THE NEW ENGLAND FLOOD OF NOVEMBER, 1927

By H. B. Kinnison

INTRODUCTION

On November 3 and 4, 1927, torrential rains fell over much of New England, causing the most severe floods of which we have knowledge over extensive areas in Vermont, New Hampshire, Massachusetts, Connecticut, and Rhode Island. Vermont experienced an exceedingly heavy rainfall, the area of greatest precipitation centering on the long ridge of the Green Mountains and extending southward over western Massachusetts into Connecticut. A smaller area of equal and possibly much greater rainfall centered on the White Mountains of New Hampshire, with lighter rainfall over the southern and northern portions of the State. A third area of much smaller extent, but with recorded intensities of precipitation practically as great as in Vermont, centered in northern Rhode Island and extended northward to Worcester, Mass.

The destructiveness of such a storm depends upon a number of circumstances, important among which are the character of the soil, the topography, the condition of the ground and of the streams and ponds, and the rate of precipitation. At the time of this storm the ground had been thoroughly saturated by heavy rains which fell from the 18th to the 21st of October. The natural lakes and swamps had been filled, and most of the rivers had been raised to medium high stages, so that practically all the surface storage available had been utilized less than two weeks before the storm.

As a result, the rivers quickly overflowed their banks, spread over meadows and farm lands in the first bottoms, and filled many of the valleys from hill to hill. The grades of the streams are so steep that excessively high velocities were attained, and the rushing waters washed out bridges, retaining walls, dams, road embankments, buildings, and farm lands. In many sections of the mountainous country near the headwaters the flood peaks arrived suddenly and at night, the inhabitants were taken unawares, and many were unable to reach safety before being drowned in their homes. The report of the Advisory Committee of Engineers on Flood Control, State of Vermont, shows that the total number of lives lost in the State was 84, and of these 55 were in the Winooski River Basin.

Robert M. Ross, commissioner of forestry, State of Vermont, and chairman of the Vermont Flood Survey, states that the damage to cities, villages, railroads, and other public utilities was over $14,000,000; to highways and bridges, $7,000,000; and the total damage more than $28,000,000. The other States suffered severely but less than Vermont.

Only by a careful analysis of data concerning flood magnitude is it possible to study adequately the problem of flood control; and flood control is a very necessary part of complete utilization of the water resources of a region. Many feasible reservoir sites in the devastated area have not yet been developed because the expense is apparently unwarranted by the demand for utilization of the stored water for power. However, a detailed study of these sites as reservoirs for flood prevention combined with power developments may show that the construction of the projects would be warranted, if the cost were equitably divided among those who would be benefited.

Although damages to property resulting from failure of engineering structures may be evaluated as a basis for determining the limit of economic cost of such structures, the loss of life can not be evaluated. Structures whose safety involves human life should be designed much more securely than those whose failure would involve damage to property alone.

ACKNOWLEDGMENTS

Special studies of the flood in Vermont were made possible through the cooperation of the Public Service Commission, H. B. Shaw, chairman. In New Hampshire the work was carried on in cooperation with the Public Service Commission, John W. Storrs, chairman. The Public Utilities Commission of Maine, Charles E. Gurney, chairman, cooperates in the regular stream-gaging work of that State. Stream gaging in Massachusetts is carried on in cooperation with the Department of Public Works, William F. Williams, chairman; Richard K. Hale, commissioner (waterways).

Acknowledgments are due to X. H. Goodnough, chief engineer, Massachusetts Department of Public Health, and to G. A. Loveland, meteorologist, United States Weather Bureau, for the rainfall data; to George V. White, Massachusetts Department of Public Health, for assembling rainfall data and preparing rainfall maps; to Prof. H. K. Barrows, of the Massachusetts Institute of Technology, whose report on the flood, published in the Engineering News-Record of November 17, 1927, has been helpful; to Prof. J. H. Weber and Prof. C. F. Brooks, of Clark University, for weather maps and information on the causes of the storm; to the New England Power Co., the Turners Falls Power & Electric Co., the New England Public Service Co., the U. G. I. Contracting Co., the Proprietors of the Locks and Canals on the Merrimack River, and others for special reports and information concerning the flood; and to Caleb Mills Saville, chief engineer of the Hartford Board of Water Commissioners; W. W.

Peabody, chief engineer of the Providence Board of Water Supply; Paul L. Bean, agent, Union Water Power Co., Lewiston, Me.; and Howard M. Turner, consulting engineer, Boston, Mass., for data concerning flood flows at several points. Individual acknowledgments are given throughout the report.

Assistance in the collection and preparation of the data was given by J. H. Morgan, M. R. Stackpole, H. F. Hill, jr., Truman Safford, and K. K. Hoyt. Mrs. L. H. Finnerty assisted in assembling the information and preparing it for publication.

The chapter on New England floods and highways was prepared by G. G. Clark, highway economist, J. V. McNary, highway bridge engineer, and C. S. Jarvis, highway engineer, of the Bureau of Public Roads, United States Department of Agriculture.

STORM OF NOVEMBER, 1927

CAUSES OF THE STORM

As a general rule, storms that visit the northeastern section of the United States approach from a westerly direction and are of moderate intensity. Occasionally a storm is blown in from the Atlantic Ocean by an east or northeast wind, and the rainfall in such a storm is likely to be high. At more rare intervals tropical storms are forced inland, entering the New England States from the south and proceeding northward. These storms are usually attended by heavy precipitation. The great storm of November, 1927, and perhaps all storms producing abnormally high rainfall in the past have been of this nature.

From a study of meteorologic data and storm centers, it appears that several factors combined their influence to cause conditions of rare occurrence, which produced a storm of unusual proportions. These factors were indicated by weather maps issued by the United States Weather Bureau immediately before and during the storm and were discussed in several published reports, especially the paper by J. H. Weber and C. F. Brooks, of Clark University, Worcester, Mass.[1]

Of greatest effect was the steady approach of a tropical storm from the south, which according to the weather map first appeared almost directly over Cuba as early as October 29. This storm was not of unusual severity and did not show much action until November 1, when it started northward, reaching a point off the coast of South Carolina by the night of November 2. By the morning of November 3 (see fig. 6) the storm center had reached the lower end of Chesapeake Bay.

As predicted by the United States Weather Bureau at Washington, on the evening of November 2, under normal conditions the storm

[1] The weather-map story of the flooding rainstorm of New England and adjoining regions, November 3–4, 1927: New England Waterworks Assoc. Jour., vol. 42, pp. 91–103, March, 1928.

would have continued up the coast with moderately heavy rains and with light showers in central New England, causing little if any disturbance. However, out to the northeast an extensive area of exceedingly high pressure prevented the storm from proceeding in that direction. At the same time a high-pressure area had moved in from the northwest to a position north of New York State. Thus the tropical storm was caught between the two cold areas of high pressure and was forced to pass over them, causing torrential rainfall.

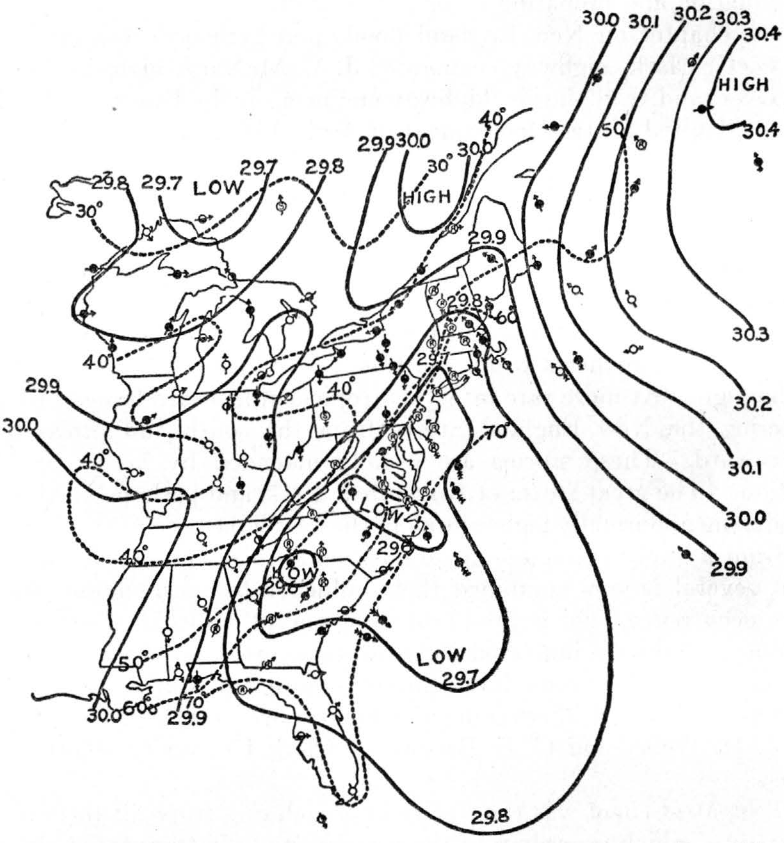

FIGURE 6.—Weather map of eastern United States for 8 a. m. November 3, 1927. From Weber and Brooks

The effectiveness of this barrier is indicated by the great range in temperature on its sides. A difference of 19° occurred in about 80 miles between warm Amherst, Mass., and cold Albany, N. Y., on the west, and between warm Brattleboro, Vt., and cold Northfield, Vt., on the north. Converging winds were observed at midnight November 3, of a velocity of 50 miles an hour from the southeast at Providence, R. I., and of 8 miles an hour from the north at Worcester, Mass. During the hour after these observations rain fell at Worcester at the rate of nearly 2 inches an hour.

The path of least resistance, as indicated by the pressures shown on Figure 7, was directly over western Massachusetts and Vermont. The great stream of warm moisture-laden air was not only forced over the Berkshire Hills and Green Mountains, whose altitudes range from 1,500 to 3,000 feet, but in addition it was thrust upward

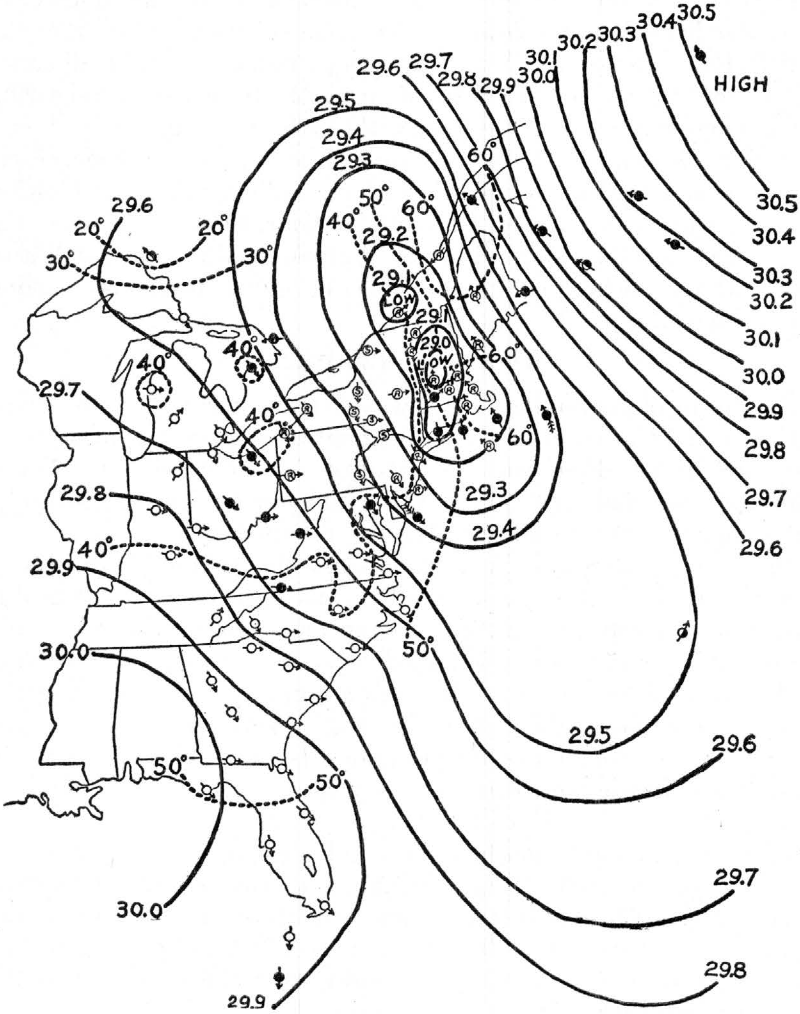

FIGURE 7.—Weather map of eastern United States for 8 a. m. November 4, 1927. From Weber and Brooks

over the barrier of cold, heavy air moving down from the north, which was just as effective as the mountains in forcing the warm air upward.

