SECTION IV—RIVERS AND FLOODS.

RIVERS AND FLOODS, JULY, 1916.

By ALFRED J. HENRY, Professor in Charge.

[Dated Weather Bureau, Washington, Sept. 2, 1916.]

FLOODS IN SOUTHERN RIVERS.

The passage of two tropical cyclones over the East Gulf and South Atlantic States separated by an interval of but a few days, both storms being attended by almost unprecedented precipitation, caused floods of great magnitude in the rivers of Alabama and the Carolinas and of lesser magnitude in the rivers of Georgia and eastern Tennessee. Many lives were lost and the destruction of property was greater than has been experienced in many years. By reason of the difficulty in securing and preparing the necessary meteorological and hydrological data for publication, a detailed account of this flood is deferred until the issue of the August, 1916, REVIEW.

FLOODS IN OTHER RIVERS.

A moderate flood occurred in the Red River of the North during the early part of the month, due to heavy rains over the watershed on June 26 and 27 and again on July 6 and 7. These rains were confined almost wholly to the watershed of the Red River of the North, and resulted in the rather unusual occurrence of a flood in summer. The damage to parks, roadways, etc., in the cities of Moorhead, Minn., and Fargo, S. Dak., did not exceed $10,000, and this was mostly unpreventable.

Hydrographs for typical points on several principal rivers are shown on Chart I. The stations selected for charting are Kekouk, St. Louis, Memphis, Vicksburg, and New Orlenas, on the Mississippi; Cincinnati and Cairo, on the Ohio; Nashville, on the Cumberland; Johnsonville, on the Tennessee; Kansas City, on the Missouri; Little Rock, on the Arkansas; and Shreveport, on the Red.

A METHOD OF FORECASTING THE MAXIMUM SUMMER LEVEL IN LAKE TAHOE FROM ONE TO FOUR MONTHS IN ADVANCE.

By HENRY F. ALCIATORE, Meteorologist.

[Weather Bureau, Reno, Nev., July 20, 1916.]

Lake Tahoe, a wonderful body of water of crystal-like clearness, about 21 miles long, 12 miles wide, and more than 500 feet deep, lies partly in Nevada and partly in California in the heart of the Sierras and has but one outlet—the Truckee River. Its waters, consisting chiefly of melted snow, pass through the United States Reclamation Service dam at Tahoe, Cal., and down the Truckee River to Pyramid Lake in northwestern Nevada. This lake is the chief source of water supply for irrigation, power, and municipal purposes in the Truckee Basin, which includes the large agricultural section in western Nevada known as the Truckee Meadows. Naturally a keen interest is taken in the behavior of Lake Tahoe by ranchers, power-plant managers, municipal officials, and many others, not only in the Truckee Valley but also in the Truckee-Carson irrigation project in Churchill County, Nev. Within the limits of the height of the gates at the Tahoe Dam the waters of this lake are under the control of the United States Reclamation Service, so that in seasons of heavy run-off the level of the lake may be regulated with a view to storing as much water as possible for irrigating the Nevada farms, operating the power plants, etc., without permitting the water in the lake to rise to a point where it might damage property on the lake front. This control of the lake's level is as nearly perfect as the ingenuity and watchfulness of the reclamation officials can make it.

A study of the available snowfall and run-off data collected by the Weather Bureau in the Tahoe watershed for the years 1909–1915, begun in the spring and completed in the Fall of 1915, led us to believe that fairly accurate estimates of the probable maximum summer level in Lake Tahoe, and therefore its water supply, might be made several months in advance by a quantitative percentage-relationship method then devised and here briefly described.

The proposed method, which has been tested for two successive seasons with satisfactory results, requires only to know how many inches of snow (unmelted) have fallen monthly from December to April at each of the mountain-snowfall stations in the Truckee-Tahoe watershed. (See Table 1.)

Precipitation data for the months of November, May, June, and July are not necessary, but should exceptionally heavy rains occur in the watershed after May 1—a very remote possibility—the estimated levels would have to be raised accordingly. This correction would be a simple matter. As a rule the precipitation that occurs after May 1 is not at all likely to alter the estimates made earlier in the season.

