

from the preceding forecast and the corrections by Rules 13 and 19 to 22, inclusive, is carried forward each day. The mean rainfall, Dardanelle plus Little Rock divided by 2, is 3.38 inches. As the ground was relatively dry and the rainfall at Fort Smith was only 0.91 inch, the lowest rate or 0.5 foot rise for each inch of rain is assigned (Rule 14), which gives 1.7 feet (see Table 3, column 9). Adding the cumulative correction, +0.5 foot, gives $0.5 + 1.7 = 2.2$ feet, the total correction to be applied to the stage indicated by the diagram figure 6, and $12.3 + 2.2 = 14.5$ feet is the forecast stage for the 14th. The actual stage was 13.8 feet or 0.7 foot below the forecast stage.

May 14, 1905.—The cumulative correction, as before, is obtained by combining the corrections for the 13th in columns 7 and 13 (Table 3). As previously explained, the correction in column 9, being for rainfall, is omitted. Thus, $-0.7 + 0.5 = -0.2$ is the cumulative correction to be carried forward. As the river rose rapidly (4.1 feet) at Dardanelle, one-tenth of this amount is entered as a minus correction in column 9 (Rule 19). A rainfall correction of +0.2 is also entered in column 9 (Rule 15). We have then -0.2 , -0.4 , and $+0.2$, or a total correction of -0.4 foot.

The stage indicated by figure 6, was 16.7 feet; subtracting the correction of -0.5 leaves 16.3 feet, the forecast stage for the 15th. The actual stage was 16.5 feet, or 0.2 foot higher.

May 15, 1905.—To get the cumulative correction for this date we take, as before, all of the corrections for the 13th except the rainfall correction. Thus (adding) -0.2 , -0.4 , and $+0.2 = -0.4$.

The stage indicated by figure 6 is 18 feet. As there are no other corrections to be applied, we have $18.0 - 0.4 = 17.6$ feet, the forecast stage for the 16th. The actual stage was 0.2 foot higher.

May 16, 1905.—Proceeding as before, we have (adding) $+0.2$, $-0.4 = -0.2$ as the cumulative correction. That amount, deducted from the stage indicated by diagram, 17.3 feet, gives 17.1 feet as the forecast stage for the 17th. The actual stage was 0.1 foot higher.

May 17, 1905.—Combining as before, $+0.1$ and -0.2 equals -0.1 foot, the cumulative correction. Subtracting this amount from the indicated stage, 16.7 feet, we have 16.6 feet as the forecast stage for the 18th. The actual stage was 16.3 feet, or 0.3 foot lower.

May 18, 1905.—The cumulative correction is $-0.3 + -0.1 = -0.4$. Subtracting this amount from the indicated stage, 15.7 feet, gives 15.3 feet as the forecast stage for the 19th. The actual stage was 15.4 feet, or 0.1 foot higher.

6. January 27 to 29, 1916.

The following examples show the lessening effect of rainfall on high stages of the river:

January 27, 1916.—A cumulative correction of -2 feet is brought forward from the 26th. As the river was high, but 0.8 foot rise was allowed for each inch of rainfall (Rule 15). Adding $-2.0 + 0.8 = -1.2$ feet, the correction to the indicated stage. The stage indicated by diagram (fig. 6) was 23.7 feet. Hence $23.7 - 1.2 = 22.5$ feet, the forecast stage for the 28th. The actual stage was 0.1 foot higher.

January 28, 1916.—Combining as before, we have a cumulative correction of -1.9 feet. As the river was high, but 0.5 foot was allowed for each inch of rainfall, which gives -1.4 as the total correction. This, subtracted from the indicated stage (25.8 feet), gives 24.4

feet as the forecast stage. The actual stage was 0.4 foot lower.

January 29, 1916.—Combining as before, we obtain a cumulative correction of -2.3 feet. As the river was very high, but 0.3 foot rise was allowed for each inch of rain. Adding: -2.3 and $+0.3 = -2.0$ as the total correction, which, applied to the indicated stage, 27.4 feet, gives 25.4 feet as the forecast stage. The actual stage was 0.1 foot lower.

THE DISAPPEARANCE OF SNOW IN THE HIGH SIERRA NEVADA OF CALIFORNIA.

By ALFRED J. HENRY, Professor of Meteorology.

