown in Table 1. With greater emphasis on stations at higher elevations during the past decade, the number of stations above 5,000 ft. at the present time comprises 36% of the total number of stations in the western area. Also in these limited population areas, there is a problem to maintain continuous records for a long period of time. The periodic snow course measurements of snow depth by the Soil Conservation Service now add valuable supplemental data in remote and high elevation areas. Keeping in mind these difficulties and limitations, there is much useful information that can be extracted and analyzed from the vast amounts of snowfall records.

Snowfall Extremes

There has always been a great deal of public interest in extreme statistics for various climatic elements. And this is particularly true in regard to snowfall. A recent survey by Weather Bureau climatologists (2) has brought forth many snowfall records that heretofore have been unavailable. This information consists of state-by-state reports of the maximum 24-hour snowfall, the greatest snowfall in a single storm, the greatest snowfall in a calendar month, the greatest snowfall in a winter season, and the record snow depth on the ground. These data are shown in Tables 2 through 6.

With one exception, these figures are also record amounts for all 50 States. At Thompson Pass in Alaska, the record snowfall for a single storm reached 175.4 inches in December 1955. All of these records in Tables 2 through 6 must be considered with regard to the limitations mentioned above. There is little doubt that greater amounts

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TABLE 1. Distribution of Precipitation Stations, by Elevation for the Eleven Western States. +

	Below Sea Level to 999 ft.	1000 ft. to 2999 ft.	3000 ft. to 4999 ft.	5000 ft. to 7999 ft.	Over 8000 ft.
			PERCENTAGE		
Arizona	6	28	27	33	6
California	44	25	16	11	4
Colorado			23	51	26
Idaho	1	24	38	35	2
Montana		31	50	18	1
Nevada		7	27	59	7
New Mexico			30	56	14
Oregon	36	30	32	2	
Utah			25	51	24
Washington	46	43	9	2	
Wyoming			38	52	10
11-State Area	18	19	27	28	8

\+ Based on precipitation stations with standard 8" gages and snow storage gages.

TABLE 2. Greatest Amount of Snowfall, 24-Hour Period, (Inches)

State	Amount	Date	Location	Coordinates		
Arizona	31.0 In.	Dec. 13, 1915	Flagstaff	35°08'	111°40'	6993'
California	60.0 In.	Jan 18-19, 1933	Giant Forest	36°34'	118°46'	6360'
Colorado	75.8 In.	Apr 14-15, 1921	Silver Lake	40°02'	105°35'	10200'
Idaho	26.0 In.	Jan 15, 1952	Arco	43°38'	113°19'	5318'
Montana	30.0 In.	Oct 29, 1951	Summit	48°20'	113°18'	5213'
Nevada	22.0 In.	Jan 12, 1952	University	39°33'	119°48'	4512'
New Mexico	30.0 In.	Dec 29, 1958	Sandia Crest	35°13'	106°27'	10675'
Oregon	37.0 In.	Jan 27, 1937	Crater Lake	42°54'	122°08'	6475'
Utah	35.0 In.	Feb 9, 1953	Kanosh	38°48'	112°26'	5016'
Washington	52.0 In.	Jan 21, 1935	Winthrop	48°28'	120°11'	1765'
Wyoming	34.0 In.	Jan 28, 1933	Bechler River	44°09'	111°03'	6300'

TABLE 3. Greatest Amount of Snowfall in Single Storm Period (Inches)

State	Amount	Date	Location	Coordinates		
Arizona	54.0 In.	Dec 29-31, 1915	Flagstaff	35°08'	111°40'	6993'
California	189.0 In.	Feb 13-19, 1959	Mt.Shasta Ski	41°22'	122°12'	7841'
Colorado	141.0 In.	Mar 23-30, 1899	Ruby	38°53'	107°06'	9850'
Idaho	52.0 In.	Jan 12-16, 1952	Sun Valley	43°31'	114°21'	5821'
Montana	46.0 In.	Mar 31-Apr 3, 1954	Summit	48°19'	113°21'	5213'
Nevada	44.0 In.	Jan 14-16, 1952	Marlette Lake	39°10'	119°55'	8000'
New Mexico	40.0 In.	Dec 14-16, 1959	Corona	34°15'	105°36'	6664'
Oregon	95.0 In.	Jan 15-19, 1951	Crater Lake	42°54'	122°08'	6475'
Utah	64.0 In.	Dec 2-7, 1951	Alta	40°36'	111°38'	8760'
Washington	129.0 In.	Feb 24-26, 1910	Laconia	47°25'	121°25'	3000'
Wyoming	52.0 In.	Jan 15-19, 1937	Bechler River	44°09'	111°03'	6300'

