and water have been removed. Since the early days of orchard heating new heaters have been developed, and the growers have equipped themselves with better thermometers; they understand the principles of orchard heating better and are better organized to properly handle the frost fighting.

No thorough, careful tests of the effectiveness of orchard heating under the weather conditions which accompany damaging temperatures during the blossoming period of deciduous fruits in the eastern portion of the United States have been made, so far as the writers are aware. Whether orchard heating will prove to be consistently successful in that portion of the country is highly problematical.

ECONOMIC PHASE OF ORCHARD HEATING.

The writers have confined the discussion of orchard heating in this paper to the question of the practicability of protecting deciduous buds, blossoms, and fruits from damage by spring frosts. The economic side of the question has been purposely ignored, and it will only be touched upon here.

The costs of orchard heating equipment, fuel, etc., vary in different parts of the country, as do the temperatures experienced and the weather conditions which accompany damaging frosts. The grade of fruit produced and prices received for the crops also vary, not only in different districts but in different orchards in the same district.

Obviously, whether orchard heating will pay in a certain orchard will depend on the amount of monetary loss by frost over a period of years and the total cost of protective operations over the same period, including interest on investment, depreciation charge on equipment, and cost of fuel and labor. If the net profit on a crop were the only consideration in determining whether frost protection will pay, the answer would be negative for most if not all the fruit districts of the country. However, when an entire fruit crop is destroyed by frost, the owner's loss is not confined to the net profit he would have made on the crop; the expense of caring for the orchard for a year, interest on the money invested in the orchard, and other similar expenses must be added.

The amount of the loss, therefore, generally speaking, will be the gross value of the crop less the expenses of picking, packing, etc. The loss calculated on this basis is often very large. Many instances have come to the attention of the writers of fruit growers who have saved enough fruit in a single season, or even on a single frosty night, to pay the total cost of equipping the orchard with heaters and auxiliary equipment, together with the expenses of protecting the orchard during the season.

In other words, orchard heating can not be considered on the same basis as fire insurance. Answering a writer who had endeavored to show that orchard heating was unsound from a business standpoint, because the cost was prohibitive when compared to the cost of fire insurance, one of the most successful growers of citrus fruits in California, who has used orchard heaters during the past 12 years, called attention to the fact that if a man was reasonably sure that his house would burn down at least once every 10 years, he would be willing to pay a high premium for insurance.

Another point that must be considered is the fact that whenever a general freeze destroys a large portion of the total crop of a certain fruit, the resulting shortage usually causes higher prices. In such years successful orchard heating usually yields a high return. In many cases this is the factor which makes orchard heating profitable.

The orchards in the United States that sustain sufficient damage by frost to justify the use of orchard heating equipment make up only a very small percentage of the total acreage in fruit trees. Even in the Pacific Coast States orchard heating is generally practiced only in the colder portions of each district.

MOUNTAIN SNOWFALL AND FLOOD CRESTS IN THE COLORADO.

By J. M. SHERIER.

[Weather Bureau, Denver, Colo., Sept. 19, 1923.]

In some respects the situation along the lower Colorado resembles that in the Nile Valley. In addition to the similarity of the soil, climate, and products, a certain amount of water is required each year for irrigation purposes, upon which growing crops are almost wholly dependent and without which there would be a desert. On the other hand, any flood of proportions sufficient to overtop or to break through the principal levees would cause enormous financial loss and endanger many lives. It is not surprising, therefore, that the apprehension felt in western Arizona and southeastern California begins to manifest itself toward the close of every winter in letters and telegrams to the district forecast center, requesting information as to the accumulations of snow in the upper portion of the drainage area, together with the opinion of the forecaster in regard to the prospects of dangerously high water during the following late spring and early summer.

For forecasting purposes, the Colorado drainage area is made up of three divisions. The lower division extends from the mouth of the main stream to Boulder Canyon; the middle division from Boulder Canyon to gaging stations at Elgin, on the Green; Fruita, on the Colorado; and Farmington, on the San Juan. As flood crests due to run-off from the middle division occur early in the season and are not high enough to cause serious trouble, they have not been considered in this discussion.

