

GREAT FLOODS IN NEW ENGLAND RIVERS.

The great floods in New England during the last 63 years were those of April, 1852, May, 1854, April, 1862, October, 1869, April, 1895, and March, 1896.

We may distinguish two kinds of floods: (1) Those due to the occurrence of heavy and continuous precipitation in the warm season; and (2) those due to the occurrence of heavy rain in conjunction with a thaw in the winter or spring. The floods of 1854 and 1869 are typical of the first class; those of 1862, 1895, and 1896 of the second class.

The flood of 1869 was due to what was probably an unprecedented rainfall throughout New England and the adjoining territory on the west and southwest. Although the United States Weather Bureau was not in existence at that time, there was a small body of observers reporting to the Smithsonian Institution, of Washington, D. C., and from their reports we are able to compile a fairly accurate table showing the amount and horizontal distribution of the rainfall that produced the flood in question. This table appears in a subsequent portion of this paper.

The tendency to a maximum of flood frequency in the spring is a marked characteristic of New England Rivers. The distribution of floods by months is shown in the table below.

TABLE 2.—Distribution of floods by months.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Hartford, Conn.	2	3	10	20	7	0	1	1	0	1	2	1	48
Lawrence, Mass.	2	3	10	12	5	0	1	0	0	1	0	1	35

Floods due to rain.

We will first consider the summer floods or those floods due wholly to rainfall as distinguished from floods due partly to rainfall and in part to melting snow.

The flood of July, 1897.—The month of July, 1897, was remarkably rainy in New England. The floods of July 16, 1897, were confined mostly to the streams that drain into the Connecticut, the maximum stage of the Connecticut at Hartford was 20.8 feet, or 4.8 feet above its flood stage. It was due wholly to heavy and continuous rains in connection with a barometric depression that approached New England on July 12, extending southward from the St. Lawrence Valley to Georgia. On July 13 and 14 the eastward progress of the storm was retarded and heavy showers fell over New England. On the 13th the greatest amounts were recorded in Connecticut, viz:

	Inches.
Bridgeport, Conn.	8.11
Canton	5.18
Middletown	5.09
New Haven	5.91
Southington	6.60
Windsor	6.90
Waterbury	6.03

The rains continued over the whole of New England on the 14th, being heavy in many places, but on the 15th, while there were showers at a number of places, heavy precipitation had ceased.

Fortunately, the rains in the upper watershed of the Connecticut did not exceed 5 inches in 24 hours at any

single point. The flood in the Connecticut was, therefore, greatest in the lower part of the river.

The flood of October, 1869.—Probably the greatest of all "rain floods" in New England was the so-called "pumpkin flood" of October 6, 1869. This flood was remarkable in that it came at a time of year when the streams were at a very low stage. In point of magnitude the flood of 1869 at Hartford ranks as the sixth in the last 63 years. (See Table 1.) Since it was due to a rainstorm of wide extent and long duration we have compiled the contemporaneous records of rainfall made by observers of the Smithsonian Institution, and present them in Table 3 below. The rainfall reports are arranged by States, beginning with Virginia and the District of Columbia.

TABLE 3.—Precipitation in the storm of October 2-5, 1869.

(In inches and hundredths.)