[Dated: Weather Bureau, Washington, Apr. 15, 1916.]

Much effort has been put forth in many parts of the world, to determine the depth and distribution of precipitation in the form of snow, yet but little attention seems to have been given to the conditions attending the disappearance of snow. The ordinary conception that the snows of winter are melted by the increased insolation of late spring and early summer seems to be sufficiently close to the truth to satisfy the average inquirer.

The object of this paper is to determine whether the available records of snowfall made by cooperative observers, afford any insight into the weather conditions which may modify or control the disappearance of snow. The subject is, moreover, rather closely associated in the public mind with flood causation. Time was when the June floods in the Missouri River were considered as being due to the melting of winter snowfall at the headwater streams, but that impression is fast disappearing in the light of modern records of precipitation and streamflow for the headwaters of that stream. Floods in the rivers of New England and the tier of northern states extending thence westward to the Dakotas, are intensified by the snow cover which may be on the ground toward the end of spring. The release of the snow water, however, is not easily accomplished except the night temperatures be continuously above freezing for several consecutive days—a rather unusual condition in spring. Hence snow floods are rare even in the more northern rivers of the United States. In Washington and Oregon, due to the proximity of those states to the Pacific Ocean, warm winter rains sometimes fall upon a deep snow cover and floods result, but even in those states snow-melting weather during the winter and late spring is of infrequent occurrence. The most pronounced snow flood of the United States is that which annually passes down the Columbia River, due almost wholly to the melting of the snow cover at the higher altitudes of its drainage basin. The depth of the snow cover is usually fairly well known from observations made by snowfall observers of the Weather Bureau, supplemented by reports from cooperative observers, but the manner in which the snow cover will disappear, whether by slow melting and rapid evaporation or by rapid melting and quick runoff, can not be determined with any certainty far in advance.

In a study of this subject one naturally turns to the high Sierra of California, where a great amount of snow falls during winter and its disappearance during spring can be carefully observed. Reports of snowfall are available for a number of stations in that region, but we have confined our attention to three stations whose altitudes and geographical coordinates are shown below in Table 1.

TABLE 1.—Location of mountain snowfall stations.

Station.	Altitude.	Latitude (N.).	Longitude (W.).	Topography.
Fordyce Dam, Cal.....	6,500	39 23	120 29	West slope Sierra Nevada.
Summit, Cal.....	7,017	39 19	120 20	Summit of Divide.
Tamarack, Cal.....	8,000	38 30	119 50	West slope Sierra Nevada.

The two stations first named are representative of the snow conditions along and near the line of transcontinental railway where it crosses the Sierra Nevada in California.

The drainage of Fordyce Dam is westward into the Yuba River, a tributary of the Sacramento; the drainage of the Summit station, on the contrary, is eastward into the Truckee River. The third station is in Alpine County, in the slight depression in which the Blue Lakes are situated and a quarter of a mile south of lower Blue Lake. The drainage is to the northwestward into the Mokelumne, a tributary of the San Joaquin River. This station is also quite near the Carson watershed and is typical of the high Sierra to the southwest of Lake Tahoe. Mountain masses 500 to 1,000 feet higher abound on the west and also to the northeast of the station.

We have summarized from the snowfall reports published in "Climatological Data—California Section," and from the manuscript data kindly supplied by Section Director George H. Willson, the facts shown in Table 2, below.

TABLE 2.—Disappearance of snow in the Sierra Nevada of Central California, February–April.

Fordyce Dam, Cal.						
Year.	February.	March.	April.	Total.	Date of final disappearance.	Average daily disappearance.
	Inches.	Inches.	Inches.	Inches.		Inches.
1908.....	36	94	32	162	June 22	1.8
1909.....	93	98	43	233	July 1	1.8
1910.....	51	51	37	139	May 26	1.6
1911.....	84	120	76	279	July 13	3.1
1912.....	18	49	65	132	June 21	1.4
1913.....	17	51	61	129	June 11	1.4
1914.....	60	39	54	153	June 20	1.7
1915.....	116	55	49	220	June 26	2.5
Mean.....	59	69	52	180	June 21	1.9