The average fall of snow for the entire watershed for any month, computed to the nearest whole inch, is obtained by dividing the sum of the several monthly amounts reported, by the number of stations reporting. No attempt at weighting the individual monthly or seasonal falls has been made, for the reason that the number of points (9) at which regular observations are made is so small relatively to the watershed's area (519 square miles) as to make that proceeding unnecessary; also for the further reason that good results have been obtained without such weighting.

To illustrate: The average snowfall for the entire watershed for the month of December, 1915, given as 38 inches in one of the subjoined tables was obtained as shown in Table 1.

TABLE 1.—*Snowfall for the entire watershed of Lake Tahoe, December, 1915.*

Stations.	Altitude (M. S. L.).	Total snowfall, December, 1915 (unmelted).
West side of lake:	*Feet.*	*Inches.*
Hobart Mills, Cal	5,900	32
Truckee, Cal	5,819	25
Tahoe, Cal	6,225	42
McKinney, Cal	6,225	43
Fallen Leaf, Cal	6,400	39
Tallac, Cal	6,225	33
East side of lake:		
Marlette Lake, Nev	7,900	68
Glenbrook, Nev	6,225	28
Bijou, Cal	6,225	29
Sum		339
Average for basin (339÷9)		38

By a similar process a table of average snowfall (cumulative) for the entire watershed, covering the 6-year period from 1909–10 to 1914–15, based on snowfall data collected at the stations named above, has been prepared, and forms the basis of comparison for determining the character, quantitatively, of a season's snowfall. The table follows.

TABLE 2.—*Average cumulative snowfall in the Truckee-Tahoe basin.*

[December to April, 9 stations, 6 seasons.]

Season.	Dec.	Jan.	Feb.	Mar.	Apr.	Entire season.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1909–10	45	126	164	173	173	173
1910–11	5	168	217	285	304	304
1911–12	39	69	69	107	130	130
1912–13	21	111	130	157	157	157
1913–14	45	175	205	207	216	216
1914–15	33	65	150	170	177	177
Cumulative means	31	119	156	183	193	193
Greatest snowfall, season of 1910–11						304
Least snowfall, season of 1911–12						130

From run-off curves for the period from 1910 to 1915, kindly furnished by Mr. L. O. Murphy, hydrographer of the Truckee River General Electric Co., Reno, Nev., Table 3 has been constructed, showing the cumulative run-off from Lake Tahoe by months, from December 1 to time of maximum level (usually June or July) for six seasons, 1910 to 1915. The means at the foot of this table are the ones used for estimating the run-off when the season's snowfall is known. The values given in Table 3 are corrected for "draft"—i. e., amount of water drawn from the lake for various purposes through the dam gates at Tahoe, Cal.

TABLE 3.—*Cumulative changes in level of Lake Tahoe, 1910 to 1915*

[December to July.]

Season.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Entire season.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1909–10	0.48	0.99	1.21	1.54	2.10	2.58	2.61	2.61	2.61
1910–11	0.07	1.40	2.01	2.18	2.71	3.52	4.75	5.07	5.07
1911–12	0.00	0.13	0.13	0.19	0.37	0.88	1.28	1.28	1.28
1912–13	0.00	0.25	0.25	0.25	0.46	1.08	1.33	1.33	1.33
1913–14	0.83	2.06	2.33	2.55	3.25	4.23	4.94	5.01	5.01
1914–15	0.14	0.26	0.94	1.04	1.41	2.03	2.53	2.60	2.60
Cumulative means	**0.25**	**0.85**	**1.15**	**1.29**	**1.72**	**2.39**	**2.91**	**2.98**	**2.98**
Monthly means	0.25	0.60	0.30	0.14	0.43	0.67	0.52	0.07	2.98
Percentage of total change	8	20	10	5	15	23	17	2	100

In Table 4 we give the monthly and seasonal snowfall for the season of 1915–16, December to April, computed for stations, and the monthly and seasonal averages for the entire watershed.