Station.	Location.	October, 1869.				Total for storm.	Remarks.
		2	3	4	5		
<i>Virginia.</i>							
Comarn	King George	In. 0.34	In. 5.05	In. 0.02	In. ....	In. 5.41	5.05" in 18 hours.
Mulberry Hill	Isle of Wight	.....	3.16	.....	.....	3.16	3.16" in 15 hours.
Johnsontown	Northampton	0.10	.....	1.05	.....	1.15	.....
Hampton	Elizabeth City	0.30	.....	1.90	.....	2.20	1.90" in 24 hours.
Lexington	Rockbridge	.....	2.75	.....	.....	2.75	.....
Norfolk	Norfolk	0.85	1.20	.....	.....	1.55	.....
Snowville	Pulaski	.....	1.25	.....	.....	1.25	.....
Staunton	Augusta	.....	1.50	0.75	.....	2.25	.....
Vienna	Fairfax	.....	.....	4.50	.....	4.50	More than 24 hrs.
<i>District of Columbia.</i>							
Washington	Dist. Columbia	.....	.....	6.55	.....	6.55	All in about 24 hrs.
<i>Maryland.</i>							
Annapolis	Anne Arundel	0.13	3.42	1.83	.....	5.38	.....
Mount St. Marys	Frederick	.....	.....	5.14	.....	5.14	In 36 hours.
St. Marys	St. Marys	.....	.....	2.25	.....	2.25	.....
Woodlawn	Cecil	0.08	.....	3.94	.....	3.97	3.94" in 24 hours.
<i>New Jersey.</i>							
Greenwich	Cumberland	.....	.....	3.25	.....	3.25	.....
Vineyard	do	.....	.....	2.87	.....	2.87	In 30 hours.
Moorestown	Burlington	.....	.....	2.41	.....	2.41	.....
Rio Grande	Cape May	.....	.....	3.50	.....	3.50	In 37 hours.
Tronton	Mercer	.....	.....	2.61	.....	2.61	In 33 hours.
New Brunswick	Middlesex	.....	.....	3.27	.....	3.27	.....
New Germantown	Hunterdon	.....	.....	4.43	.....	4.43	In 27 hours.
Paterson	Passaic	.....	1.09	3.06	.....	4.15	.....
Newton	Sussex	.....	.....	7.11	.....	7.11	5.21" in 27 hours.
Haddonfield	Camden	.....	.....	3.32	.....	3.32	In 28 hours.
Newark	Essex	.....	.....	3.30	.....	3.30	In 12 hours.
<i>Pennsylvania.</i>							
Canonsburg	Washington	1.00	.....	0.40	.....	1.40	.....
Franklin	Venango	0.14	0.15	0.13	.....	0.42	.....
Pennsville	Clearfield	.....	.....	0.57	.....	0.57	.....
Johnstown	Cambria	.....	0.76	.....	.....	0.76	.....
Carlisle	Cumberland	0.30	.....	4.20	.....	4.50	4.20" in 24 hours.
Fountaindale	Adams	.....	.....	4.58	.....	4.58	In 36 hours.
Lewisburg	Union	T.	.....	3.60	.....	3.60	.....
North Abington	Luzerne	.....	1.60	2.80	.....	4.40	In 30 hours.
Blooming Grove	Pike	.....	.....	7.50	.....	7.50	In 32 hours.
Dyberry	Wayne	.....	1.15	3.00	.....	4.15	All in 24 hours.
Hamlington	do	.....	6.00	.....	.....	6.00	In about 39 hours.
Fallsington	Bucks	.....	.....	2.90	.....	2.90	In 27 hours.
Moorland	Montgomery	.....	4.50	.....	.....	4.50	.....
Plymouth Meeting	do	.....	.....	6.00	.....	6.00	In 27 hours; 4.10" in 12 hours.
Ephrata	Lancaster	.....	.....	8.05	.....	8.05	In 60 hours.
Mount Joy	do	.....	.....	8.00	.....	8.00	.....
Philadelphia	do	.....	.....	3.95	.....	3.95	In 31 hours.
Pocopson	Chester	0.04	5.00	0.20	.....	5.24	.....
West Chester	do	.....	.....	5.80	.....	5.80	In 36 hours.
Reading	Berks	.....	.....	6.73	.....	6.73	Do.
Tioga	Tioga	.....	1.50	0.50	.....	2.00	.....
<i>New York.</i>							
Little Genesee	Allegany	1.05	.....	.....	.....	1.05	.....
Gouverneur	St. Lawrence	.....	.....	2.87	.....	2.87	.....
N. Hammond	do	.....	1.07	1.40	.....	2.47	.....

1 See also Francis, James B. Distribution of rainfall during the great October storm of 1869. Trans., Amer. soc. civil eng., New York, 1878, 7: 224.

TABLE 3.—Precipitation in the storm of October 2-5, 1869—Continued.