TABLE 4. Greatest Amount of Snowfall in a Calendar Month (Inches)

State	Amount	Date	Location	Coordinates		
Arizona	104.8 In.	Jan 1949	Flagstaff	35°08'	111°40'	6993'
California	390.0 In.	Jan 1911	Tamarack	39°18'	120°30'	6265'
Colorado	249.0 In.	Mar 1899	Ruby	38°53'	107°06'	9850'
Idaho	101.5 In.	Jan 1952	Island Park Dam	44°25'	111°24'	6300'
Montana	123.0 In.	Jan 1954	Summit	48°19'	113°21'	5213'
Nevada	107.0 In.	Jan 1950	Glenbrook	39°05'	119°55'	6400'
New Mexico	88.0 In.	Jan 1915	Anchor Mine	36°46'	105°20'	10200'
Oregon	256.0 In.	Jan 1933	Crater Lake	42°54'	122°08'	6475'
Utah	165.0 In.	Mar 1948	Alta	40°36'	111°38'	8760'
Washington	363.0 In.	Jan 1925	Paradise R.S.	46°47'	121°44'	5550'
Wyoming	188.5 In.	Jan 1933	Bechler River	44°09'	111°03'	6300'

TABLE 5. Greatest Amount of Snowfall in a Season (Inches)

State	Amount	Date	Location	Coordinates		
Arizona	212.2 In.	1940-41	Bright Angel	36°12'	112°04'	8400'
California	884.0 In.	1906-07	Tamarack	39°18'	120°30'	6265'
Colorado	811.9 In.	1936-37	Wolf Creek Pass	37°29'	106°52'	9455'
Idaho	355.5 In.	1951-52	Island Park Dam	44°25'	111°24'	6300'
Montana	406.5 In.	1958-59	Kings Hill	46°50'	110°42'	7300'
Nevada	308.0 In.	1951-52	Marlette Lake	39°10'	119°55'	8000'
New Mexico	428.0 In.	1914-15	Anchor Mine	36°46'	105°20'	10200'
Oregon	879.0 In.	1932-33	Crater Lake	42°54'	122°08'	6475'
Utah	663.0 In.	1951-52	Alta	40°36'	111°38'	8760'
Washington	1000.3 In.	1955-56	Paradise R.S.	46°47'	122°44'	5550'
Wyoming	491.6 In.	1932-33	Bechler River	44°09'	111°03'	6300'

TABLE 6. Greatest Snow Depth of Record (Inches)

State	Amount	Date	Location	Coordinates		
Arizona	86 In.	Feb 8, 1949	Bright Angel	36°12'	112°04'	8400'
California	451 In.	Mar 10, 1911	Tamarack	39°18'	120°30'	6265'
Colorado	254 In.	Mar 30, 1899	Ruby	38°53'	107°06'	9850'
Idaho	182 In.	Feb 20, 1954	Mullan Pass	47°27'	115°41'	6022'
Montana	132 In.	Apr 3, 1954	Summit	48°19'	113°21'	5213'
Nevada	140 In.	Mar 19, 1952	Marlette Lake	39°10'	119°55'	8000'
New Mexico	72 In.	Feb 28, 1915	Anchor Mine	36°46'	105°20'	10200'
Oregon	246 In.	Mar 19, 1950	Timberline L.	45°20'	121°43'	5935'
Utah	179 In.	Apr 5, 1958	Alta	40°36'	111°38'	8760'
Washington	367 In.	Mar 9, 1956	Paradise R.S.	46°47'	122°44'	5550'
Wyoming	96 In.	Mar 3, 1939	Bechler River	44°09'	111°03'	6300'