The warm moist air was cooled so greatly as it reached the higher altitudes that much of its moisture-carrying capacity was lost, and it therefore yielded tremendous quantities of rain. As the air became cooled it moved on, giving place to more moist air from the unfailing supply, and this in turn yielded its quota of moisture. As the meteorologic conditions remained practically unchanged over a period of 24 hours, it is not difficult to account for the excessive rainfall which was reported in the path of the storm.

The magnitude of the northward movement of the moist tropical air was indicated by the low-pressure area which extended from the Appalachian Mountains on the west to a point a considerable distance east of the Atlantic coast. This immense body of moisture-bearing air was moving at a high velocity through the funnel-shaped exit over New England. At Boston, Mass., the highest aerologic observation, nearly 2 miles above the surface, indicated a wind blowing from the south at a velocity of 45 miles an hour, while at 6,500 feet the rate was 51 miles an hour. Both at Worcester, Mass., and at Washington, D. C., the highest clouds visible during the storm were moving rapidly from the south.

RAINFALL RECORDS

The storm of November, 1927, was general over the northeastern section of the United States, but the greatest effect was concentrated over western New England. Records from Vermont and New Hampshire indicate that the precipitation increased with the altitude. Unfortunately, no rainfall records were obtained from the high areas of the Green Mountains in Vermont and the White Mountains in New Hampshire. Were such records available, they would undoubtedly show a much greater rainfall than any record obtained during the storm. Records were obtained from only two areas receiving more than 9 inches of rain. One was a long, narrow area along the summit of the Green Mountains in central Vermont, and the other was a small area in southwestern Rhode Island. The total area in which there was a precipitation of 9 inches or more was about 500 square miles.

Records of precipitation have been collected by the United States Weather Bureau, by X. H. Goodnough, chief engineer of the Department of Public Health of the Commonwealth of Massachusetts, and by many private persons. The rainfall records were well distributed over the territory affected by the storm, with the exception of the areas near the tops of the mountain ranges.

The following records have been taken from a paper by Goodnough.[2] They include the records of the numerous rain gages of the United States Weather Bureau in all parts of New England and the adjacent sections of New York, the records of the Department of Public Health in Massachusetts, and the results of observations by many power companies, water departments and companies, and private observers.

[2] Goodnough, X. H., Rainfall in New England during the storm of November 3 and 4, 1927: New England Waterworks Assoc. Jour., vol. 42, pp. 175-182, June, 1928.

Daily and total rainfall, in inches, at stations in New England, November 2–5, 1927

Station	Drainage basin	November				Total
		2	3	4	5	
MAINE						
Aziscohos Dam	Androscoggin				0.84	3.71
Bangor	Penobscot			0.06	0.84	1.90
Bar Harbor	Coast			1.95		1.95
Danforth	St. Croix			.80	1.55	2.35
Eastport	Coast			2.93	.21	3.14
Ellsworth	Union			3.25		3.25
Eustis	Kennebec		0.64	2.81	.06	3.51
Farmington	do		.35	2.02		2.37
Fort Fairfield	do		.05	.04	1.99	2.08
Fort Kent	St. John		.50	2.00		2.50
Gardiner	Kennebec		.02	1.64	.02	1.68
Greenville	do		.44	2.90	.04	3.38
Hiram	Saco			2.90		2.90
Houlton	St. John		.51	.25	1.83	2.59
Jackman	Kennebec	0.01	.41	1.62	.02	2.06
Lewiston	Androscoggin		.06	1.38		1.44
Lincoln	Penobscot			1.42		1.42
Machias	Coast			1.40		1.40
Madison	Kennebec		.18	1.29		1.47
Middle Dam	Androscoggin					5.14
Millinocket	Penobscot	.45	Tr.	3.73		4.18
Milo	do		.20	.93	.43	1.56
North Bridgton	Saco		.18	3.36		3.54
Old Town	Penobscot				2.31	2.31
Portland	Coast		.01	.75		.76
Presque Isle	St. John		.06	.25	2.15	2.46
Ripogenus Dam	Penobscot	.29	.26	2.76		3.31
Rockport (West)	Coast				1.41	1.41
Rumford	Androscoggin	.05	.33	3.43		3.81
The Forks	do	.02	.77	.79	1.85	3.43
Upper Dam	do					4.52
Van Buren	St. John		.15	.08	1.66	1.89
Winslow	Kennebec			1.56		1.56
Woodland	St. Croix		.14	1.97		2.11
NEW HAMPSHIRE						
Berlin	Androscoggin		.63	4.25	.96	5.84
Bethlehem (New England Power Co.).	Connecticut			2.40		3.65
Bethlehem	do			4.50		4.50
Claremont	do					4.65
Concord	Merrimack	.03	1.37	2.73		4.13
Dummer	Androscoggin		.48	2.70		3.18
Durham	Coast			2.76		2.76
Errol	Androscoggin					3.27
Fitzwilliam	Connecticut	1.19	2.24	.33		3.76
Franklin	Merrimack		.60	5.42		6.02
Garvins Falls	do	.09	4.10			4.19
Glencliff	do		.95	4.70	.25	5.90
Gorham	Androscoggin		.74	4.21	1.26	6.21
Greggs Falls	Merrimack	Tr.	4.51	.09	.02	4.62
Hanover	Connecticut		3.81	2.55		6.36
Keene	do		1.70	2.87		4.57
Lakeport	Merrimack		.35	3.71		4.06
Lancaster	Connecticut		.65	1.70	.25	2.60
Lincoln	Merrimack	.60	3.97	.47	.02	5.06
Littleton	Connecticut					4.42
Manchester	Merrimack	.02	2.88			2.90
Merrymeeting Lake	do		.13	3.95		4.08
Nashua (Pennichuck waterworks)	do		.03	4.04	.02	4.09
Nashua (Jackson Mills)	do			3.92		3.92
North Stratford	Connecticut		1.02	2.20	.50	3.72
Pittsburg (First Connecticut Lake)	do	.86	2.70	.65		4.21
Pittsburg (Second Connecticut Lake).	do	1.23	3.02	.96		5.21
Plymouth	Merrimack	.40	4.65	.25		5.30
Plymouth (Weather Bureau)	do	Tr.	.94	5.19		6.13
Pontocook Dam	Androscoggin					3.18
Twin Mountain	Merrimack			4.74		
West Stewartstown	Connecticut		.98	1.86	.26	3.10
Woodsville	do		.96	4.16	.05	5.17

Daily and total rainfall, in inches, at stations in New England, November 2–5, 1927—Continued

Station	Drainage basin	November				Total
		2	3	4	5	
VERMONT						
Bellows Falls	Connecticut		0.24	4.07	0.18	4.49
Bennington	Hudson			7.36		7.36
Bloomfield	Connecticut		1.02	2.20	.50	3.72
Brattleboro	do	0.43	4.12	.12	.01	4.68
Burlington	St. Lawrence	.52	3.75	1.35	Tr.	5.62
Cavendish	Connecticut		4.92	3.04		7.96
Chelsea	do		2.83	4.52		7.35
Chittindon (Vermont Hydroelectric Co.).	St. Lawrence	1.65	6.60	.35		8.60
Cornwall	do					5.30
East Ryegate (New England Power Co.).	Connecticut			4.08		5.11
Enosburg Falls	St. Lawrence		3.20	3.10	.05	6.35
Garfield	do		4.07	3.87		7.94
Middlebury	do		2.00	2.80		4.80
Mollys Falls	do					9.14
Newfane	Connecticut					6.64
Northfield	St. Lawrence		6.17	2.46	.03	8.66
Rutland (Vermont Hydroelectric Co.).	do	1.90	6.12	.45	Tr.	8.47
Searsburg (New England Power Co.).	Connecticut		.70	6.47	.03	7.20
Searsburg, Mount	do		.96	7.34	.17	8.47
Sherman	do					4.00
Silver Lake (Vermont Hydroelectric Co.).	St. Lawrence	.85	4.17	1.00	.49	6.51
Somerset	Connecticut		.68	8.77	.20	9.65
South Londonderry (New England Power Co.).	do			2.53		3.60
St. Johnsbury	do		1.00	5.39	.17	6.56
Vernon (New England Power Co.)	do		.35	3.58	.18	4.11
White River Junction (New England Power Co.).	do		1.00	5.41	.18	6.59
Whitingham (New England Power Co.).	do		.45	5.50	.06	6.01
Wilder (New England Power Co.)	do			4.87		6.53
Woodstock	do		4.26	3.12		7.38
MASSACHUSETTS						
Adams (New England Power Co.) (incomplete).	Hudson		5.10			5.49
Amherst	Connecticut	.30	3.43	1.90	Tr.	5.63
Ashby	Merrimack			4.80	.07	4.87
Ashland	do			4.82		4.82
Athol	Connecticut	1.00	4.83	.09		5.92
Athol (Fryville)	do	1.13	4.05	.04	Tr.	5.22
Attleboro	Blackstone	Tr.	2.25			2.25
Baldwinville	Connecticut	.42	3.62	.39		4.43
Barre	do	.23	4.32			4.55
Beverly (Wenham Lake)	Coast		1.70	.64		2.34
Blue Hill Observatory	do		.04	2.12		2.16
Bondsville (Palmer)	Connecticut	.15	3.31	Tr.	Tr.	3.46
Boston (Weather Bureau)	Coast		.44	1.37		1.81
Boylston	Merrimack			6.77		6.77
Brockton	Taunton		2.27	.07		2.34
Cambridge	Coast		.80	1.30		2.10
Charlton	Thames	.39	3.04	.01		3.44
Chester	Connecticut	.55	6.95			7.50
Chesterfield	do	.41	6.20	.03	.02	6.66
Chestnut Hill	Coast	Tr.	2.24	.07		2.31
Clinton	Merrimack			6.76		6.76
Colrain	Connecticut	.27	4.02	.40		4.69
Concord	Merrimack		Tr.	2.84		2.84
Cummington	Connecticut	.33	5.70	.48	.01	6.52
Dalton	Housatonic		2.00	4.51		6.51
Dana	Connecticut		4.15	.18		4.33
Dana (North)	do			4.97		4.97
Edgartown	Coast		1.40	.30		1.70
Egremont	Housatonic		6.10	.06		6.16
Fall River (Weather Bureau)	Coast		.45	1.81		2.26
Fall River (waterworks)	do		.55	1.11		1.66
Falmouth	do		1.86	.05		1.91
Fitchburg	Merrimack	.05	5.12	.14		5.31
Framingham	do			4.60		4.60
Franklin	Neponset	.01	2.67			2.68

Daily and total rainfall, in inches, at stations in New England, November 2–5, 1927—Continued