Location.		October, 1869.				Total for storm.	Remarks.
Station.	County.	2	3	4	5		
<i>New York—Continued.</i>							
Cooperstown....	Oswego.....		1.10	2.00		3.10	
Ardenia.....	Putnam.....			4.66		4.66	
Brookhaven....	Suffolk.....			5.34		5.34	In 28 hours.
Erasmus Hall..	Kings.....			3.46		3.46	
Hudson.....	Columbia....			7.90		7.90	In about 34 hours.
Minville.....	Montgomery..			5.25		5.25	In about 36 hours.
New York City..	Kings.....			4.00		4.00	In about 43 hours.
Do.....	do.....			3.98		3.98	
South Hartford.	Washington...	0.65		4.15	1.10	4.80	In 38 hours.
West Point....	Orange.....			5.00*		5.00	In 36 hours.
<i>Connecticut.</i>							
Colebrook.....	Litchfield....			8.44		8.44	In about 42 hours.
Canton.....	Hartford....			12.35		12.35	
Brookfield....	Fairfield....			5.50		5.50	In 36 hours.
Hartford.....	Hartford....			8.43		8.43	
Middletown....	Middlesex....			8.96		8.96	In 36 hours.
New Haven....	New Haven...			4.30		4.30	
<i>Massachusetts.</i>							
Amherst.....	Hampshire....			5.84*		5.84	In 15 hours.
Hinsdale.....	Berkshire....	1.80		3.60		5.30	3.10" in 4 hrs; 4.70" in 23 hrs.
Kingston.....	Plymouth....			1.75		1.75	
Lawrence....	Essex.....			3.56		3.56	In about 36 hours.
Lunenburg....	Worcester....			7.50		7.50	In about 35 hours.
Mendon.....	do.....			2.80		2.80	
Milton.....	Norfolk.....			1.15		1.15	In 19 hours.
New Bedford..	Bristol.....			4.37		4.37	In 19½ hours.
Topshfield....	Essex.....			1.77		1.77	In 28 hours.
West Newton..	Middlesex....			2.33		2.33	Do.
Williamstown..	Berkshire....			6.00		6.00	In about 39 hours.
Worcester....	Worcester....			4.75*		4.75	In 29 hours.
Cambridge....	Suffolk.....			1.58		1.58	
Boston.....	do.....			1.76		1.76	
Georgetown..	Essex.....			2.25		2.25	
Waltham.....	Middlesex....			1.65		1.65	
Lake Cochituate.	do.....			4.00		4.00	
Lowell.....	do.....			2.84		2.84	
Fitchburg....	Worcester....			7.53		7.53	3.99" in 2½ hours.
Chicopee....	Hampden....			8.71		8.71	
Springfield..	do.....			8.05		8.05	8.05" in 37 hours.
Pittsfield....	Berkshire....			6.00		6.00	
Richmond....	do.....			3.97		3.97	More than half in 3 hours.
<i>Vermont.</i>							
Middlebury....	Addison....		3.40	0.58		3.98	3.40" in 30 hours.
Ferrisburg....	do.....		3.50	0.87		4.37	
Brandon.....	Rutland....		4.25			4.25	
Burlington....	Chittenden..		3.71			3.71	
West Charlotte.	do.....	0.87	3.12	0.87		4.86	4.00" in 20 hours.
Castleton....	Rutland....		4.60	1.97		6.57	4.60" in 30 hours.
Craftsbury..	Orleans....		4.49			4.49	In 50 hours.
Lunenburg....	Essex.....		3.90	0.10		4.00	3.90" in 35 hours.
Randolph....	Orange.....		5.00	0.30		5.30	5.00" in 36 hours.
Woodstock....	Windsor....	1.75	4.60			6.35	6.35" in 35 hours.
<i>New Hampshire.</i>							
Hanover.....	Grafton.....			5.88		5.88	
N. Barnstead.	Belknap....			7.40		7.40	In about 36 hours.
Weirs Landing.	do.....			6.40		6.40	
Whitefield..	Coccs.....	1.60	3.41	0.40		5.31	2.75" in 14 hours.
Stratford....	do.....	1.17	2.53			3.70	
Tamworth....	Carrol.....			6.35		6.35	In 30 hours.
Goffstown....	Hillsboro..	0.78	7.28			8.06	4.27" in 3 hours.
Concord.....	Merrimack..			7.40		7.40	4.00" in 2 hours.
Dover.....	Stratford....			3.20		3.20	
<i>Maine.</i>							
Standish....	Cumberland..		4.31			4.31	
Fort Preble..	do.....		1.99			1.99	In 37 hours.
Cornish.....	York.....	2.63	3.80			6.43	2.63" in 26 hours.
Gardiner....	Kennebec....		3.37			3.37	In 31 hours.
West Waterville.	do.....		4.10			4.10	In 36 hours.
Rumford....	Oxford.....		8.00			8.00	
Norway.....	do.....		6.70			6.70	2.50" in 2 hours.
Oxford.....	do.....		6.70			6.70	In 36 hours.
Orono.....	Penobscot..		2.13			2.13	
Houlton....	Aroostook..		3.60			3.60	In about 54 hours.
Lisbon.....	Androscoggin.		2.70			2.70	
Williamsburg.	Piscataquis..	1.80	3.50			5.30	