It must be apparent to all who have had experience in the forecasting of floods that crests produced by melting snow depend not only upon the accumulation of snowfall at the end of the cold season, but also upon the rate at which it is melted and finds its way into the river. In other words, a moderate accumulation in the mountains may disappear so quickly, due to protracted high temperatures, as to cause alarmingly high stages, while unusual amounts of snow at the higher elevations may be taken off by a number of warm periods of only a few days' duration each, followed by weather cool enough to check or to stop the consequent melting. Under the latter conditions, a series of flood crests would result, the highest of which might not be sufficient to cause much alarm. It is not intended to minimize the danger of excessive snow accumulations in the mountains of the upper drainage area at the beginning of spring, but rather to emphasize the fact that the height of subsequent

stages depends largely upon temperature distribution throughout the months of May and June, which, of course, varies from year to year.

During the period from 1900 to 1923 the average crest at Yuma produced by floods that moved down from the upper Colorado was 26.9 feet, gage height. Records of snow depths at stakes now in use at the higher elevations of Colorado are available for the 13 years from 1911 to 1923, inclusive (see Table 1.) Similar records from 18 stakes located on the Green River drainage area in Utah are on hand for the eight years from 1916 to 1923 and for that portion of the Green River drainage area in Wyoming for the nine years from 1915 to 1923.

TABLE 1.—*Average depth of snow on ground in the upper Colorado drainage area at the end of March, together with the resulting combined discharges in the upper Colorado and its tributaries and the discharges and stages at Yuma.*

Year.	Average depth of snow, upper Colorado drainage, Mar. 31.	Departure from the normal for 13 years.	Greatest combined discharge.	Date.	Highest stage at Yuma, May and June.	Date.	Greatest discharge at Yuma, May and June.	Date.	Departure of crest stage at Yuma from normal.
	Inches.		*c. f. s.*				*c. f. s.*		
1911...	[1] 22	−6	80,770	June 10	25.8	June 24	78,300	June 24	−1.1
1912...	[1] 34	+6	139,030	....do....	29.0	June 22	144,000	June 22	+2.1
1913...	[1] 25	−3	69,570	May 31	22.8	June 11	62,508	June 10	−4.1
1914...	[1] 23	−5	137,740	June 3	29.0	June 14 and 15	137,000	June 14 and 15	+2.1
1915...	[2] 22	−17	62,310	June 13	24.0	May 8	66,200	May 8	−2.9
1916...	32	−2	86,030	May 13	25.0	May 23 and 24	74,800	May 24	−1.9
1917...	39	+5	153,200	June 20	29.5	July 1	142,900	July 4	+2.6
1918...	26	−8	118,590	June 15	24.7	June 26	94,300	July 3	−2.2
1919...	21	−13	64,650	May 29	23.4	June 1	57,600	June 6	−3.5
1920...	45	+11	137,940	May 27	30.5	June 8	170,000	June 8	+3.6
1921...	29	−5	169,820	June 16	31.3	June 28	185,700	June 28	+4.4
1922...	43	+9	112,030	May 29	27.4	June 10	115,000	June 10	+0.5
1923...	45	+11	108,830	....do....	25.4	June 9	100,000	June 9	−0.5

[1] For Colorado only.
[2] For Colorado and Wyoming; Utah missing.

There was a deficiency in snow on the ground at the end of March during the years 1911, 1913 to 1915, 1918, 1919, and 1921, with the greatest departure from the average in 1915. In all of these years, excepting 1914 and 1921, the flood crests at Yuma were also below the normal. The maximum stage in 1914, however, was 29 feet, or 2.1 feet above the average, while in 1921 the highest summer stage of record occurred on June 28. In 1916 the snowfall was slightly below normal, and the highest stage in the lower river was also less than the average. In 1912 and 1917, with a snow accumulation considerably above normal, the maximum stages at Yuma were 2.1 feet and 2.6 feet, respectively, above the average flood crest. Excessive accumulations of snow were recorded at the end of March in 1920, 1922, and 1923. In the first of these years one of the three summer stages of record above 30 feet occurred on June 8, when the gauge reading at Yuma was 30.5 feet. In 1922 and 1923, however, although the situation at the beginning of spring seemed especially alarming and much anxiety was expressed by users of the waters of the Colorado and by some of the scientists who were directly interested in the action of the stream, unusually high water failed to result, the maximum stage for the two years being but 27.4 feet on June 10, 1922.

Although the breaking of the levee at Hauser Bend, near Ripley, Calif., in 1922 resulted in the inundation of 30,000 acres, including the important towns of Ripley, Palo Verde, and Rannels, with a property loss that has been estimated at $1,000,000, this local disaster was due more to the weakness of the levee itself than to especially high water, as the stage at the time was not greatly above flood.