Station	Drainage basin	November				Total
		2	3	4	5	
MASSACHUSETTS—continued						
Gardner	Connecticut		4.06	0.03		4.09
Gloucester	Coast			2.18		2.18
Granville (West)	Connecticut			6.70		6.70
Greenfield	do	0.57	4.47	.02		5.06
Greenwich	do	.50	3.80	.04		4.34
Groton	Merrimack	.02	6.67	.01		6.70
Hardwick	Connecticut	.23	4.50	.05		4.78
Haverhill	Merrimack		Tr.	2.14		2.14
Haverhill (Kenoza Lake)	do	Tr.	2.19	.09		2.28
Heath	Connecticut	.23	4.73	.24		5.20
Hingham (town)	Coast		1.79	.60		2.39
Holyoke (Weather Bureau)	Connecticut		1.21	3.73		4.94
Holyoke (Whiting Street)	do		1.66	3.46		5.12
Holyoke (Ashley Ponds)	do		1.72	3.31		5.03
Holyoke (high service)	do	.04	1.63	3.43		5.10
Housatonic	Housatonic	.70	4.93	.08		5.71
Hubbardston	Connecticut	.21	3.93	.02	0.02	4.18
Hubbardston (Williamsville)	do	.22	3.20	.04		3.46
Huntington	do	.31	5.93	.04		6.28
Hyannis	Coast	1.15	.10			1.25
Ipswich	do		1.96	.54		2.50
Jefferson	Merrimack			4.27		4.27
Lakeville	Coast			2.91		2.91
Lawrence	Merrimack		Tr.	2.30		2.30
Lawrence (experiment station)	do		1.80	.18		1.98
Leominster	do		.27	4.89		5.16
Lincoln (Hobbs Brook Reservoir)	do		2.17	Tr.		2.17
Littleton	do	Tr.	6.32	Tr.		6.32
Lowell	do			3.28		3.28
Ludlow	Connecticut	.66	3.58			4.24
Lynn	Coast	.01	1.74	.34		2.09
Manchester	do		1.37	.41		1.78
Mansfield	Taunton		2.03	.02		2.05
Mansfield (Weather Bureau)	do	Tr.	.18	1.92		2.10
Marlborough	Merrimack			7.48	.19	7.67
Middleborough	Taunton		2.62	.08		2.70
Middlefield	Connecticut	.64	6.28	.08	Tr.	7.00
Middleton	Coast	.01	2.00	.24		2.25
Milford	Blackstone		2.95	3.41		6.36
Millbury (New England Power Co.)	do		6.50			6.50
Millis	Charles		.03	2.48		2.51
Monroe Bridge (New England Power Co.).	Connecticut		.42	5.78	.10	6.30
Monson	do		.24	4.00		
Nantucket	Coast		.03	1.52		1.55
Natick (Lake Cochituate)	Charles		.01	2.57		2.58
New Bedford (L. J. Hathaway)	Coast		2.84	.07		2.91
New Bedford (Weather Bureau)	do		.51	1.35		1.86
New Salem	Connecticut			6.05	.05	6.10
Newburyport	Coast		2.05	.30		2.35
Newton	Charles		2.11	.04		2.15
North Adams (Broad Brook)	Hudson		.83	4.93	.28	6.04
North Adams (Notch Brook)	do		.57	6.93	.24	7.74
North Andover	Coast		.02	2.60	.49	3.11
Northbridge	Blackstone	Tr.	7.74			7.74
Norwood	Neponset	.01	2.30	.02		2.33
Otis	Connecticut		.55	5.85	.15	6.55
Otis (West)	do	.10	7.35	.08		7.53
Peabody (West)	Coast	.03	2.28	.24		2.55
Pelham	Connecticut	1.32	2.93	.14		4.39
Pembroke	Coast		1.91			1.91
Peru	Housatonic	.38	5.55	.08		6.01
Petersham	Connecticut			2.09		2.09
Pittsfield	Housatonic		.85	4.86		5.71
Plainfield	Connecticut	.70	6.09	.04	.01	6.84
Plymouth	Coast	.01	1.52	.03		1.56
Prescott	Connecticut	.93	4.12			5.05
Princeton	Merrimack			4.00		4.00
Provincetown	Coast			1.40		1.40
Reading	do	.02	2.00	.03		2.05
Rochester	do		2.51	.13		2.64
Rockport	do			1.14		1.14
Rutland (North)	Connecticut	.20	3.96		.03	4.19
Rutland (West)	do			3.35		3.35
Salem	Coast	Tr.	2.43	.29		2.72
Savoy	Connecticut	1.97	2.34	1.43		5.74

Daily and total rainfall, in inches, at stations in New England, November 2–5, 1927—Continued

Station	Drainage basin	November 2	November 3	November 4	November 5	Total
MASSACHUSETTS—continued						
Shelburne Falls (New England Power Co.).	Connecticut		0.26	3.54	0.02	
Shutesbury	do	1.12	3.91	0.30		5.33
Southhampton (former reservoir)	do		3.18	2.67		5.85
Southborough (Sudbury Dam)	Merrimack		Tr.	5.31		5.31
Southborough (Cordaville)	do			8.39		8.39
Southbridge	do	.51	3.35	.01		3.87
Spot Pond	Coast	.01	1.85	.15		2.01
Springfield (U. S. Arsenal)	Connecticut	1.00		3.06		4.06
Springfield (city hall)	do	.06	3.08	1.14		4.28
Springfield (West Parish Filters)	do	.80	5.61	.03	.02	6.46
Springfield (Provin Mount Reservoir).	do	1.32	2.87			4.19
State Farm (Bridgewater)	Taunton	Tr.	.63			0.63
Sterling	Merrimack			4.57		4.57
Stockbridge	Housatonic	.86	4.95	.10	.01	5.92
Taunton	Taunton			2.60		2.60
Turner Falls	Connecticut	.49	3.48	.49		4.46
Walpole	Neponset		Tr.	2.10	.08	2.18
Waltham (waterworks)	Charles	.01	2.36			2.37
Ware	Connecticut	.17	4.12	.08	.01	4.38
Ware (West)	do			4.15		4.15
Wareham	Coast		1.70	.04		1.74
Wareham (East)	do		Tr.	1.62	.05	1.67
Warren	Connecticut	.19	3.75	.06		4.00
Warwick	do	1.37	2.08	.36	Tr.	3.81
Webster	Thames	.22	3.70	Tr.		3.92
Wendell	Connecticut		1.81	4.10	.12	6.03
West Brookfield	do	.39	3.72	.03		4.14
West Roxbury (Brookline pumping station).	Coast	Tr.	Tr.	2.05	.01	2.06
Westfield	Connecticut	.80	3.90			4.70
Westhampton (White Reservoir)	do		2.23	2.45		4.68
Westminster (Wachusett Lake)	Merrimack			4.30		4.30
Westminster (Meetinghouse Pond)	do			4.12		4.12
Weston (Stony Brook Reservoir)	Charles		.01	2.48		2.49
Williamsburg	Connecticut	.48	4.07			4.55
Williamstown	Hudson		5.08	1.07	.01	6.16
Winchendon	Connecticut	.91	3.80	.33		5.04
Wollaston	Coast		1.98	.12		2.10
Worcester (sewage works)	Blackstone		.06	5.09		5.15
Worcester (waterworks, Lynde Brook).	do		.19	3.92		4.11
Worcester (Holden Reservoir)	do		.15	4.30		4.45
Worcester (Kettle Brook)	do		.31	4.19	.09	4.50
Worcester (Kendall Reservoir)	do		.20	4.79		4.99
Worcester (Clark University)	do		.10	4.59		4.69
Worthington	Connecticut	.50	6.00	.02	.02	6.54
Wrentham	Taunton	.10	2.60			2.70
RHODE ISLAND						
Block Island	Coast	Tr.	2.87			2.87
Fiskeville (Providence water supply).	do		.01	4.83	.01	4.85
Hopkins Mills (Providence water supply).	do		.07	7.85	.02	7.94
Kent (Providence water supply)	do		.11	7.51	.09	7.71
Kingston	do		.48	2.50		2.98
Newport	do					1.68
North Scituate (Providence water supply).	do		.03	6.80		6.83
Pawtucket (Diamond Hill)	Blackstone		.06	2.69		2.75
Pawtucket (pumping station No. 3)	do		Tr.	2.77		2.77
Pawtucket (Masonic Building)	do		Tr.	2.24		2.24
Providence (Sockonosset Reservoir)	Coast			2.57		2.57
Providence (Pettaconset Reservoir)	do			2.20		2.20
Providence (precipitation plant)	do			2.26		2.26
Providence (Fruit Hill Reservoir)	do			2.95		2.95
Providence (Hope Reservoir)	do			1.97		1.97
Providence (Weather Bureau)	do	Tr.	.52	.74		1.26
Rocky Hill (Providence water supply).	do		.02	6.86	.02	6.90
Wakefield	do		.15	2.26		2.41
Westerly	do			9.12		9.12
Westerly (waterworks)	do			9.37		9.37
Woonsocket	Blackstone			4.20	.18	4.38

Daily and total rainfall, in inches, at stations in New England, November 2–5, 1927—Continued

Station	Drainage basin	November				Total
		2	3	4	5	
CONNECTICUT						
Bakersville (Hartford waterworks)	Connecticut			6.06		6.06
Burkhamsted (Hartford waterworks).	do			6.76		6.76
Bridgeport	Coast	0.01	3.09	.73	0.01	3.84
Colchester	Connecticut			4.21	.02	4.23
Hartford	do	.11	2.43	1.03	.01	3.58
Middletown	do		.39	3.29		3.68
Nepaug Dam (Hartford waterworks).	do			6.14		6.14
New Haven	Coast	.02	3.27	.51	.02	3.82
New London	do		.52	3.45		3.97
North Grosvenordale	Thames		.14	4.14		4.28
Norwalk	Coast			3.52	.05	3.57
Reservoir No. 4 (Hartford waterworks).	Connecticut		.71	3.27		3.98
Reservoir No. 6 (Hartford waterworks).	do		.56	3.46	.02	4.04
Storrs	Thames	.50	4.50			5.00
Thompsonville	Connecticut		.62	2.08		2.70
Waterbury	Housatonic	Tr.	2.91	2.21	.01	5.13
West Cornwall	do	.03	2.45	2.85	.05	5.38
West Hartland (Hartford waterworks).	Connecticut			6.64		6.64
West Hill (Hartford waterworks)	do			5.96		5.96
NEW YORK						
Albany	Hudson	.05	3.28	.53	.01	3.87
Bedford Hills	do	.02	1.70	1.55		3.27
Carmel	do		.39	2.52		2.91
Chazy	St. Lawrence		1.75	.73		2.48
Cutchogue	Coast	.19	1.91	1.40	.03	3.53
Dannemora	St. Lawrence		.85	1.10	.20	2.15
Flushing	Coast		.19	2.08	.03	2.30
Glens Falls	Hudson		.35	3.10		3.45
Harkness	St. Lawrence	Tr.	1.70	1.21		2.91
Mechanicville	Hudson		1.28	4.27	.12	5.67
New York City	Coast	.02	1.68	.15	.07	1.92
Roslyn	do		2.05	1.15	.09	3.29
Scarsdale	do	.30	2.10	1.17	.10	3.67
Setauket	do		2.58	.53		3.11
Spier Falls	Hudson		2.18	.88	.02	3.08
Wappingers Falls	do	Tr.	3.32	1.43	.04	4.79
West Point	do	.96	4.14	.17	.07	5.34
Yonkers	do		2.22	.38	.13	2.73
CANADA						
Brome	St. Lawrence		1.45	2.02	.39	3.86
Drummondville	do		2.35	3.49		5.84
East Angus	do		.56	2.62	.30	3.48
Farnham	do		1.92	2.67	.02	4.61
Lambton	do	.55	.25	.40		1.20
Lennoxville	do		2.29	2.40		4.69
Megantic	do		.58	1.75		2.33
Montreal	do					2.50
Nicolet	do		.53	4.50		5.03
Quebec	do					2.02
Sherbrooke	do	.01	3.11	1.92	.01	5.05

INTENSITY AND DISTRIBUTION OF RAINFALL

A study of the isohyetal lines (lines of equal rainfall) shown on Plate 2 indicates that the storm was most severe over the Green Mountains of Vermont and the Berkshire Hills of western Massachusetts. The highest recorded rainfall for the storm was at Somerset, Vt., where the total precipitation was 9.65 inches. The area of the Green Mountains was not well covered by records of precipitation, and it is possible that considerably greater amounts of rain fell over much of their higher portion. This possibility is shown to some extent by the high rates of discharge per square mile on the White River and on the Winooski River and its tributaries.