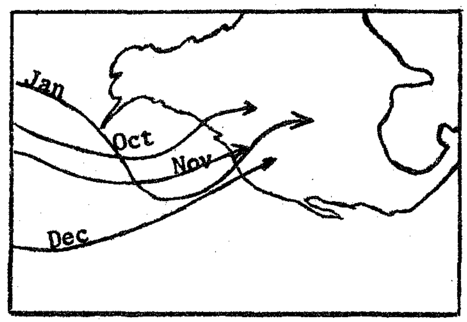

Figure 1. Mean Monthly Position of Jet Stream, Oct. 1955-Jan. 1956 (from USWB).

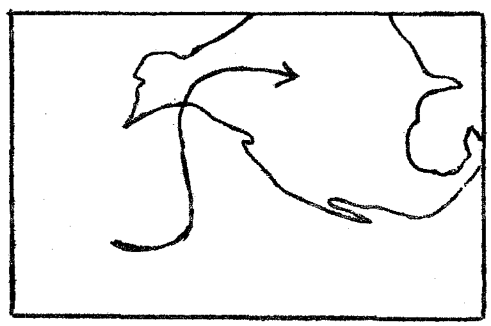

Figure 2. Generalized Position of Jet Stream, Winter, 1962-63.

of snow in all categories have fallen in remote areas. Nevertheless, these extremes can be considered as good estimates of the maximum amounts of snow that can be expected for inhabited areas of the country.

The Meteorological Situation

In general, the record or near-record snowfalls in the west are the result of not only certain terrain and elevation features, but also a combination of certain meteorological factors. In regard to the records for monthly and seasonal totals, the large scale atmospheric patterns that prevail and persist for long intervals of time become most important and to a large degree determine the extent and the amount of the snow anomaly. For example, the winter of 1955-56 resulted in record-breaking snowfall over much of the Pacific Northwest. From a meteorological standpoint, this winter was characterized by weak prevailing westerly winds (low zonal index), the jet stream was displaced southward over western United States (Figure 1), the prevailing air moving over the northwest was cool (for snow instead of rain) and weather fronts moved across the area with above average frequency. Within this meteorological setting, large accumulations of snow occurred over a rather large area.

This past winter has been a good example of the opposite meteorological situation. It is now apparent that the far west has had one of the lightest snow packs on record. During this period, the main atmospheric circulation patterns have been radically different. First, a large high pressure system persisted over much of the area and effectively blocked most of the weather systems (and precipitation) from entering the western States. The jet stream (Figure 2) and other meteorological phenomena were abnormally displaced. During much of February, moderate and persistent southerly air flow prevailed along the entire west coast. Therefore, whenever precipitation did occur, it was generally rain instead of snow except at the very high elevations. Thus, whenever extreme weather conditions-dry or wet, cold or warm--persist for long periods of time, it is axiomatic that the large scale atmospheric circulation patterns have also been altered or displaced. It is those factors that make attempts to substantially modify the weather so difficult. The ultimate in weather modification will be when it becomes possible to re-orient and to redirect these main atmospheric systems (3).

Analyses of Heavy Snow Data

For those interests that are concerned with heavy snowfall and large accumulations of snow cover, there are many ways in which the data might be analyzed and presented. The remainder of this paper will give examples from selected heavy snow stations over the west.

For planning purposes, the date when the snow season begins (and ends) can be of real interest. A technique of analysis for various snowfall thresholds was developed by Thom (4); from this, the chance of the first (and last) snowfall by certain dates can be evaluated. Figure 3 shows that the threshold date distribution approaches the normal distribution. Tables 7 and 8 present this information for a few selected points. Similar results for a snow depth analysis are given in Tables 9 and 10. From this information, certain statements can be derived as to the probable length of the snowfall or snow cover season (Table II).

There is also considerable interest in snowfall intensity. For the majority of the reporting stations, the intensity interval is 24 hours and increments thereof. In Table 12 (5), the 1- to 3-day snowfall intensities have been determined for selected probability levels for Crater Lake, Oregon.

There is also interest in the persistency of snowfall. How frequently do we have consecutive days of snowfall? An example of this is shown in Table 13 from the data compiled for the 1960 Olympics at Squaw Valley, California (7).