Summit, Cal.						
Year.	February.	March.	April.	Total.	Date of final disappearance.	Average daily disappearance.
	Inches.	Inches.	Inches.	Inches.		Inches.
1907.....	86	91	167	344	July 14	3.9
1908.....	58	116	51	225	June 11	2.5
1909.....	41	68	71	180	June 21	2.0
1910.....	47	46	63	156	June 6	1.8
1911.....	56	76	90	222	June 13	2.5
1912.....	21	31	56	108	June 13	1.2
1913.....	53	37	45	135	May 31	1.5
1914.....	75	64	58	197	June 9	2.0
1915.....	61	81	76	218	June 6	2.4
Mean ¹	51	65	64	180	June 11	2.0

Tamarack, Cal.						
Year.	February.	March.	April.	Total.	Date of final disappearance.	Average daily disappearance.
	Inches.	Inches.	Inches.	Inches.		Inches.
1907.....	113	63	167	343	July 27	3.9
1908.....	59	95	38	192	June 7	2.1
1909.....	51	44	55	150	July 1	1.7
1910.....	51	42	45	138	June 3	1.6
1911.....	12	169	213	394	July 8	4.4
1912.....	19	41	72	132	June 24	1.5
1913.....	32	33	50	115	June 12	1.3
1914.....	42	39	32	113	June 20	1.3
1915.....	51	62	54	167	June 26	1.9
Mean ¹	40	65	70	175	June 20	2.0

¹ For the period 1908–1915.

The depth of snow which disappeared during the months of February, March, and April is easily obtained by considering the depth of snow on the ground at the beginning of the month as the initial point, adding thereto the fall during the month and comparing the sum thus obtained with the depth on the ground at the end of the month. The depths in Table 2 were thus obtained and these figures represent the amount of snow that disappeared from whatever cause during the month. As might be expected, the daily rate of disappearance varies according to the weather conditions, ranging from a little more than an inch to as much as four inches per day, and a greater amount for short periods. The total amount of snow that disappears during the months February to April, inclusive, on the average, of all conditions, at the three stations, is shown in the small table below.

TABLE 3.—Disappearance of snow by months.

Station.	Month.			
	February.	March.	April.	Total.
Fordyce Dam.....	Inches. 59	Inches. 69	Inches. 52	Inches. 180
Summit.....	51	64	64	180
Tamarack.....	40	65	70	175

The very close agreement in the average values for so short a period is evidence that they represent a real phenomenon. The variations from the mean values may be seen from the detailed amounts for each season, as given in Table 2. Thus in 1907, notably in the month of April, the weather was particularly effective in causing a rapid disappearance of snow, but the greatest amount of snow to disappear during any one year within the period of observations was in 1911, in the months of March and April. The weather conditions during February, March, and April, 1907, may be summarized as follows: February, a warm month with not much precipitation; March, a wet month with heavy precipitation, mostly in the form of snow at the higher levels, with temperatures mostly below freezing at Summit and Tamarack; April a warm and relatively dry month, with plenty of sunshine in the last half of the month. The weather of 1911 may also be summarized as follows: February, a cold month with much cloudy weather and frequent precipitation; March, a little warmer than the average, a large amount of precipitation, and a period of about 20 consecutive days of dry, warm weather, during which snow disappeared very rapidly as will be later pointed out; April, cold and cloudy in the beginning but after the first decade there was a period of clear, dry weather, during which the snow melted at the uniform rate of about 4 inches daily.

A significant circumstance in connection with the very large disappearance of snow in 1907 is the fact that the Truckee River which drains the region about Summit reached and maintained higher stages than the average from March to November of that year, thus indicating the absorption by the ground of a large amount of snow water which later found its way into the river. The effect on the rivers of the second season of high melting 1911, was not apparent beyond July of that year.

The seasons of small melting were as follows: 1910, 1912, 1913, and, for Tamarack, 1914, in addition to the 3 years first named. The weather conditions during 1910 were as follows: February, cold and dry without warm

rains; March, warm and dry with steady decrease in snow cover during first 20 days; April, warm and dry light snowfall and much sunshine, snow melting rapidly.

1912. February, a very dry month with warm sunny days. No snow during last half of month; March cool and rainy; April, very cold with somewhat more precipitation than the average. Very little packed snow at high altitudes, owing to the deficiency during January and February.

1913. February, cold and dry with light snowfall in the mountains; March, cool and dry, no warm spells and a shortage in snow; April, cool and dry, light snowfall in the mountains.