\* Gage overflowed.

1913, are prominent examples of the kind of rains which fell over the lower portions of the Connecticut Valley during October, 1869. It will be noted that the Connecticut River had relatively higher stages along its lower reaches than in the upper portion of its course, due to the fact that the very heavy rainfall was apparently concentrated over the western portions of Massachusetts and Connecticut.

The lesson to be drawn from the foregoing appears to be that although summer floods, or more strictly speaking what may be called "rain floods," occur very infrequently in New England, the probability of such a flood can not be disregarded. The occurrence of flood-producing rains in the warm season, such as those of October, 1869, and July, 1897, seems to be due to an extraordinary combination of atmospheric conditions, such as may occur probably but once in a lifetime.

*Spring floods due to rain and snow.*

A destructive spring freshet or flood due solely to the breaking up of ice in the streams and the melting of the snow cover, is practically unknown. The accumulated snow on the headwaters of a watershed is therefore considered merely as an important modifying factor in flood causation. Further, the writer is of the opinion that, as a rule, the snow cover is of less importance in producing severe floods than is generally believed. Snow that has remained on the ground for some time melts almost imperceptibly into itself and thus the first effects of melting are to increase the density of the snow. Generally a subsequent freezing takes place, and the snow cover is finally not in a condition to melt rapidly, thus the danger of a severe flood due only to melting of snow becomes a remote probability.

*New England flood of April, 1895.*—The floods of April, 1895, and March, 1896, in New England streams were due in both cases to heavy and continued rains at a time when the snow cover was sufficient, if melted, to greatly intensify the flood waters.

The barometric minimum that was the direct cause of the rains that fell over New England on April 13, 14, 15, 1895, was not unusual in any way, but its movement across New England occupied about three days. On the 14th the center of the Low was partly over the ocean and partly over the land, a position favorable to a continuous inflow of air from the ocean. The precipitation of the second day was the heaviest of the storm period; at a number of places the amount exceeded 2 inches. On the third day the rains became lighter and ceased in some portions. The average precipitation for the storm is shown by States in Table 4.

TABLE 4.—Average precipitation over New England, Apr. 13-15, 1895, by States.

State.	Number of stations.	Average precipitation.
Maine.....	12	Inches. 2.17
New Hampshire.....	16	2.87
Vermont.....	14	2.42
Massachusetts.....	35	2.01
Rhode Island.....	5	3.46
Connecticut.....	14	0.94

The central area of New England had, therefore, an average rainfall of slightly over 2 inches in the three

From Table 3 we see that the rainstorm of October 2-5, 1869, was of wide extent and that its maximum intensity was of unusual duration. It is very exceptional that heavy rains persist for so long a period as 24 hours. The rains in the Ohio Valley during the latter part of March,

days. The extremes were of course much greater. At North Conway, N. H., the fall was 6.25 inches from the morning of the 13th until the morning of the 15th. Over 4 inches fell in 24 hours at North Bridgeton, Me., Plymouth and Berlin, N. H., Woodstock, Vt., and Natick, Mass.