TABLE 4.—*Monthly and seasonal snowfall in Truckee-Tahoe Basin, season of 1915–16.*

Station.	Dec.	Jan.	Feb.	Mar.	Apr.	Season.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Hobart Mills	32	206	22	31	T*	291
Truckee	25	143	18	24	T	210
Tahoe	42	238	22	41	T	343
McKinney	43	227	35	29	T	334
Fallen Leaf	39	187	46	38	0	310
Tallac	33	155	20	38	0	246
Marlette Lake	68	200	36	25	1	330
Glenbrook	28	185	27	16	0	256
Bijou	29	132	26	19	0	206
Means	38	186	28	29	T	281
6-year means	**31**	**88**	**37**	**27**	**10**	**193**
Cumulative means, 1915–16	38	224	252	281	281	281
6-year cumulative means	31	119	156	183	193	193
Season, 1915–16, as a percentage of the 6-year mean	123	188	162	154	146	146

* T indicates amounts less than 1 inch.

LAKE-LEVEL FORECASTS FOR 1916.

In the Spring of 1916 the writer made three forecasts of the probable maximum summer level in Lake Tahoe—the first, March 8, the second, April 6, and the last, May 4—based on the percentage-relationship between the snowfall and change in lake level from December 1 to to February 29, December 1 to March 31, and December 1 to April 30.

First forecast, March 8.

Snowfall, December to February	inches	252
Normal snowfall for same period	do	156
Percentage of normal		162
Normal change in level, March to July	feet	1.83
Probable change in level, same period, 1.62×1.83=	feet	2.96
Lake level on Feb. 29, 1916 (above M. S. L.)	do	6,228.09
Probable maximum stage for 1916	do	6,231.05
Actual maximum lake stage	do	6,230.65

Looking at this forecast from our viewpoint, it will be seen that the snowfall of 1915–16, from December to February, was 62 per cent greater than the normal. Table 3 shows that the normal spring rise after March 1 is 1.83 feet. Now, since the average change in level is proportional (within certain limits) to the average snowfall, and since the latter was 62 per cent above normal, it was assumed that the change in level after March 1 would exceed the normal in practically the same ratio. Of course, it is known that the run-off in this watershed does not vary directly as the snowfall, nor even as the total precipitation. By reason of its great depth and the agitation of its waters by the storms of winter, Lake Tahoe never freezes over. It is, therefore, obvious that from December to February, this season, that part of the precipitation which occurred as rain over the lake plus that part which fell as snow, influenced the lake level as rapidly as it fell and caused the lake to rise 1.61 feet. Of this rise, 1.23/1.61, or 76 per cent, occurred in January, which was a month of phenomenal snowfall. In our computations we have ignored the rainfall because of a regrettable paucity of data and the insuperable difficulties encountered in all attempts to segregate the rain from the snow. However, the writer believes that in an average season the total rainfall will not exceed 10 per cent of the total precipitation. This rainfall factor and losses by evaporation and soil absorption probably account for the observed differences between the predicted and the actual change in level.

Second forecast, April 6.

Snowfall, December to March	inches	281
Normal snowfall, December to March	do	183
Percentage of normal fall		1.54
Normal change in level, April to July	feet	1.69
Probable change in level, April to July, 1.54×1.69=	do	2.60
Actual lake level, Mar. 31 (above M. S. L.)	do	6,228.10
Probable maximum stage for 1916	do	6,230.70
Actual maximum stage for 1916	do	6,230.65

Third forecast, May 4.

Snowfall, December to April	inches	281
Normal snowfall, December to April	do	193
Percentage of normal fall	per cent	146
Normal change in level, May to July	feet	1.26
Probable change in level, May to July, 1.46×1.26=	do	1.84
Actual lake level, Apr. 30	do	6,228.56
Probable maximum lake stage for 1916	do	6,230.40
Actual maximum lake stage for 1916	do	6,230.65

First year trial forecasts, 1915.

By the same method as that described in the foregoing paragraphs, *trial estimates* of the maximum level of the lake for the summer of 1915 were made in the fall of that year.