A secondary storm center of great intensity covered an area in western Rhode Island and eastern Connecticut and extended northward over the Blackstone Valley to Worcester, Mass. The highest recorded precipitation for this area was 9.37 inches at Westerly, R. I. This area was fairly well covered with rain gages, and it is likely that no rainfall of much greater intensity occurred there. Precipitation of 9 inches or more occurred over a total area of 457 square miles in Vermont but only 40 square miles in Rhode Island and Connecticut. The following table, taken from Goodnough's paper already cited, indicates the areas over which the rainfall exceeded certain amounts:

Areas in which rainfall exceeded amounts indicated during storm of November, 1927

	Square miles
Over 9 inches:	
Vermont	457
Rhode Island and Connecticut	40
	497
Over 8 inches:	
Vermont	1, 660
Massachusetts, Rhode Island, and Connecticut	135
	1, 795
Over 7 inches:	
Vermont	3, 320
Western Massachusetts	220
Eastern Massachusetts	130
Rhode Island and Connecticut	372
	4, 042
Over 6 inches:	
Vermont and New York	5, 530
New Hampshire	715
Connecticut	500
Western Massachusetts	902
Eastern Massachusetts and Rhode Island	827
	8, 474
Over 5 inches:	
Vermont and New York	8, 135
New Hampshire and Maine	8, 300
Western Massachusetts and New York	2, 680
Connecticut	920
Eastern Massachusetts, Rhode Island, Connecticut	1, 999
	22, 034

From an analysis of the information contained in the table of maximum discharge and total run-off during the flood (pp. 73–79), and from personal observations of the effect of the flood on stream channels in the areas of highest run-off, it has been concluded that the precipitation in the vicinity of Mount Washington, in the White Mountains of New Hampshire, exceeded that of all other sections affected by the storm. Although no rain gages were in operation in the higher parts of the White Mountains during the storm, a study of rainfall data in relation to altitude indicated that the total amount of rainfall increased as the altitude increased.

Higher rates for discharge in second-feet per square mile were obtained in the vicinity of Mount Washington than in any other locality. Two independent determinations of discharge were made at points on the Peabody River, which drains an area near the foot of Mount Washington. The drainage area at the upper point is only 43 per cent of that at the lower point, yet the determinations indicate that 74 per cent of the flow at the lower point came from the area of high altitude above the upper point. It is assumed, therefore, that the rainfall in this higher part of the drainage area was much greater than the 6.21 inches recorded near the mouth of the river at Gorham, N. H.

Another explanation of the extremely high peak flows in the White Mountain region is that the rainfall may have been abnormally high, possibly of cloudburst proportions, for a period of not over three or four hours. During this time a sufficient quantity of water may have fallen to cause these high peaks.

The intensity rather than the total amount of rainfall largely determines the height of the crest of a flood in the headwaters of a stream or near the storm center. Figure 8 shows the hourly rainfall in inches at Northfield, Vt., and the depth of run-off in inches over the drainage area for the gaging station on the Dog River at the same place. The peak of the flood occurred at 6.30 p. m. November 3, following a period of 7 hours of intensive rainfall. During this time the precipitation averaged about half an inch an hour. After the peak passed the storm continued for 16 hours, during which nearly 3 inches of rain fell, or one-third of the total precipitation. The ratio of the crest hourly run-off to the crest hourly rainfall is 43 per cent; and the ratio of the total storm run-off to the total storm rainfall is 62 per cent. These percentages are subject to large error owing to the fact that the rainfall record applies to a single spot in the drainage area, whereas the run-off recorded is that collected from the whole drainage basin above Northfield. At points down the river, farther removed from the storm center, the peak discharges are more nearly proportional to the total precipitation.

The following tables, also taken from Goodnough's paper, contain records of hourly rainfall and rainfall intensities for various periods of time from charts of recording rain gages located in the storm area.

Hourly rainfall in inches from the records of recording gages during the storm of November 2–5, 1927

Place	Date	A. M.												P. M.											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Albany, N. Y	2																						Tr.	0.05	Tr.
	3	0.01	0.03	0.03	0.04	0.25	0.09	0.16	0.14	0.25	0.30	0.18	0.31	0.27	0.18	0.12	0.25	0.08	0.13	0.12	0.16	0.05	Tr.	.01	.12
	4	.15	.05	.07	.05	.03	.03	.05	.05	Tr.	Tr.	.04	.01	Tr.											
Blue Hill Observatory	3					Tr.	Tr.	Tr.												.02	.02	.05	.11	.26	.40
	4	.46	.17	.05	.04	.12	.19	.15	.07	.02	.01	.01	.01												
Boston Mass. (Weather Bureau)	3		Tr.			Tr.															Tr.	.01	.01	.09	.33
	4	.28	.15	.41	.09	.07	.11	.04	.15	.07	Tr.	Tr.	Tr.	Tr.											
Brookline, Mass	3																					.01		.07	.20
	4	.28	.16	.26	.10	.06	.10	.04	.04	.01															
Burlington, Conn. (Phelps Brook Dam), Hartford waterworks.	3			.16	.04	.18	.08	.02	.00	.01	.02	.01	.05	.38	.01	.05	.08	.28	.03	.23	.50	.29	.35	.34	.37
	4	.20	.05	.27	.16	.42	.32	.06	.04	.05	.28	.18													
Concord, N. H	3																						.12	.39	.80
	4	.43	.62	.34	.66	.26	.31	.05	.04	.01	Tr.	.01	Tr.												
Eastport, Me	4																		.01	.46	.77	.51	.71	.32	.15
	5	.12	.06	.03	Tr.																				
Hartford, Conn	2													Tr.						Tr.	Tr.	Tr.	.01	Tr.	.10
	3	.01	.01	.03	.03	.06	.09	.01	Tr.	Tr.	Tr.	Tr.	.08	.10	.05	.01	.04	.10	.16	.44	.25	.27	.20	.26	.23
	4	.25	.34	.08	.05	Tr.	.14	.15	.02		Tr.	Tr.													
Lowell, Mass	3																					.01	.05	.20	1.04
	4	.53	.37	.67	.15	.07	.09	.07	.01																
Montreal, Quebec	2																.02	.05	.04	.03	.04	.06	.12	.07	.05
	3	.04	.07	.01	.03	.06	.02	.01	.00	.02	Tr.	.07	.02	.03	.11	.06	.09	.08	.11	.12	.11	.02	.06	.16	.13
	4	.09	.02	.03	.09	.06	.06	.06	.03	.02	.02	.04	.03	.02	Tr.	.01	Tr.	.01							
New Haven, Conn	3	Tr.	.00	.03	.06	.02	.00	.05	.02	Tr.	.00	Tr.	.02	.08	.12	.24	.25	.30	.53	.27	.39	.06	.25	.30	.28
	4	.22	.07	.06	.01	.13	.01	.01			Tr.	Tr.		Tr.											
New York, N. Y	2													Tr.	.01		.01				Tr.				
	3			Tr.	.04	.15	.02	Tr.	Tr.	.03	.09	.27	.03	.01	.15	.25	.19	.04	.27	.04	Tr.		.05	.05	Tr.
	4	Tr.	Tr.	Tr.	Tr.	.01	.02	.02	.06	.03	.01														
Northfield, Vt	2																						.02	.20	.01
	3	.03	.01	Tr.	.04	.43	.29	.20	.14	.30	.15	.14	.45	.51	.54	.57	.62	.51	.31	.35	.38	.14	.35	.43	.24
	4	.18	.16	.21	.11	.11	.10	.04	.02	.14	.15	.03	Tr.	Tr.	Tr.	.02	Tr.								
Pawtucket, R. I	3																			.01	.04	.14	.31	.14	.33
	4	.35	.30	.21	.09	.08	.08	.03	.13																
Portland, Me	3			Tr.	.01	Tr.																			
	4				.02	.03	.25	.23	.03	.02	Tr.	.02	.11	Tr.	.04										
Providence, R. I	3																			Tr.	.02	.08	.12	.07	.23
	4	.12	.16	.16	.06	.07	.06	.03	.08																
Providence, R. I. (Hope Reservoir)	3																					.05	.11	.10	.07
	4	.12	.32	.20	.27	.05	.07	.10	.06	.04	.01	Tr.													
Springfield, Mass	2																					.00	.01	.03	.02
	3	.04	.15	.06	.04	.07	.12	Tr.	.00	Tr.	.01	.00	.04	.24	.11	.06	.00	.02	.19	.29	.55	.28	.24	.28	.29
	4	.18	.33	.11	.06	.02	.04	.35	.04	.00	.00	Tr.	.01												

West Hartford, Conn. (West Hartford filters, Hartford waterworks).	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.03	.01	.11
	3	.02	.04	.01	.10	.06	.03	.04	.00	.01	.00	.02	.09	.05	.06	.12	.14	.27	.35	.23	.30	.24	.10	.28	.22
	4	.32	.31	.04	.04	.03	.12	.11	.01	.01	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Worcester, Mass. (Winter Hill Observatory).	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.06	.02	Tr.
	3	Tr.	----	----	----	----	----	.04	.02	----	----	----	----	----	----	----	.05	.00	.00	Tr.	.09	.26	.68	.24	.59
	4	1.26	.35	.21	.32	.07	.01	.02	.11	Tr.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Worcester, Mass. (sewage-treatment plant).	3	----	----	----	----	----	----	.06	----	----	----	----	----	----	----	.03	.01	.01	.01	Tr.	.07	.39	.60	.88	1.42
	4	1.19	.10	.23	.09	.01	Tr.	.02	.03	.01	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

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Rainfall intensities for different periods of time during storm of November, 1927

[From recording gage records]

	Minutes				Hours		
	5	10	15	30	1	2	24
Albany, N. Y	0.07	------	0.13	0.22	0.32	0.63	3.49
Block Island, R. I	.16	------	.34	.57	.84	1.40	2.87
Blue Hill Observatory, Mass	.07	------	.17	.30	.51	1.07	2.16
Boston, Mass	.09	------	.14	.27	.41	.58	1.81
Brookline, Mass	.05	------	.11	.20	.33	.45	[a] 1.54
Burlington, Vt	.07	------	.15	.26	.46	.76	4.50
Concord, N. H	.11	------	.38	.56	.85	1.37	4.04
Eastport, Me	.17	------	.39	.52	.77	1.40	3.14
Hartford, Conn	.11	------	.20	.33	.46	.63	3.22
Lowell, Mass	.20	------	.44	.72	1.20	1.73	[a] 3.26
Montreal, Quebec	.03	------	.07	.12	.16	.29	1.64
Nantucket, Mass	.14	------	.24	.39	.70	.99	1.55
New Haven, Conn	.13	------	.28	.40	.59	.84	3.67
New York City	.16	------	.23	.27	.30	.47	1.68
Northfield, Vt	.15	0.19	.23	.42	.69	1.22	3.58
Pawtucket, R. I	.06	------	.16	.26	.41	.66	2.24
Portland, Me	.05	------	.08	.14	.25	.48	.75
Providence, R. I	.06	------	.09	.17	.24	.37	1.26
Providence, R. I. (Hope Reservoir)	.08	------	.13	.21	.32	.52	[a] 1.97
Springfield, Mass	.09	------	.27	.41	.55	.83	3.08
Worcester, Mass. (Winter Hill)	.27	------	.66	.73	1.26	1.87	[a] 4.92
Worcester, Mass. (sewage works)	.30	------	.61	1.04	1.65	2.60	5.07

[a] Stick measurement.