Since most stations measure snow depth each day, it is possible to determine the length of the snow cover season for various depth levels. Table 14 is an example of this type of summary for Crater Lake.

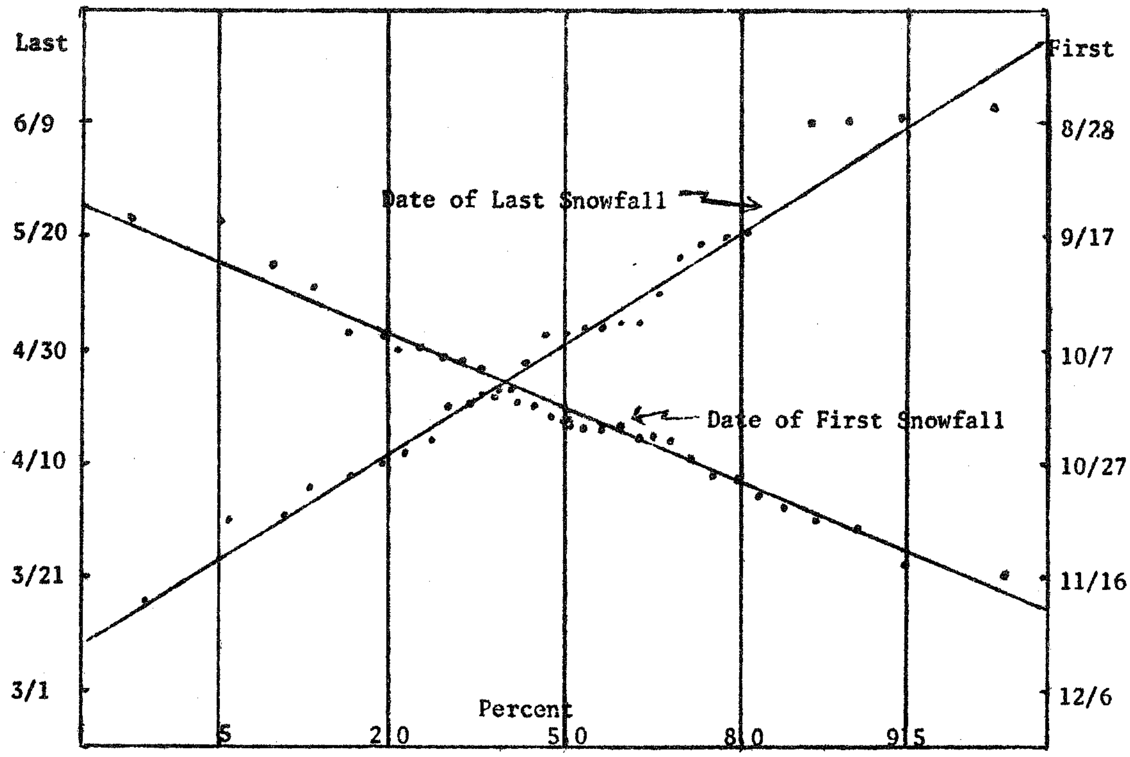

Figure 3. Dates of First and Last Snowfall (6"), Paradise R.S., Wash.