Earlier in the month there had been considerable rain and the soil where not frozen was doubtless saturated with water; moreover there was still some snow on the ground in the central and northern portions of New Hampshire, Vermont, and Maine. The greater portion of this snow was melted and ran into the streams in connection with the heavy local rains of the 8th-10th of the month. The heavy rains of the 13th-15th, therefore, must have come upon streams already at a moderately high stage.

At the time of the flood no systematic measurements of the stages of the rivers of New England were being made by the Weather Bureau, and, so far as known, but few private measurements were made. The few actual records we have been able to obtain are as follows:

Stations.	Stages.	Below highest previous stage.
<i>Connecticut River.</i>		
Holyoke, Mass.....	Feet. 9.3	Feet. 2.7
Springfield, Mass.....	20.3	1.9
Hartford, Conn.....	25.7	3.4
<i>Merrimac River.</i>		
Lawrence, Mass.....	26.9	2.8

*New England flood of March, 1896.*—A second severe flood occurred in New England rivers in March, 1896. In the Merrimac River this flood gave a stage of 29.7 feet at Lawrence, the highest stage recorded in the sixty-odd years during which measurements have been made.

The weather leading up to the flood was stormy and rainy. The rains began on February 29, 1896, and were universal over New England, the daily amounts varying from less than ½ inch up to as much as 4 inches. The average daily amounts for each of the New England States are shown in Table 5.

TABLE 5.—Average precipitation over New England, Feb. 29 to Mar. 4, 1896.

States.	Number of stations.	Average precipitation.					Total.
		Feb. 29.	March.				
			1	2	3 <sup>1</sup>	4 <sup>1</sup>	
Maine.....	11	1.00	1.94	0.25	0.57	0.25	4.01
New Hampshire.....	16	1.05	1.30	.73	.25	.14	3.47
Vermont.....	13	1.20	0.29	.16	.29	.07	2.01
Massachusetts.....	30	0.97	.74	.46	.40	.07	2.64
Rhode Island.....	6	1.22	.67	.21	.35	.06	2.51
Connecticut.....	13	2.62	.27	.11	.06	.02	3.07

<sup>1</sup> Precipitation on Mar. 3 and 4 was mostly in form of snow.

When the rain began there were from 1 to 2 feet of snow on the ground in the northern portion of New England, and except in the densest woods most of it melted and ran into the streams.

The storm which was the immediate cause of the rain advanced rapidly from the mouth of the Mississippi River on February 29, 1896. Its northeastward course

over New England was, however, apparently blocked by high pressure over the Canadian maritime Provinces, and an area of high pressure advancing from the west across the Great Lakes. In any event, the ordinary movement of the storm to the northeast across New England was prevented, with the result that it lingered over southern New England until March 5, when it apparently moved eastward south of Nova Scotia.

The rain turned to snow on March 2, and the weather became much colder on the 3d and 4th, thus mitigating the severity of the floods.

*New England flood of May 1, 1854.*—There remains but one more great flood in New England to consider, viz, the flood of May 1, 1854. This flood gave the highest water in the Connecticut ever recorded at Hartford, Conn., and Springfield, Mass. It was not a remarkable flood in the Merrimac, the only other New England river for which reliable records are available. Although more than half a century has elapsed since the occurrence of the flood, the meteorological reports made at the time to the Smithsonian Institution show that the extremely high water in the lower Connecticut resulted from the prevalence of heavy rains, which began on the evening of Thursday, April 27, and continued practically without intermission until noon of Sunday, May 1, a period of about 90 hours. During these 90 hours the following amounts of rainfall were recorded:

	Inches.
Springfield, Mass.....	5.16
Southwick, Mass.....	7.52
Saybrook, Conn.....	6.00
Pomfret, Conn.....	3.45
Concord, N. H.....	3.50
Manchester, N. H.....	3.25
St. Johnsbury, Vt.....	2.60
New York City.....	4.67
Philadelphia, Pa.....	4.87

and smaller amounts were recorded at many other places.