Rainfall intensities for 2 and 24 consecutive hours during storm of November, 1927

[From power-station records furnished by New England Power Co.]

	2	24
Monroe Bridge, Mass	0.78	5.78
Searsburg, Vt	1.17	6.47
Shelburne Falls, Mass	.49	3.54
Somerset, Vt	1.31	8.77
Vernon, Vt	.80	3.58
Whitingham, Vt	.81	5.14
Whitingham, Vt. (Davis Bridge Dam)	.71	5.50

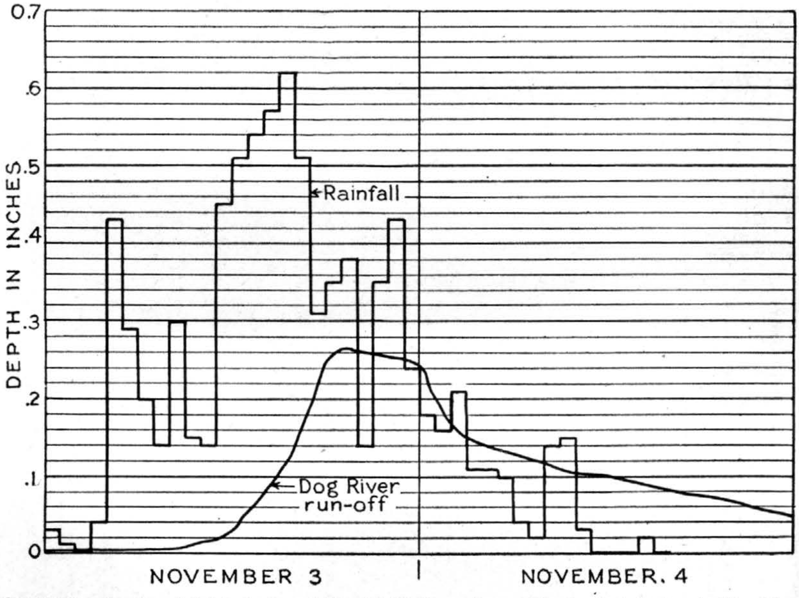

FIGURE 8.—Hourly rainfall, in inches, at Northfield, Vt., and run-off in depth, in inches, for Dog River at Northfield. November 3–4, 1927

FLOOD OF NOVEMBER, 1927

GENERAL FEATURES [3]

Floods on streams in New England during November, 1927, were caused by excessively heavy rains on November 2-4, falling on ground that was well saturated from rains during October. The areas of greatest recorded rainfall were in Vermont, eastern and western Massachusetts, and Rhode Island, and floods causing considerable damage to property and loss of human life followed immediately. So heavy was the rain that the floods attained destructive proportions hours before the rain had ceased, and, most unfortunately, over much of the area they occurred during the night.

The greatest floods occurred in the Hudson Valley of New York, virtually all of Vermont and New Hampshire, Massachusetts, and western Connecticut. There were lesser floods in western Maine, eastern Connecticut, and Rhode Island. The flood was most severe in the White and Winooski Valleys of Vermont, where the loss of life and property marked the disaster as the greatest in the history of the valleys. Only slightly less disastrous were the floods in the Connecticut Valley, the Lake Champlain drainage basin, and the basins of smaller streams in Massachusetts and Connecticut. One very remarkable feature was the rapidity with which the rivers rose. There was no time for preparation except in the lower Connecticut Valley, and in many places not even time for escape. Tragedy followed upon tragedy in such rapid succession that the people were stunned and helpless for a time, and the losses of life and property were staggering for an area comparatively so small.

The October precipitation in the Winooski Valley was about 50 per cent in excess of the normal, so that when the November rains began the ground was well saturated and the brooks were higher than usual. The rainfall from November 2 to 4 broke all records for continuous rain in Vermont and also all 24-hour records. At Burlington the total rainfall for the period was 5.62 inches, of which 4.49 inches fell in 24 hours. At Northfield the total was 8.63 inches, and the 24-hour fall 7.61 inches. Montpelier reported a high-water mark for the Winooski River 3 feet higher than the previous mark, and the entire business district was under 8 to 10 feet of water. The Winooski River drains an area of a little more than 1,000 square miles. Two determinations of the maximum discharge made near the mouth after the flood had subsided indicated that the crest discharge was about 113,000 second-feet, or more than 110 second-feet per square mile. Views of flooded streets in Montpelier and Barre are shown in Plate 3.

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[3] Compiled principally from the following published reports: Frankenfield, H. C., November floods in New England and eastern New York: U. S. Weather Bur., Monthly Weather Review, November, 1927, pp. 496–499; Shaver, J. W., Some aspects of New England's greatest flood: Eng. News-Record, November 24, 1927, pp. 841–845; Kinnison, H. B., Run-off figures in Vermont flood reach high values: Eng. News-Record, June 7, 1928, pp. 890–891.

Conditions were much the same over other parts of the Lake Champlain drainage basin. Great damage was done in the valleys of the Missisquoi and Lamoille Rivers and on the headwaters of Otter Creek. Views of the flood on the Missisquoi River at Richford, Vt., and of a bridge destroyed by the flood at Enosburg Falls, on the same river, are shown in Plate 4.

A view of the flood at the railroad station in Proctor, Vt., on Otter Creek, and a view showing débris left by the flood at Waterbury, Vt., on the Winooski River, are shown in Plate 5. The character of the damage to highways is indicated by the views on Plate 6, which show the same point on the Mendon road near Rutland, Vt., before and after the flood.

At Somerset, Vt., in the Connecticut River Basin, 8.77 inches of rain fell in one day, and the total for the storm 9.65 inches, is the maximum recorded. Other points in Vermont at which the rainfall exceeded 7 inches for November 2–4 are Bennington, 7.36 inches; Cavendish, 7.96 inches; Chelsea, 7.35 inches; Rutland, 8.47 inches; Searsburg Mountain, 8.30 inches; Woodstock, 7.38 inches.

The average rainfall over the Connecticut Valley for November 3–4 was 4.43 inches (9 stations), with maxima of 6.41 and 6.39 inches at White River Junction and St. Johnsbury, Vt., respectively. Unofficial reports from other points in New Hampshire and Vermont indicated even heavier rains—as much as 15 inches in some mountain sections. The central part of the valley suffered most, especially the tributary basins, as the channels of small streams were wholly unable to carry the flood waters, which rose to unprecedented heights.

The principal flood wave in the Connecticut Valley came from the White River, which had a higher run-off per square mile in proportion to the size of its drainage basin than any other stream in New England. At the time White River was discharging its peak flow of 140,000 second-feet, on the morning of the 4th, the Connecticut River above the mouth of the White River was discharging only about 8,000 second-feet. The flood peak from the upper Connecticut basin did not reach the mouth of the White River until the next day and was not severe, the peak discharge being only 25 second-feet per square mile. The only noticeable effect it had upon the flood of the lower Connecticut Basin was to prolong the falling stage.

Plate 7, *B*, is a view of the Connecticut River at Bellows Falls, Vt.

The gage-height graphs in Figure 9 and the hydrographs of discharge in Figure 10, for various points on Connecticut River, show the progress downstream of the crest of the flood. Plate 8 shows the enveloping line of the peak stages.

At White River Junction, Vt., the Connecticut River was 5 feet higher than the former record of March, 1913, and at Bellows Falls, Vt., it was 6.6 feet higher than in 1913. At Springfield, Mass., the

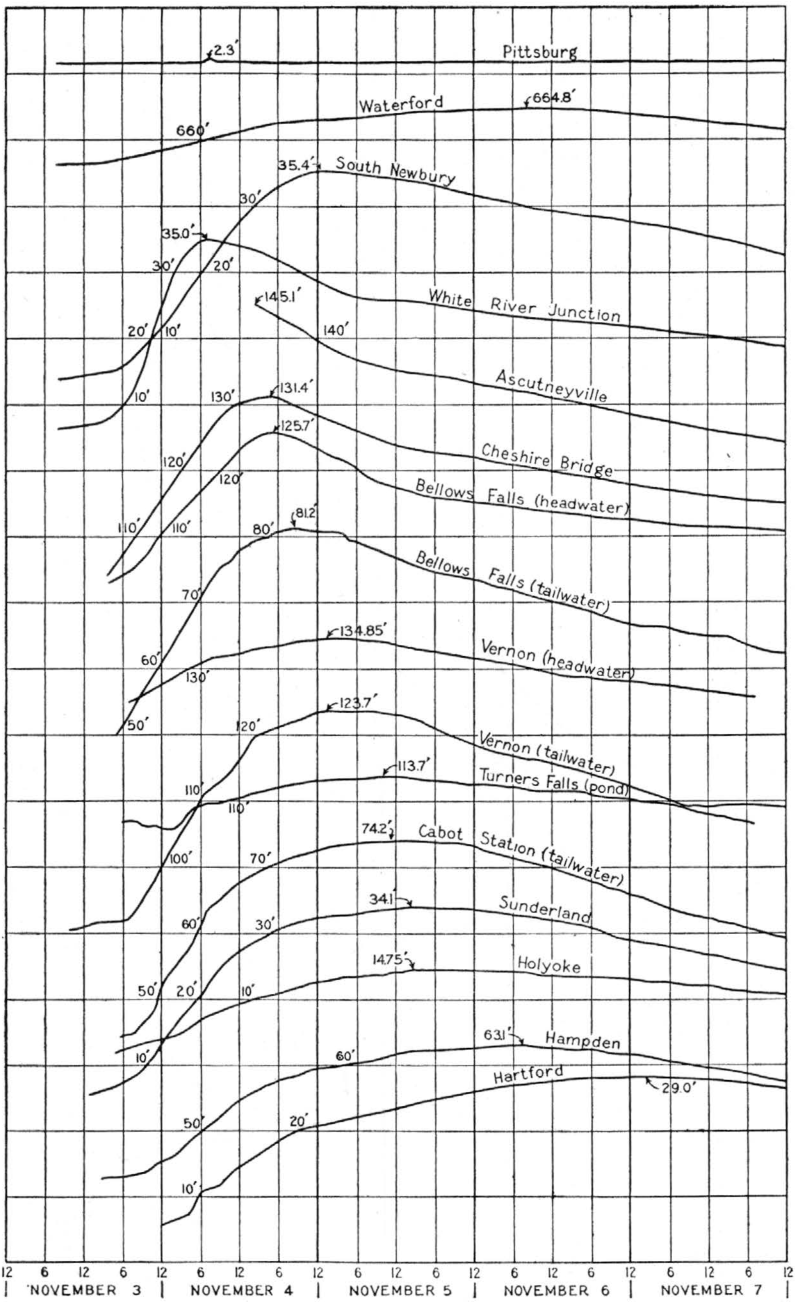


FIGURE 9.—Gage-height graphs of the Connecticut River at different points during the flood of November, 1927