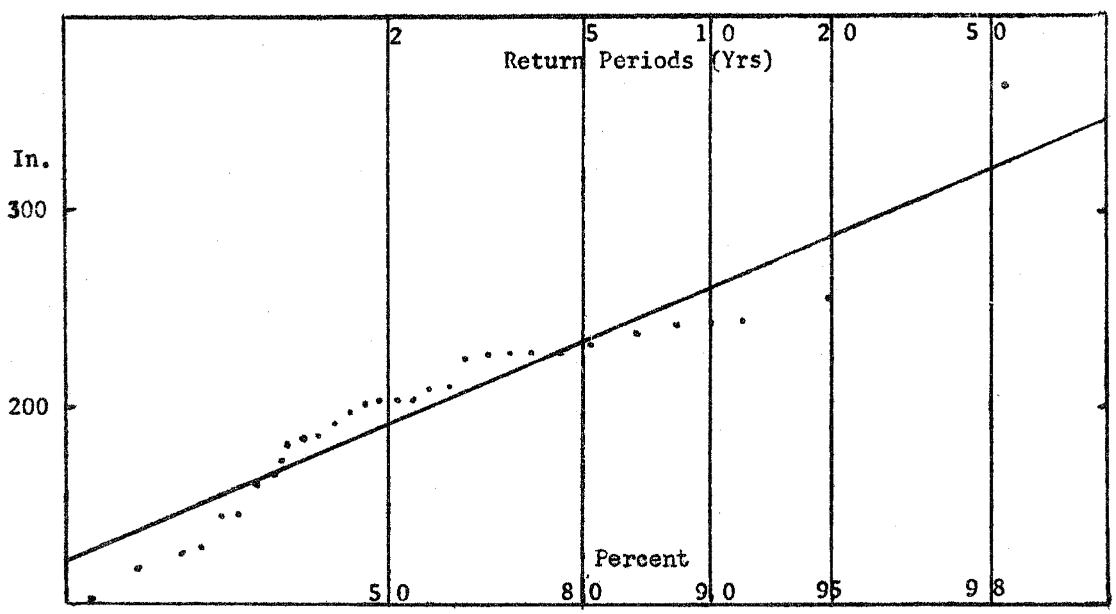

Figure 4. Seasonal Greatest Snow Depths, Paradise R.S., Wash.

TABLE 7. Dates of First Snowfall for Selected Probabilities

	1 YR in 30 (.033)	1 YR in 10 (.10)	5 YRS in 10 (.50)	9 YRS in 10 (.90)	29 YRS in 30 (.967)
			Flagstaff, Arizona		
First 1"	Oct 1	Oct 15	Nov 17	Dec 18	Jan 2
			Tamarack, Calif.		
First 2"	Sep 9	Sep 18	Oct 10	Nov 1	Nov 10
First 6"	Sep 13	Sep 27	Oct 28	Nov 29	Dec 12
			Crater Lake, Oregon		
First 4"	Sep 11	Sep 22	Oct 17	Nov 10	Nov 21
First 8"	Sep 25	Oct 6	Nov 2	Nov 29	Dec 10
			Paradise R. S., Wash.		
First 2"	Sep 10	Sep 18	Oct 6	Oct 24	Nov 1
First 6"	Sep 18	Sep 27	Oct 17	Nov 6	Nov 15

TABLE 8. Dates of Last Snowfall for Selected Probabilities

	1 YR in 30 (.033)	1 YR in 10 (.10)	5 YRS in 10 (.50)	9 YRS in 10 (.90)	29 YRS in 30 (.967)
			Crater Lake, Oregon		
Last 8"	Mar 18	Mar 30	Apr 26	May 25	Jun 6
Last 4"	Apr 16	Apr 26	May 20	Jun 13	Jun 24
			Paradise R. S., Wash.		
Last 6"	Mar 20	Apr 2	May 2	May 31	Jun 13
Last 2"	Apr 15	Apr 26	May 23	Jun 18	Jun 29

TABLE 9. Dates When Fall Snow Depths Reach Certain Levels for Selected Probabilities

	1 YR in 30 (.033)	1 YR in 10 (.10)	5 YRS in 10 (.50)	9 YRS in 10 (.90)	29 YRS in 30 (.967)
			Tamarack, Calif.		
First 6"	Sep 13	Sep 25	Oct 24	Nov 22	Dec 4
First 24"	Oct 23	Nov 3	Nov 30	Dec 27	Jan 7
			Deadwood Dam, Idaho		
First 5"	Oct 13	Oct 23	Nov 15	Dec 8	Dec 18
First 25"	Nov 10	Nov 24	Dec 26	Jan 27	Feb 10
			Sandia Crest, N. Mexico		
First 5"	Oct 10	Oct 20	Nov 10	Dec 1	Dec 10
First 10"	Nov 1	Nov 11	Dec 2	Dec 27	Jan 6
			Crater Lake, Oregon		
First 6"	Sep 15	Sep 27	Oct 25	Nov 21	Dec 4
First 12"	Oct 3	Oct 13	Nov 5	Nov 28	Dec 8
First 24"	Oct 12	Oct 23	Nov 17	Dec 13	Dec 24
First 48"	Nov 9	Nov 16	Dec 12	Jan 8	Jan 19
			Paradise R. S., Wash.		
First 6"	Sep 21	Sep 29	Oct 19	Nov 8	Nov 16
First 12"	Oct 3	Oct 11	Oct 30	Nov 18	Nov 27
First 24"	Oct 11	Oct 20	Nov 9	Nov 30	Dec 8
First 48"	Oct 27	Nov 11	Dec 4	Dec 31	Jan 11