The 24-hour fall in this storm was not exceptionally large, the greatest recorded amount being 3.50 inches in 12 hours, at Southwick, Mass. It seems probable that in this storm the rains of greatest intensity fell over extreme southeastern New York, western Massachusetts, and western Connecticut. The precipitation for a part of the storm in Vermont, New York, and New Hampshire was in the form of snow. There may have been some snow on the north slopes of the watershed in New Hampshire and Vermont at the beginning of the warm spell that immediately preceded the storm, but of this we have no reliable record. The storm was preceded by warm southerly winds and thunderstorms over southern New England, New Jersey, and southeastern New York on April 25, 26, and 27. On the 27th there was a marked change to lower temperature over western Massachusetts, and a cold easterly rain immediately set in, continuing, as above stated, with but little intermission until Sunday, May 1.

PRECIPITATION AND RUN-OFF DURING A TYPICAL FLOOD.

Since it seems of interest to compare the precipitation and the run-off that occur during a typical New England flood, the writer has compiled the data for the flood of April 14-19, 1895, in the Merrimac River, New Hampshire.

The drainage basin of the Merrimac above Lawrence, Mass., embraces 4,664 square miles. The average precipitation over New Hampshire for the period April 13-15, 1895, was 2.87 inches, as averaged from the reports of 22 stations. Since 1 inch of rainfall over an area of 1 square mile involves 2,323,200 cubic feet of water,

then the above rainfall of 2.87 inches depth amounted to 6,667,584 cubic feet per square mile. Therefore the volume of water precipitated upon the 4,664 square miles of the drainage basin of the Merrimac during the period April 13-15, 1895, amounted in all to 31,097,611,776 cubic feet. This precipitation was carried off by the Merrimac as shown by Table 6.

TABLE 6.—Discharge of the Merrimac River at Lawrence, Mass., Apr. 14-19, 1895.

Date.	Stage.	Equivalent discharge per second.	Total daily discharge.
1895.			
	<i>Feet.</i>	<i>Sec.-feet.</i>	<i>Cubic feet.</i>
Apr. 14.....	*18.0	*34,300	*2,963,520,000
Apr. 15.....	19.9	40,267	3,479,068,800
Apr. 16.....	26.9	62,100	5,365,440,000
Apr. 17.....	24.2	54,800	4,734,720,000
Apr. 18.....	18.2	35,000	3,024,000,000
Apr. 19.....	15.2	28,060	2,246,400,000
Total.....			21,813,148,800

\* Estimated; no reading made.

If no rain had fallen after the 13th it is estimated that the stage of the river due to the water supply then on

hand would have been 10.5 feet, and that the total discharge for the 6 days would have equaled 6,531,840,000 cubic feet. Subtracting this amount from the actual total flood discharge, there remains 15,281,308,800 cubic feet, the approximate discharge due to the rains. The total precipitation that caused the flood was 31,097,611,776 cubic feet and the percentage of run-off is therefore 49. This run-off value corresponds fairly well with the run-off values for certain Maine rivers given in Table 7.

TABLE 7.—Rainfall and run-off for certain drainage basins in Maine for 1903.

Basin and river.	Gaging station.	Drainage area.	Precipitation.*		Run-off.*	
			<i>Sq. miles.</i>	<i>Inches.</i>	<i>Inches.</i>	<i>Per cent.</i>
Penobscot:						
Mattawamkeag.....	Mattawamkeag....	1,510	34.3	19.40	53	
Piscataquis.....	Foxcroft (near)....	280	34.5	25.33	69	
Penobscot, East Branch.	Grindstone.....	1,130	35.0	16.44	47	
Kennebec:						
Kennebec.....	The Forks.....	1,670	31.7	21.30	67	
Do.....	North Anson.....	2,880	32.0	19.20	60	

\* Precipitation from the few existing stations of the Weather Bureau; run-off from the values published in the Water Supply Papers of the U. S. Geological Survey.