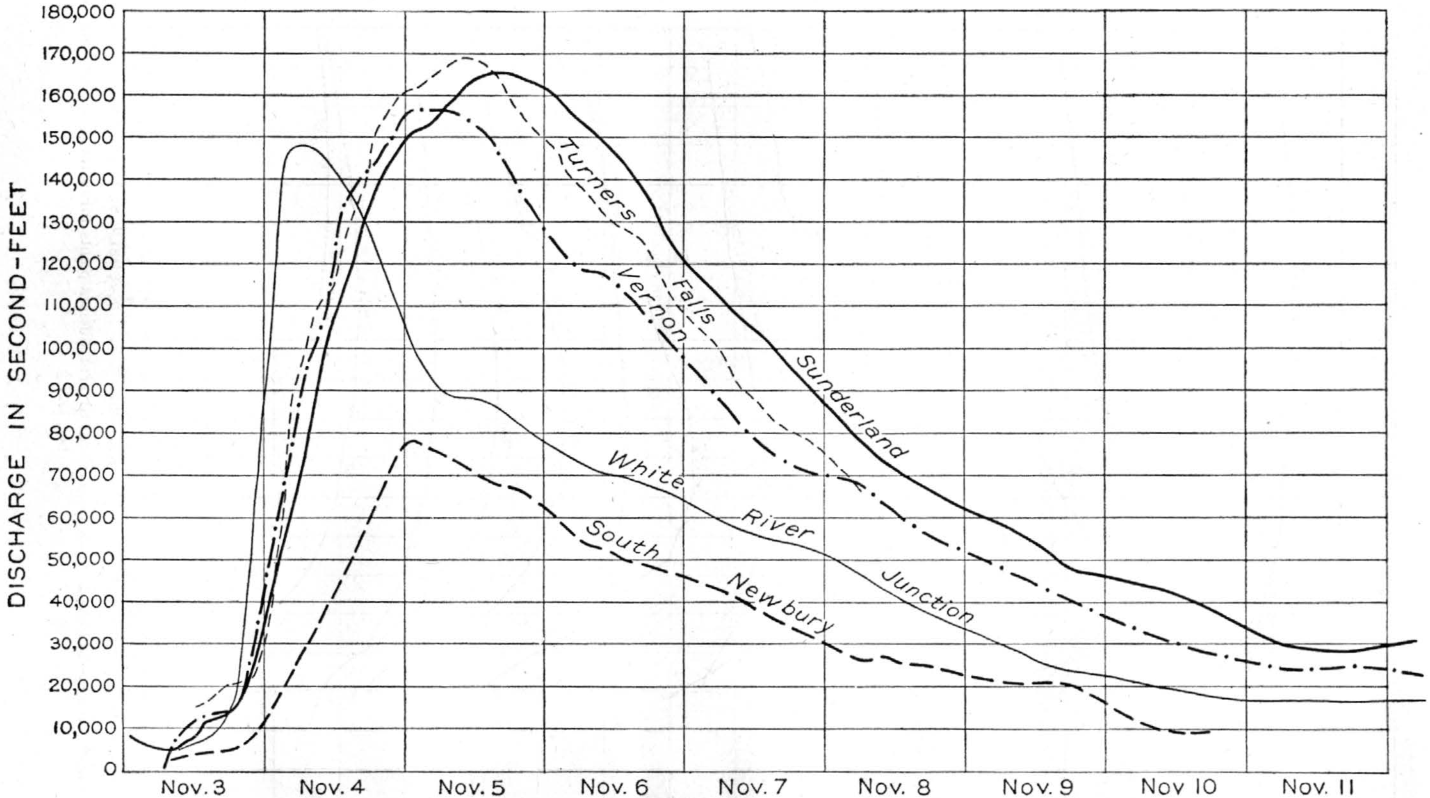
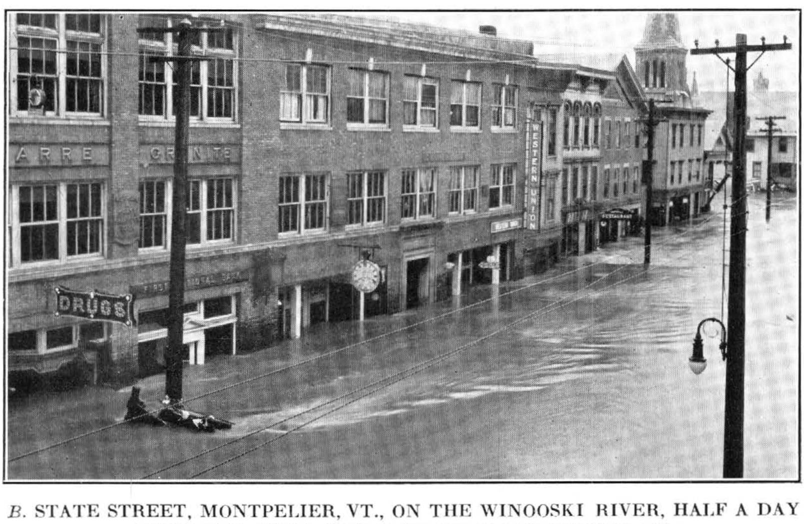


FIGURE 10.—Hydrographs of discharge at points on the Connecticut River during the flood of November, 1927

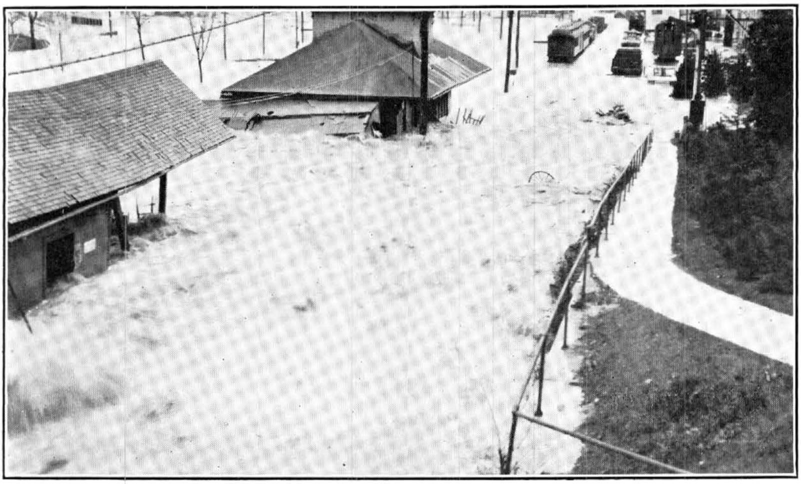
A. EAST STATE STREET, MONTPELIER, VT., ON THE WINOOSKI RIVER, THE DAY AFTER THE PEAK OF THE FLOOD OF NOVEMBER, 1927



B. STATE STREET, MONTPELIER, VT., ON THE WINOOSKI RIVER, HALF A DAY AFTER THE PEAK OF THE FLOOD OF NOVEMBER, 1927

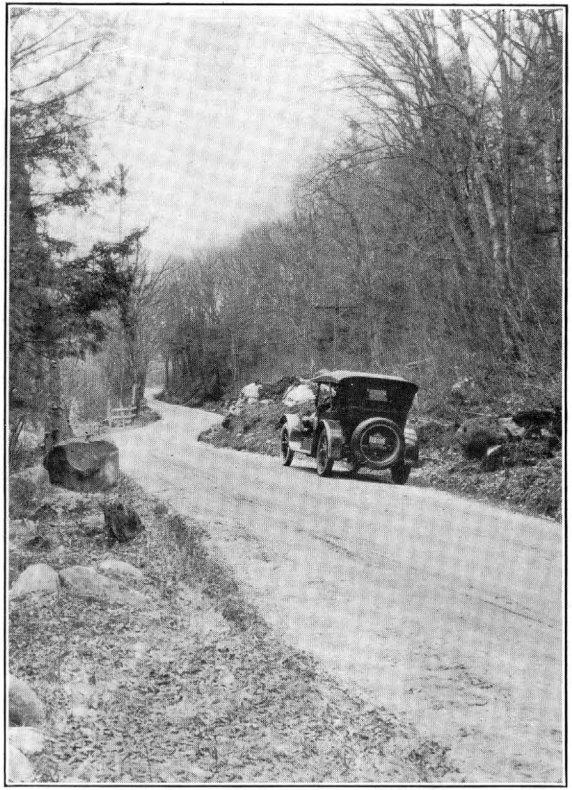
A. FLOOD SCENE IN RICHFORD, VT., ON THE MISSISQUOI RIVER, NOVEMBER, 1927