TABLE 10. Dates When Spring Snow Depths Reach Certain Levels for Selected Probabilities

	1 YR in 30 (.033)	1 YR in 10 (.10)	5 YRS in 10 (.50)	9 YRS in 10 (.90)	29 YRS in 30 (.967)
			Deadwood Dam, Idaho		
Last 25"	Mar 19	Mar 26	Apr 13	May 1	May 8
Last 5"	Apr 14	Apr 19	May 1	May 13	May 18
			Sandia Crest, N. Mexico		
Last 10"	Mar 8	Mar 15	Mar 30	Apr 16	Apr 22
Last 5"	Mar 20	Mar 26	Apr 11	Apr 27	May 3
			Crater Lake, Oregon		
Last 48"	Apr 24	May 5	May 30	Jun 23	Jul 3
Last 24"	May 5	May 15	Jun 8	Jul 2	Jul 14
Last 12"	May 10	May 20	Jun 12	Jul 6	Jul 22
			Paradise R. S., Wash.		
Last 48"	May 12	May 23	Jun 19	Jul 16	Jul 27
Last 24"	May 26	Jun 5	Jun 28	Jul 21	Jul 31
Last 12"	May 31	Jun 10	Jul 2	Jul 24	Aug 3

TABLE 16. Water Content of Snow Pack on April 1 for Selected Return Periods.+

	1 YR in 50	1 YR in 10 (Less Than)	1 YR in 2 (Average)	1 YR in 10	1 YR in 50 (Greater Than)
			INCHES		
Sonora Pass, Calif., 8800'	7	13	24	34	41
Wolf Creek Pass, Colo., 10,000'	9	17	30	43	51
Big Bend, Nev., 6700'	1	4	10	16	20
Rainy Pass, Wash., 4780'	23	29	39	48	54
Cayuse Pass, Wash., 5300'	31	52	88	123	144

+ Basic data from USDA, SCS publications of summaries of snow survey measurements for each given State.

Earlier in Table 6, information was given on the all-time record snow depth for each State. This data gives little information on how frequently excessive snow cover can occur (except that it occurred once during the period of record at each listed station). Seasonal snow cover data can be analyzed to determine the frequency of occurrence of extreme snow depths (sometimes called return periods). Table 15 gives the maximum snow depth observed snow depth data fits the distribution function (extreme value theory) quite well as shown in Figure 4.

In addition to the information on the distribution of snow depths, there is also interest in the average and variation of the water content of the snow pack at given locations. Monthly series of water content data are now available in connection with the USDA, SCS snow survey program. From their summary publications, the water content of the snow pack for selected return periods has been determined for several locations (Table 16).

There remains large quantities of snowfall data to be exploited and used. Until recent years, it has been quite difficult and time consuming to extract the pertinent data from the official records. Since 1949, data on snowfall have been published in Climatological Data and also have been entered on punch cards. In addition, a number of universities and state colleges have initiated programs to punch the historical portions of these records. Each Weather Bureau State Climatologist plus the resources of the Weather Bureau's National Weather Records Center in Asheville, N. C. (6) are in a position to assist any potential user of snowfall data.

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5. Data for Crater Lake, Oregon, was extracted from a new publication "Climatology of Crater Lake National Park". A rather complete snow climatology of this area was compiled for this bulletin by the Weather Bureau State Climatologist, Portland, Oregon. Copies of this bulletin are available from the National Park Service, Crater Lake, Oregon.

6. Barger, G. L., Climatology at Work, U. S. Dept. of Commerce, Weather Bureau, Washington, D. C., October 1960.

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