The estimates for 1915 were based on 10 stations, instead of nine; the 10th station was Lewer's ranch, Nevada, which was dropped from the list because the observations were discontinued at that place in November, 1915.

In the Spring of 1916 another investigation was undertaken and completed for the purpose of ascertaining whether satisfactory results might be had by the same method, but with a smaller number of records. For that purpose we selected four stations—namely, Tahoe, Cal.; McKinney, Cal.; Marlette Lake, Nev.; and Bijou, Cal. In making this selection we had in mind the fact that at ordinary levels the average seasonal snowfall is appreciably less on the east side of Lake Tahoe than on the west side. The average snowfall for the entire Tahoe basin used in the second investigation was that based on the records for the four stations named.

CONCLUSIONS.

The results obtained in 1915, a season of light snowfall, and those for 1916, a season of heavy snowfall, indicate that the proposed method is practical, and that the estimates based on snowfall records for four stations are of practically the same degree of accuracy as those based on a larger number of records.

ANNUAL RISE IN THE COLUMBIA RIVER.

By FLOYD D. YOUNG, Assistant Observer.

(Abstract.)

As is well known the annual rise in the Columbia River is due to the melting of the accumulated snow of spring in the higher levels of headwater streams, and is, therefore, conditioned to a greater or less extent upon the amount of snow which remains upon the ground until early summer and also the temperature over the watershed during the months when melting is going on.

The following table, compiled from the MONTHLY WEATHER REVIEW, shows the temperature and precipitation over the northern Plateau during the snowfall season of 1915–16.

TABLE 1.—*Temperature and precipitation over the northern Plateau.*

Month.	Mean temperature.	Departure.	Mean precipitation.	Departure.
1915.	°F.	°F.	Inches.	Inches.
December	32.2	+0.2	1.58	−0.2
1916.				
January	19.9	−8.9	1.92	+0.3
February	33.9	+1.8	2.26	+0.8
March	43.8	+3.6	1.97	+0.4
April	49.8	+0.8	0.97	−0.4

The above table shows that the temperature was below normal and the precipitation above normal. These conditions were probably more pronounced at higher levels, for many snowfall stations reported more snow than had been previously recorded, and many old settlers reported the greatest depth of snow in the mountains they had ever known.

The following summary was published by the Weather Bureau in the Oregon Snowfall Bulletin for March, 1916:

> Last winter was unusually cold, and the snowfall not only began earlier in the fall and ended later in the spring than usual, but the amounts that fell were the heaviest in years. The snow now in the mountains is well packed and has a high water content. Much of that which has so far melted, soaked into the ground and the soil is well moistened to a good depth. Under normal temperature conditions during April and May higher water than usual will occur during the annual rise in the Columbia River and those cultivating bottom lands should govern themselves accordingly.

The upper tributaries of the Columbia began to rise early, the Kootenai near the end of April, and the Pend d'Oreille early in May; the upper Columbia itself rose gradually and steadily after the first of April. Cold weather near the end of May temporarily checked the rise in the tributaries and the crests occurred in the Pend d'Oreille early in July and in the Kootenai late in June. The Snake River reached the crest later than usual, about the middle of June, but was well on its way down when the crest in the Columbia arrived.

The small discharge of the Snake River was the most unexpected feature of the flood. The highest stage reached at Lewiston was 5.3 feet below the flood stage and at Riparia the crest was 13 feet below the flood stage. As usual, the Columbia at Umatilla, and to a lesser extent the backwater from the Columbia at Portland, closely followed the movements of the Snake River.

The flood stage was reached at Portland, Oreg., on May 7, but cooler weather over the upper watershed caused the water to recede on May 19. The river was again above the flood stage from May 23 to 25 inclusive, after which it fell about 0.5 foot, remaining nearly stationary until June 8 when it began to rise again. The crest was reached on July 4 and 5 with a stage of 23.9 feet. This is the latest date on which the crest of the annual rise has occurred at Portland since gage readings were begun at that place; the latest date previously recorded was July 2, 1880. The crest at Portland was accurately forecast as to time of occurrence, but the actual height was 0.2 foot higher than the stage forecast,