In the season just ended, 1923, warm periods were so alternated with temperatures low enough to check the melting at the higher elevations that the crest stage at Yuma was but 25.4 feet, 1.5 feet below the average summer crest, and only 0.4 foot above the flood stage.

To summarize, the crest stages in the extreme lower river agreed fairly well with what might have been expected from the snowfall data in all of the years from 1911 to 1920, with the single exception of the year 1914. During the past three seasons any forecast as to relative stages, based upon snow depths, would have been remarkable failures, especially in 1921 and the current year. The percentage of verification for the entire 13-year period would not have averaged more than 69.

Heavy general rains seldom occur over the upper drainage area at the time when the snow is disappearing most rapidly, but it naturally follows that excessive precipitation here, as elsewhere, will aggravate flood conditions. During June, 1921, a year in which the snowfall at the end of March was considerably below normal, general showers occurred in the upper portion of the drainage area from the 4th to the 9th and on the 14th and 15th, when the upper Colorado and the Green were already in flood. The precipitation which occurred at that time, combined with the effects of unusually high temperatures from the 8th to the 13th, inclusive, produced a stage at Yuma of 31.3 feet on the 28th, as already stated, the highest summer gage reading of record at that place. Failure to make adequate preparation for high water, based upon the deficient snow accumulation in the upper drainage area, would have resulted in a catastrophe in the region of Yuma.

The method of forecasting for the Lower Colorado was devised by Brandenburg and described in the May, 1919, issue of the MONTHLY WEATHER REVIEW, pages 309–311. Briefly, this is based upon the combined discharge at the rating stations at Elgin, Utah, upon the Green, and at Fruita, Colo., upon the Colorado River, together with a discharge for the San Juan that is estimated from the gauge readings made at Farmington, N. Mex. Prior to 1922, about the only checks upon the predictions made for the extreme lower Colorado, based upon the stages and discharges in the upper drainage area, were the stages reported from Topock, Ariz. Owing to frequent changes in the bed of the stream at that place, however, there was a considerable variation in gauge heights for nearly the same discharges. With the establishment, in 1922, of a rating station at Lees Ferry, Ariz., by the Southern California Edison Co., in cooperation with the United States Geological Survey and the United States Weather Bureau, and the subsequent opening of similar stations at the foot of Bright Angel Trail, Grand Canyon, Ariz., and Topock, Ariz., by the United States Geological Survey and the Weather Bureau, it is now possible to check the combined discharge of the Green, the upper Colorado, and the San Juan at least twice and probably three times, depending upon the ability of the hydrographer at Lees Ferry to have his reports delivered to a distant telegraph office before the flood reaches the lower division of the stream. The checks provided by the rating stations at Lees Ferry and the Grand Canyon, especially, during the time these data have been available, have shown the estimates of the combined discharges in the upper drain-

age basin to have been remarkably accurate and reliable. After the middle of May, the time interval between the rating stations at Elgin and Fruita and the gauge at Yuma is about 12 days. By estimating the discharge at the upper stations a couple of days in advance, a general prediction for the extreme lower division of the Colorado can be made two weeks before the occurrence of the crest stage at Yuma. The final check at Topock is made six days in advance of the arrival of the flood crest at Yuma.

Forecasts based upon these data are sufficiently accurate for all practical purposes, usually to within a few tenths of a foot at the time of the highest water of the season. It does not seem possible, therefore, under the present conditions for any flood to pass from the upper reaches of the Colorado to the Imperial Valley without the distribution, nearly two weeks in advance, of such warnings as will prepare all interested persons to meet the emergency. It is not safe to attempt to make predictions for a longer period.

FLOOD OF OCTOBER 22-25, 1923, IN CANAL ZONE.[1]

By R. Z. KIRKPATRICK, Chief Hydrographer.

[Balboa Heights, Canal Zone, Nov. 23, 1923.]

The week previous to the flood, Isthmian weather conditions were influenced by a West Indian hurricane, reported as central between Colon and the Island of Jamaica. Strong south and southeast winds were experienced and unusually dry weather for this season of the year occurred. Whether or not the hurricane had any influence on the extreme rainy period that followed is conjectural; however, as soon as the center of the disturbance had moved northward sufficiently that it no longer caused prevailing southerly winds, normal direction of northerly and westerly winds was again recorded; their velocity increased and conditions of the "norther" type began.