In setting forth the weather conditions associated with snow melting we are impressed with the fact that years with little snow melting are primarily years of greatly diminished fall, coupled with low temperature, and that years of great melting are years with heavy precipitation and relatively high temperatures. It would also seem that the opportunities for melting are as great if not greater during years of little snow as during years of much snow. The air temperatures and probably the wind seem to be the prime factors in the disappearance of snow, although doubtless there are other important causes. February, 1912, was a month during which but a small amount of snow disappeared; the weather was very dry in the sense that precipitation was light and infrequent and the total snowfall at the mountain stations was much less than the quantity which disappeared. The temperature was slightly above the average and the sunshine was fairly abundant, conditions which would seem to be favorable to rapid evaporation and melting, yet the amount which disappeared at the three stations considered, was far below the average. The depth on ground on January 31, 1912, and the amount that disappeared at the three stations considered was:

Station.	Depth on ground.	Disappeared.
	Inches.	Inches.
Fordyce Dam.....	59	18
Summit.....	41	21
Tamarack.....	55	19

The individual records of the three stations during snowless periods of varying length were examined, with the result that it appears that the weather in the high Sierra Nevada of California during a dry period is mostly dominated by high atmospheric pressure with little or no wind; the temperature rises above freezing in daytime and sinks below at night.

There is no apparent relation between small changes in temperature, either positive (upward) or negative (downward) and the rapid or slow melting of snow, nor does the disappearance of snow seem to be conditioned upon the day temperatures being above 32°F. The daily mean temperature is constantly oscillating up and down through a range of 1 to 10 degrees; these short-period changes do not appear to noticeably influence the melting of the snow cover even when the daily mean temperature passes above 32°F. and remains above for three or four consecutive days. After the first of February the majority of the short-period changes are positive, but their duration is short until the warm season is well advanced.

The weather conditions during a typical snowless period at Fordyce Dam, Cal., are given in the Table 4, below, for the month of February, 1912.

TABLE 4.—Meteorological record for February, 1912, at Fordyce Dam, Placer County, Cal.

[By E. E. Roenig, cooperative observer.]

Date.	Temperature.			Precipitation.			Prevailing wind direction.	Character of day, sunrise to sunset.
	Maximum.	Minimum.	Mean.	Amount.	Snowfall, in inches.	Depth of snow on ground at time of observation.		
	° F.	° F.	° F.	Inches.		Inches.		
1.....	35	22	28			59.0	sw.	Clear.
2.....	31	19	35			58.0	sw.	Clear.
3.....	45	13	29			58.0	sw.	Clear.
4.....	53	19	36			57.0	sw.	P't cl'dy.
5.....	45	27	36			56.0	sw.	Clear.
6.....	49	22	25			55.0	sw.	P't cl'dy.
7.....	43	23	33	0.04		54.0	sw.	P't cl'dy.
8.....	49	35	42			53.0	sw.	P't cl'dy.
9.....	46	35	40	0.10		52.0	sw.	P't cl'dy.
10.....	41	33	37			51.0	sw.	Clear.
11.....	43	26	34			51.0	ne.	P't cl'dy.
12.....	50	24	37			50.0	sw.	P't cl'dy.
13.....	45	32	38	T.		50.0	sw.	Cloudy.
14.....	46	38	42	0.35	3.0	52.0	sw.	Cloudy.
15.....	49	26	37			52.0	sw.	P't cl'dy.
16.....	50	34	42			51.0	sw.	P't cl'dy.
17.....	43	38	40	0.95		50.0	sw.	P't cl'dy.
18.....	47	39	43	0.35		49.0	sw.	P't cl'dy.
19.....	39	32	35			49.0	ne.	Clear.
20.....	47	25	36			48.0	ne.	P't cl'dy.
21.....	32	27	30			48.0	ne.	Clear.
22.....	46	26	36	T.		47.0	sw.	P't cl'dy.
23.....	31	37	29	T.		47.0	ne.	P't cl'dy.
24.....	29	24	26			46.0	ne.	P't cl'dy.
25.....	41	26	34			46.0	nw.	Clear.
26.....	49	20	34			46.0	nw.	P't cl'dy.
27.....	48	23	35			45.0	s.	Clear.
28.....	57	30	40			45.0	sw.	Clear.
29.....	50	28	39			44.0	sw.	Clear.
Mean.....	45.6	27.7		1.79	3.0		sw.	