B. HIGHWAY BRIDGE OVER THE MISSISQUOI RIVER AT ENOSBURG FALLS, VT., DAMAGED BY FLOOD

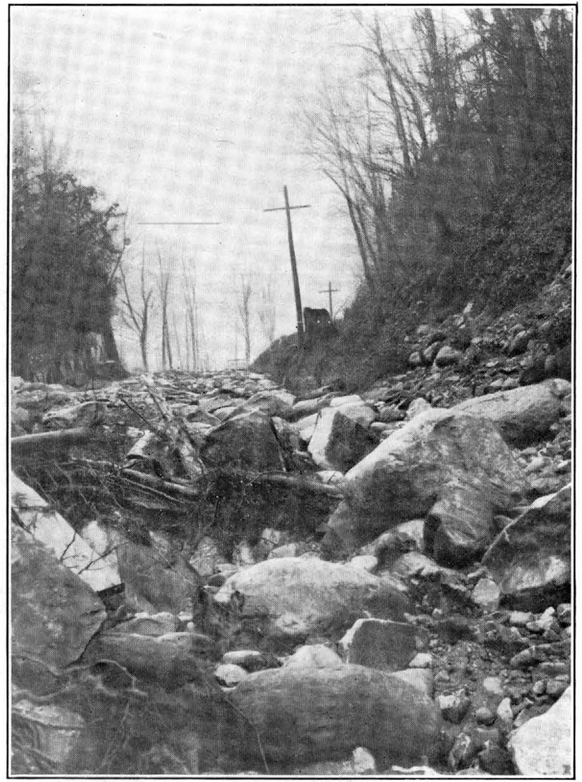


A. FLOOD OF NOVEMBER, 1927, AT RAILROAD DEPOT AT PROCTOR, VT., ON OTTER CREEK

B. DÉBRIS FROM FLOOD OF NOVEMBER, 1927, AT WATERBURY, VT., ON THE WINOOSKI RIVER

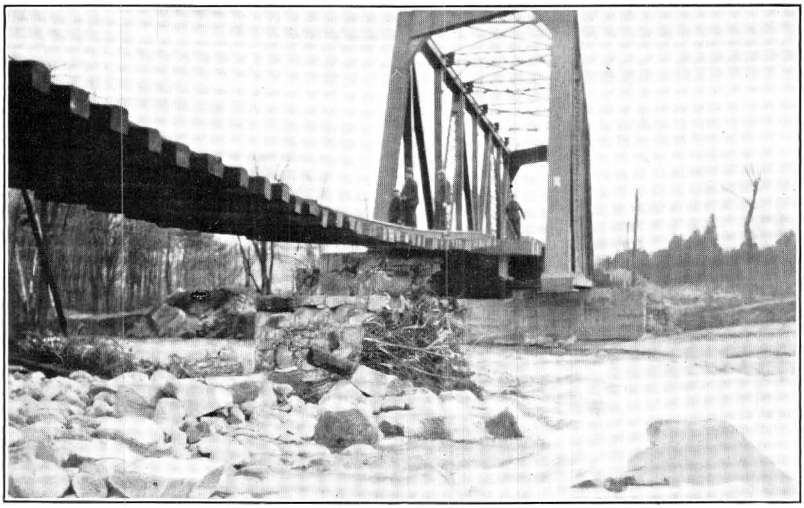


A. BEFORE THE FLOOD

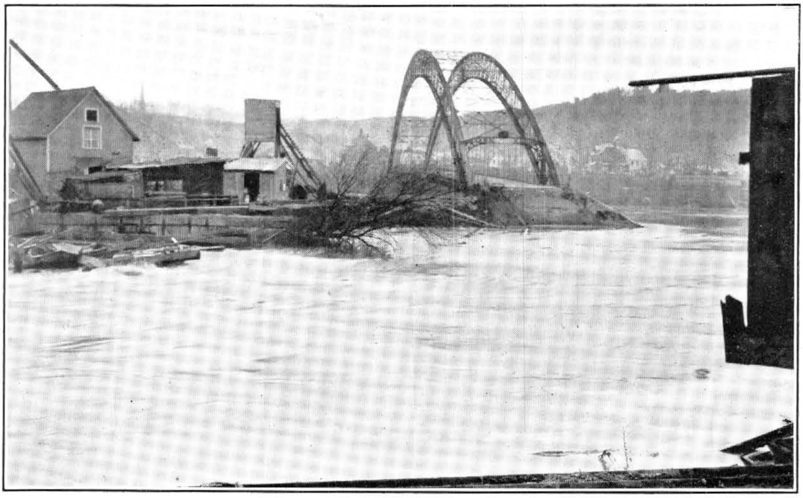


B. AFTER THE FLOOD

MENDON ROAD NEAR RUTLAND, VT., NOVEMBER, 1927

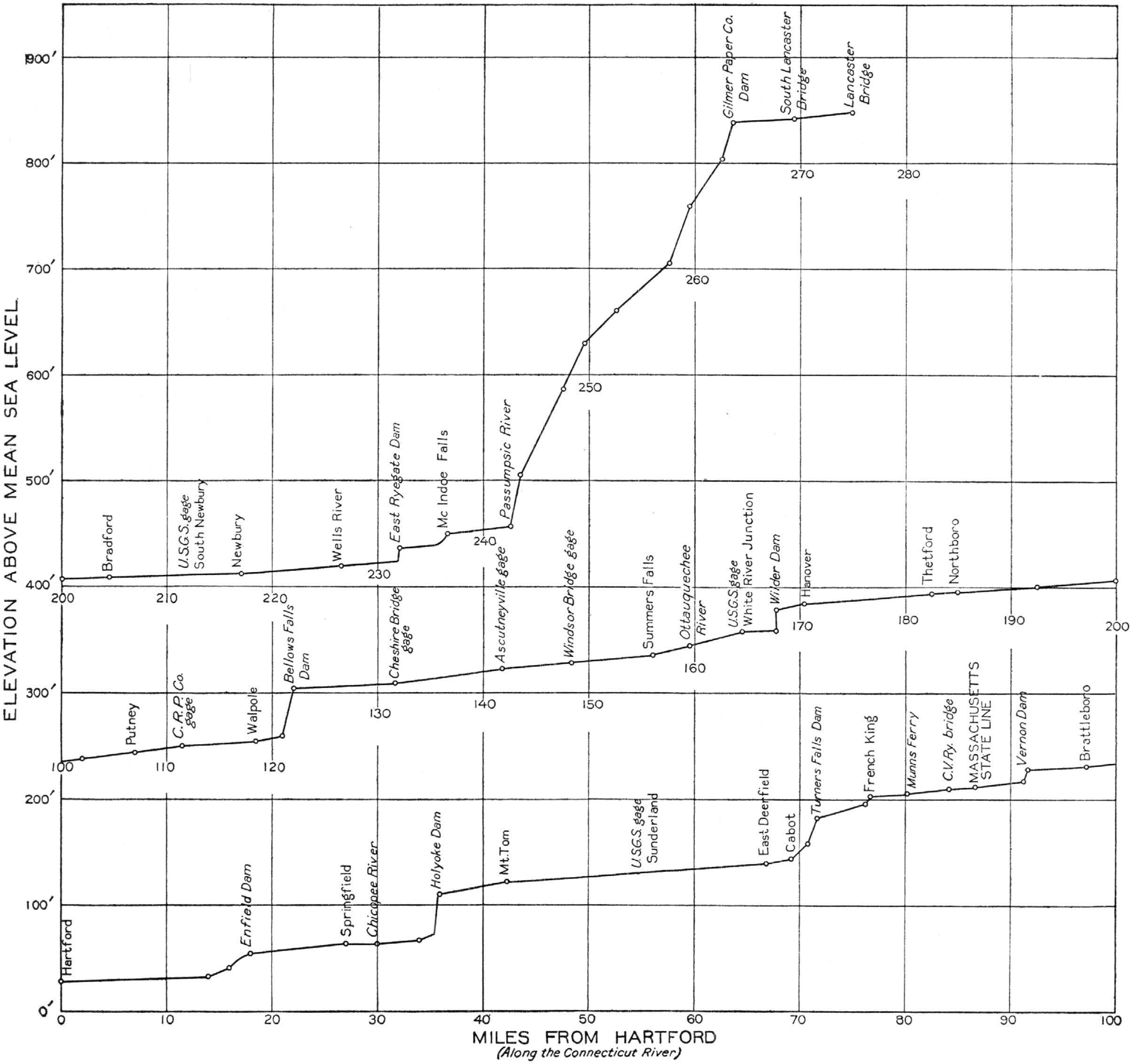


A. EFFECTS OF FLOOD OF NOVEMBER, 1927, ON THE PEABODY RIVER AT CANADIAN NATIONAL RAILWAY BRIDGE AT GORHAM, N. H.



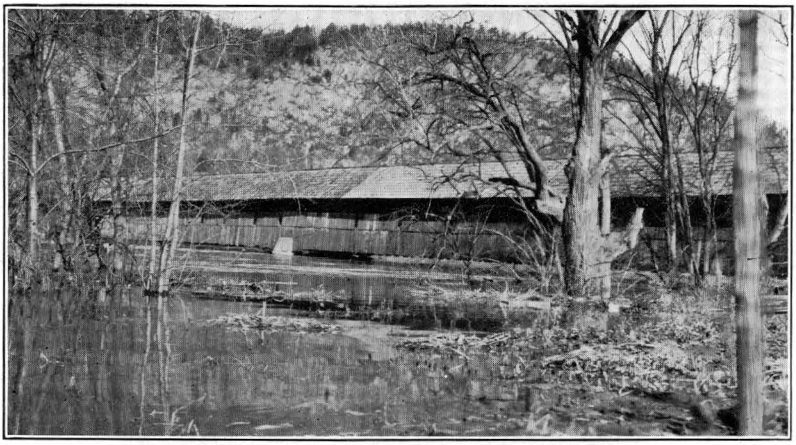
B. THE CONNECTICUT RIVER AT BELLOWS FALLS, VT.

Size of overflow channel indicates inadequacy of main channel under the bridge

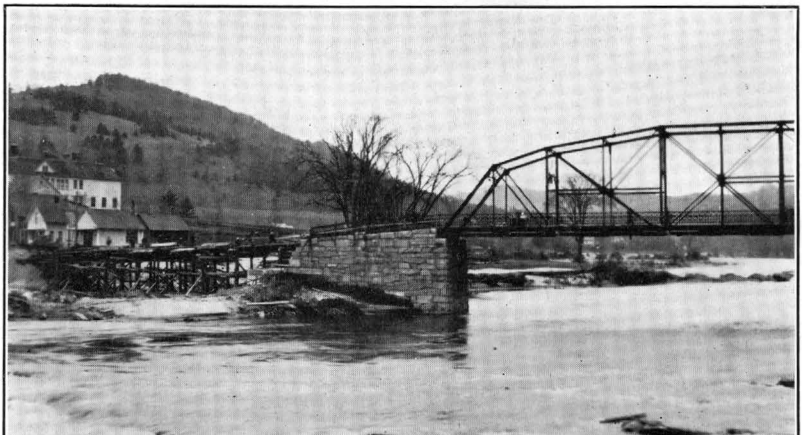


LINE OF PEAK FLOOD STAGES OF THE CONNECTICUT RIVER DURING THE FLOOD OF NOVEMBER, 1927

FLOOD OF NOVEMBER, 1927, PASSING OVER HOLYOKE DAM, AT HOLYOKE, MASS., ON THE CONNECTICUT RIVER



A. BRIDGE AT ORFORD, N. H., DURING THE FLOOD OF NOVEMBER, 1927



B. BRIDGE OVER THE WHITE RIVER AT SOUTH ROYALTON, VT., 1927 crest was only 0.2 foot above the previous record of May 1, 1854, and at Hartford, Conn., the crest was 0.8 foot below the previous record of May 1, 1854. Thus it is seen that north of the Connecticut-Massachusetts State line this flood was greater than any previously recorded floods by amounts increasing as the storm center was approached, while south of the State line it had been exceeded by previous great floods.

A view of the flood passing over Holyoke Dam about two hours before crest stage was reached is shown in Plate 9.

In the Merrimack Valley, although the rainfall averaged more than 5 inches, the flood conditions were not as severe as in other areas. The crest of the flood on the Pemigewasset River at Plymouth, N. H., was 9 feet higher than previously recorded peaks, and at Franklin Junction, on the Merrimack River, it was 7 feet higher. At Lowell and Lawrence, Mass., the crests were 5 and 4 feet respectively below previous records. The hydrographs of discharge at points on Merrimack River (fig. 11) show the progress downstream of the crest of the flood.

In the Androscoggin Basin the precipitation was less than in the region to the west but was sufficient to cause flood stages in the upper reaches of the river. In the Rangeley Lake district the flood was the highest known, and between Gorham, N. H., and the Maine boundary it was from 3 to 4 feet above any previous record. A view of the effects of the flood on the Peabody River near Gorham is shown in Plate 7, *A*. At Rumford, the crest was 0.8 foot lower than in 1895. Outside the Androscoggin system, flood stages in the State of Maine were not unusual in height, though unusual in the season of their occurrence.

In the Hudson River Basin the rainfall was heavy over the Mohawk and upper Hudson Valleys, yet the greater part of the water came from the eastern tributaries, which have their sources in Vermont and northern Massachusetts. Batten Kill at Battenville, N. Y., discharged 51 second-feet per square mile; Hoosic River near Eagle Bridge, N. Y., 58 second-feet per square mile; Poesten Kill near Troy, N. Y., 81 second-feet per square mile. The Hudson River was not in flood much above Troy. At this place the crest was 6.7 feet above flood stage, and at Albany 4.9 feet above flood stage.

Soon after the recession of the flood waters it became clear from the available information that this was by far the worst flood that New England has known in modern times. Field examinations and computations of flood flows indicated that the streams in western Vermont, particularly, reached heights and velocities considerably beyond the flood of 1869, although the recorded rainfall of this storm was less than that of the storm of 1869. The greatest damage was done in

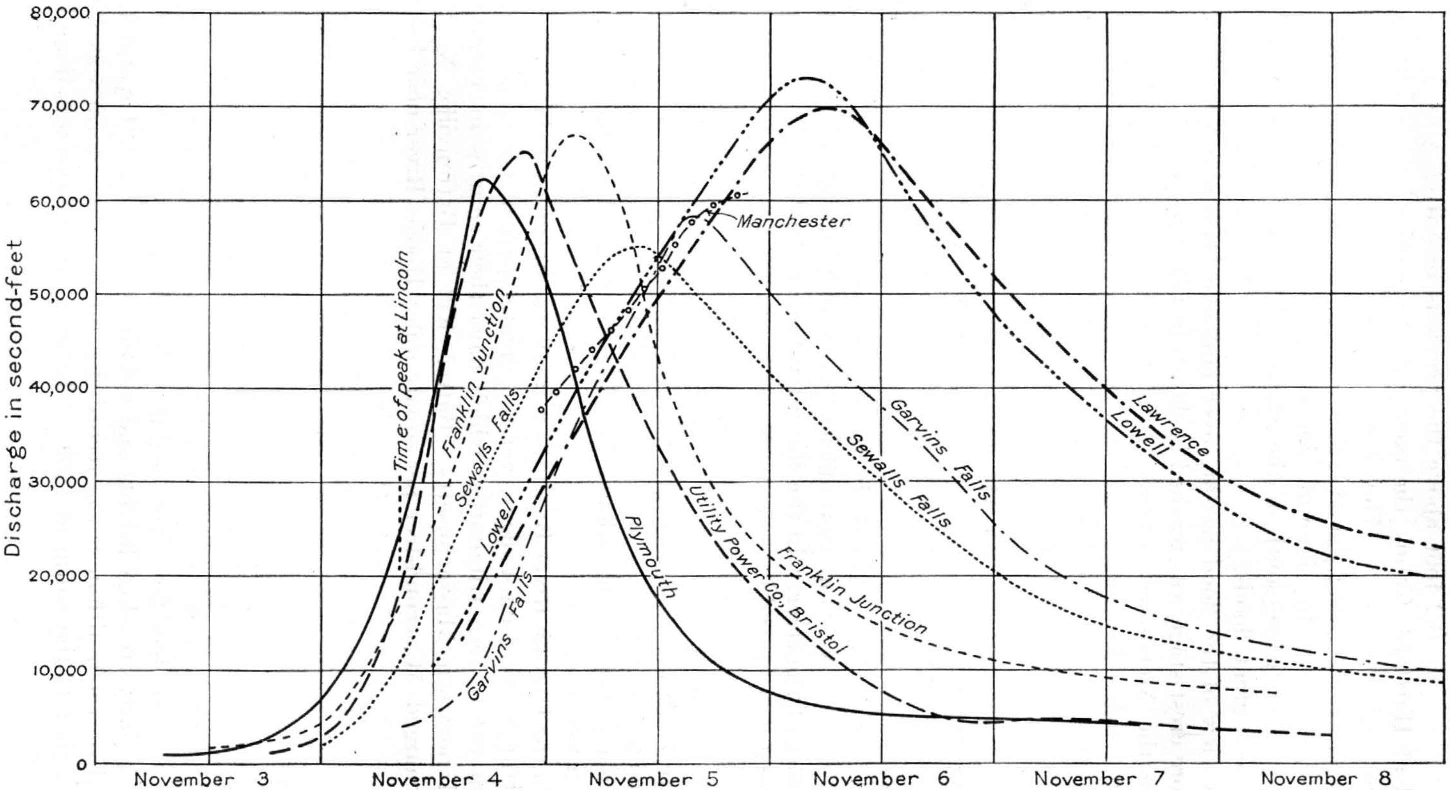


FIGURE 11.—Hydrographs of discharge at points on the Merrimack River during the flood of November, 1927