Rainfall.—Early Sunday morning, October 21, rain began to fall and continued with few breaks until Saturday, October 27. The temporary lull in the storm that occurred on the 23d was a very fortunate occurrence, in that it gave a few hours for lowering the already high level of the lake and thus facilitated the handling of the enormous quantity of water that came in on the 24th. Previous rainfall records were broken and new maxima established at several stations north of the Continental Divide. The following table gives the amount of rainfall recorded at selected stations during the storm period:

Rainfall (inches).

Date.	Porto Bello.	Colon.	Gatun.	Monte Lirio.	Gamboa.	Alhajuela.	Vigia.	Pedro Miguel.	Balboa Heights.
Oct. 21....	1.48	4.26	4.58	4.94	1.88	0.89	0.34	0.57	0.36
Oct. 22....	3.27	9.02	9.09	6.84	6.75	7.33	7.40	3.64	3.14
Oct. 23....	5.43	4.23	3.36	5.02	1.89	2.81	3.54	1.09	.88
Oct. 24....	4.17	10.03	10.99	7.97	4.64	8.22	7.51	3.65	2.98
Oct. 25....	1.96	1.76	.63	1.58	.35	.34	.38	.09	.04
Oct. 26....	3.78	5.94	3.98	4.58	.90	.16	.57	.10	.01
Oct. 27....	1.56	.71	2.54	4.04	2.06	1.75	2.17	.69	.35
Total.. .	21.65	35.95	35.17	34.97	18.47	21.50	21.91	9.83	7.76

A maximum 24-hour rainfall of 12.25 inches was recorded at Gatun from 7:34 p. m. on the 23d to 7:34 p. m. on the 24th. This breaks all records for 24-hour isthmian rainfall, the previous maximum being 10.86 inches at Porto Bello on December 28-29, 1909.

In order to give a comparison of the recent flood with that of December, 1909. the following table showing rainfall for this period is furnished below:

Rainfall (inches).

Date.	Porto Bello.	Colon.	Gatun.	Monte Lirio.	Gamboa.	Alhajuela.	Vigia.	Pedro Miguel.	Balboa Heights.[1]
1909.									
Dec. 26....	5.55	3.69	3.99	5.35	2.66	5.56	2.25	2.12	2.16
Dec. 27....	2.21	1.85	3.84	1.00	1.10	1.70	(2)	2.31	1.31
Dec. 28....	3.64	.50	.21	.62	.32	3.49	.....	.06	.06
Dec. 29....	7.96	.36	.30	.10	.34	1.09	.....	.06	.20
Dec. 30....	4.94	3.29	2.36	2.77	2.18	2.91	.....	2.25	1.16
Dec. 31....	1.07	.40	.84	.18	.08	.02	.....	.05	.08
1910.									
Jan. 1.....	3.02	1.13	.97	.78	.30	.24	.....	.36	.03
Total....	28.39	11.22	12.51	10.80	6.98	15.01	.....	7.21	5.00

[1] Station then Ancon. [2] Station washed out at 8 a. m., 26th.

A comparison of the two tables shows that while the rainfall at the headwaters of the Chagres and Pequeni Rivers was lower during the recent flood, the rainfall over the Gatun Lake area, especially the northern end, was about three times as heavy as during the 1909 flood period.

THE CHAGRES RIVER.

Alhajuela.—A slight rise on the Chagres occurred in the early morning of the 21st, but the crest was soon reached and the river dropped to elevation 93 feet and continued near this elevation until the beginning of the big flood. At 9 a. m. on the 22d, the river began to rise rapidly, continuing to rise steadily until 10:30 p. m., when a crest of 117.40 feet was recorded. The crest of the flood really lasted from about 9 p. m. until 12:30 a. m., after which it fell about as fast as it had risen, reaching 99.20 feet at 6:30 p. m. of the 23d. A second and slower rise then began, reaching elevation 112.80 feet at 4:30 p. m. of the 24th. This second crest was of shorter duration, lasting from 4 to 5 p. m., after which the river dropped about as rapidly as it had risen, and was at elevation 101 feet by 7 a. m. the morning of the 25th. From this point the drop in the river was very slow.

Vigia.—At Vigia the initial height of the river was 128.40 feet at 8 a. m. of the 22d. The rise in the river began about 45 minutes earlier than at Alhajuela. No record was obtained after 6:45 p. m., owing to the instrument house being flooded. Telephone communications between Alhajuela and Vigia were also severed about this time and nothing further was heard from Vigia

[1] See MO. WEATHER REV., Oct., 1923, 51:530.