Rapid disappearance of snow.—In studying the records of rapid disappearance of snow, it was found, as might have been expected, that freshly fallen snow disappeared much more rapidly than a cover of old snow that had been well packed by the wind and by alternate melting and freezing, and this is believed to be the explanation of the fact that years of greatest snowfall are also years of most rapid disappearance of snow.

The depth of snow may diminish (1) by melting and ground absorption when the ground is not frozen; (2) by settling or packing under the influence of high winds; (3) by evaporation. It is a matter of common observation that fresh snow packs or settles upon exposure for a few days to the weather. The following examples will perhaps make the application of the above clearer:

Example No. 1: On February 27, 1908, at Fordyce Dam snow began to fall, with a layer of 79 inches already on the ground. It snowed continuously for 9 days, during which a total of 95 inches was recorded. This amount, added to the old cover, increased the latter by 43 inches only, or less than 50 per cent of its full value. Immediately after the snow ceased falling the daily disappearance for a period of 6 days was on the average 4.6 inches per day. The mean temperature for the same period was 23°, but the mean maximum was 46°.

Example No. 2: At Summit, Cal., from March 1 to 10, 1911, a total of 99 inches of snow fell; then followed a period of 25 consecutive days without precipitation and with day temperatures above freezing and night temperatures slightly below. The depth of the snow cover at the beginning was 215 inches. At the end of the snowfall period it was 307 inches. Immediately the snow ceased falling it began to disappear very rapidly; there was a period of 9 consecutive days from March 16 to 24, when the average daily rate of decrease was at a maximum, viz, 11.4 inches. For the entire period

of 25 days the average rate of diminution was 7.4 inches daily. During the time of maximum decrease the mean temperature was 36°, the mean maximum was 43°, mean minimum 29.7°. The weather was mostly clear with southwest and south winds.

The practical application of the foregoing seems to be that whatever the amount of snow on the ground in midwinter a considerable portion of it will disappear through natural causes aside from the occurrence of warm weather attended by rain. The depth that disappears, on the average, expressed in percentages of the amount on the ground on the first of the month, is as follows:

TABLE 5.—Percentage of disappearance of snow.

Station.	February.	March.	April.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Fordyce Dam.....	67	70	51
Summit.....	45	54	42
Tamarack.....	29	36	42

These figures show that altitude is a function in the disappearance of snow, the greater the altitude the slower the melting, as is perfectly obvious. The stations at Fordyce Dam and Summit show a greater melting in March than in April, contrary to the showing for Tamarack, and the natural expectation that the rate of melting would increase with the advance of the season.

Conclusions.—The most favorable weather conditions for the conservation of a snow cover are low temperature and little wind movement. The average loss by evaporation under these conditions appears to be about three-quarters of an inch per day.

Unfavorable weather conditions are relatively high temperature, brisk wind movement, and plenty of strong sunshine. Under the most unfavorable conditions for

the conservation of snow the loss of freshly fallen snow may average 10 inches per day and of old snow from 3 to 4 inches.

BIBLIOGRAPHY.

Le Conte, J. L. Snowfall in the Sierra Nevada, *Sierra Club Bulletin*, 1908, Vol. 6, pp. 310-14.
McAdie, Alex. G. Snowfall Records at Summit, *MONTHLY WEATHER REVIEW*, 38: 940.
 Forecasting the Supply of Water for the Summer from the Depth of Snow. *Ibid.* 39: 445.
 Forecasting the Water Supply of California. *Ibid.* 41: 1092-3.
Palmer, Andrew H. The Region of Greatest Snowfall in the United States, *MONTHLY WEATHER REVIEW*, 43: 217.

CORRIGENDA.

January Review, 1916:
 Page 35, Table 16. The daily amounts of rainfall at San Diego, Cal., January, 1916, should read:

	Amount.
Jan. 16.....	0.95
17.....	1.55
18.....	0.31
19.....	0.80
20.....	0.00
Total.....	3.61
Jan. 24.....	T.
25.....	0.21
26.....	0.22
27.....	2.19
28.....	0.06
29.....	0.17
Total.....	2.85

Page 35, Table 14. Daily precipitation at Mill Creek, for the leaders under January 16, 17, 18, and 27, 28, read an asterisk (*).