valleys traversed by rivers rising along the divide between the Connecticut River basin and the Hudson and Lake Champlain Basins. Damage along the lower Connecticut was due mostly to flooding, but in the upper tributaries and the Lake Champlain Basin most of the losses resulted from high velocity of flow. The damage in the Winooski, White, Lamoille, and Missisquoi Valleys was the greatest, although the Passumpsic, Otter, and Hoosic Valleys were badly flooded.

In New England freshets of considerable magnitude occur rather regularly in the spring, but destructive floods occur so seldom that the possibility of a flood as great as that of November, 1927, had not been considered. The ordinary spring freshet discharges 15 to 30 second-feet per square mile from small drainage areas; the maximum during a 10-year period has seldom reached more than 50 second-feet per square mile. For instance, the 12-year record on the Westfield River near Westfield, Mass., shows a maximum discharge, in April 1924, of 49 second-feet per square mile from an area of 496 square miles. Farther upstream, at Knightville, Mass., the maximum discharge in a period of 18 years occurred at the same time and reached 65 second-feet per square mile from an area of 162 square miles. On the Pemigewasset River at Plymouth, N. H., over a period of 24 years the maximum flow occurred in 1923, with a discharge of 46 second-feet per square mile from an area of 615 square miles. Over a period of 14 years on the White River at West Hartford, Vt., the maximum flow of 44 second-feet per square mile from an area of 687 square miles occurred in 1913. The 15-year record on the Winooski River at Montpelier, Vt., where the drainage area in 420 square miles, indicates a maximum flow, in 1912, of 48 second-feet per square mile. On the Connecticut River at Sunderland, Mass., where the drainage area is 8,000 square miles, a record covering 23 years gives a maximum discharge of 17 second-feet per square mile in 1913.

In view of these records it is not surprising that dam spillways and bridge openings were found woefully inadequate to pass the flood flow resulting from the great storm of November, 1927, a flow that greatly exceeded any recorded discharge in this region. The failure may have been due in part to the old practice of building dams without the services of capable engineers. It is imperative that all dams built in the future be designed to pass safely flood flows at least as great as the largest that occurred in 1927 in the respective drainage basins. In general, the flood flows reached a maximum of well over 100 second-feet per square mile, and several determinations show 300 to 500 second-feet per square mile. It is doubtful if any dam spillways in the area of maximum flood discharges had sufficient capacity to pass the flood safely except where the flow was controlled in part by storage.

METHODS OF DETERMINATION OF FLOOD FLOWS

At the time of the flood the United States Geological Survey, in cooperation with the States of Maine, New Hampshire, and Massachusetts, was operating about 60 stream-flow measurement stations in New England at which records of peak stages were obtained. While the flood was in progress a number of discharge measurements were made at stations in Massachusetts. As soon as it was possible to travel over the roads in the flooded area field parties were sent to the sections affected by the storm to determine maximum stages and discharges at gaging stations, dams, and other points on the principal streams. Four methods were employed in the determination of maximum discharge, the method used depending on the local conditions at each site. Wherever possible the results obtained by one method were checked by another. The methods used were (1) extension of rating curves for gaging stations, (2) computation of flow over dams, (3) the slope-area method, and (4) computation of flow through contracted openings.

Extension of rating curves for gaging stations.—Daily records of the flow of a river at a gaging station are based on (1) a daily record of stage and (2) measurements at selected stages, by current meter, of the discharge in cubic feet per second. The measured discharges and the corresponding stages are used as ordinates for plotting on graph paper points through which a curve is drawn. The curve shows the relation between stage and discharge for all stages between the highest and lowest measured discharges, and the record of daily flow within the same limits may be obtained by using the curve with the record of daily stages.

Measurements of discharge are not always obtainable at the stages of maximum flow, and therefore it becomes necessary to extend the rating curve to obtain the discharge at maximum stage. A well-defined curve may be extended with reasonable accuracy for a few feet, but long extensions, such as are necessary to cover unusual flood stages, are subject to considerable error and must be used with caution. Changes in shape of the cross section due to overflowed banks or backwater caused either by tributaries in flood or by contracted sections of the channel are the principal factors that affect the shape of the extended rating curve.

At some gaging stations the results of discharge measurements may be plotted on paper having the ordinates graduated to logarithmic scales. The relation curve thus developed becomes a straight line, which can be extended more accurately than the usual curved line. The principal conditions under which the logarithmic method of plotting and extending curves is feasible are as follows: (1) The cross section of the channel at the control section must increase uniformly with stage and not show abrupt increases such as would result from overflowed banks; (2) the control section of the channel, which fixes the relation between stage and discharge, must remain at the same place and not move upstream or downstream as the stage changes. The method of logarithmic extension of rating curves was used successfully at several gaging stations in New England to obtain the peak discharge during the flood of November, 1927.

Computation of flow over dams.—Under favorable conditions a dam over which all water at the peak of a flood passes between the abutments can be used for determining the peak discharge. The flow over a dam may be computed by a formula of which the principal elements are the length of crest between abutments, the head on the crest, and a coefficient which depends on the shape of the crest and the head. The base formula is usually written

$$Q = CLH^{\frac{3}{2}}$$

in which Q = discharge in second-feet, C = coefficient for the dam, L = effective length of crest, and H = head on the crest taken far enough above the dam to avoid the surface curve.

The velocity of approach in the channel above the dam virtually causes an increase in the head. If the head due to velocity of approach is designated by h the formula becomes

$$Q = CL\ (H+h)^{\frac{3}{2}}$$

Values of the coefficient C have been determined by experiment on models of dams of different shapes, and the practical application of the formula to full-size dams depends largely upon the selection of the coefficient. The velocity of approach in the channel above the dam may be determined by trial solutions of the usual discharge formula, $Q = av$, in which a equals the cross-sectional area of the channel of approach and v the velocity. The discharge (Q) for trial is taken as approximately equal to that found by solving the base formula without including the head due to velocity of approach. After a satisfactory figure for velocity of approach has been obtained it is converted to head h by use of the formula $h = \frac{V^2}{2g}$, in which V is the velocity and g is the acceleration due to gravity.

Where this method was used in determining discharge during the flood of November, 1927, the head over the dam was obtained by means of gage readings made during the flood or by leveling to points marked at the time of the flood or to other high-water marks. The velocity of approach was computed and converted to velocity head in all determinations at dams. At most dams the area of the approach channel was obtained from plans based on previous surveys or from soundings above the dam, and at the others it was estimated. The length of the spillway was obtained from existing plans of the dam, from plant operators, or by actual measurement after the flood. The proper coefficient C to be used in the formula was selected from Water-Supply Paper 200 [4] or from the most modern handbooks. Where the dams were submerged the coefficients were reduced by the method based on experiments made in 1899 at the Cornell University hydraulic laboratory.[5]

Slope-area method.—In the slope-area method the discharge of a river is obtained from measurements of the slope and mean cross section and the use of formulas. The mean velocity of a stream has been expressed in the Chezy formula as $V=C\sqrt{RS}$, in which R is the hydraulic radius, S the slope, and C a coefficient combining the total effects of roughness of bed and banks and all other factors that may affect the velocity, except the slope and hydraulic radius. The Chezy formula was used by Kutter, who developed an expression for the coefficient C in terms of S, R, and n, in which n is the coefficient of roughness. Chezy's formula for velocity with Kutter's expression for C then becomes

$$V=\left\{\frac{\frac{1.811}{n}+41.6+\frac{0.00281}{S}}{1+\left\{41.6+\frac{0.00281}{S}\right\}\frac{n}{\sqrt{R}}}\right\}\sqrt{RS}$$

In measuring discharge by the slope method it is necessary to determine the mean area of cross section and the slope of the surface of the water for a stretch of the channel and to observe the roughness of the bed and banks, which will determine the proper value of the coefficient of roughness. In making such a measurement a straight channel 200 to 1,000 feet long must be selected and measured. In this stretch the slope and cross section should be reasonably uniform, and the bed and banks should preferably be permanent. The slope should be sufficiently large to be measured without a large percentage of error. The results obtained by the slope method are in general only roughly approximate, owing to the difficulty in obtaining accurate data and the uncertainty of the value for n to be used in the formula. This method is commonly used in estimating flood discharge, generally after the crest of the flood has passed and when the data available are the slope and area of cross section as determined from marks along the banks and a knowledge of general conditions of channel and banks during the flood.

For the flood of November, 1927, in New England the slope-area method of determining flood discharge was used only where other

[4] Horton, R. E., Weir experiments, coefficients, and formulas: U. S. Geol. Survey Water-Supply Paper 200, 1907.

[5] U. S. Board of Engineers on Deep Waterways Rept., pt. 1, p. 291, 1900.

methods were not applicable. The slope and area determinations were based on such high-water marks as could be identified in the stretch of river selected. Two or three cross sections were determined by means of a Y level, the depths below the water surface usually being measured from a boat. The slope between cross sections was carefully determined by leveling, and distances between cross sections, which varied, according to conditions, from a few hundred to 2,000 feet, were measured by chain or stadia. Coefficients of roughness (n) were selected and discharge computed by using the Chezy-Kutter formula. The values of n as used in these investigations ranged from 0.03 to 0.08. In each computation the engineer making the survey carefully considered the conditions affecting the value of n before selecting its value. Modern handbooks on hydraulics were used as guides in determining the appropriate value for n.

Contracted-opening method.—Where a stream passes through a contracted opening in which the area of cross section is much less than the normal cross section of the channel there is an increase in the velocity of the water while passing through the opening. Such an increase in velocity can be produced only by the conversion of head into velocity, and the amount of head so used shows as a sudden drop of the water surface beginning at the entrance of the opening. The flow through the opening is equal to the product of the area of cross section and the velocity in the section. The velocity is computed from the velocity head shown by the "drop-off," plus the head due to velocity of approach, reduced by the friction head.

The necessary field data for a determination of flow by this method consist of several cross sections of the channel above the contracted section as well as at the contracted section, and data from which the longitudinal profile of the surface above and below the contracted section may be developed. The surface drop through the contracted section is obtained from the profile, and velocity of approach is obtained from the cross section and slope of the channel above the contracted section by the slope formula or by trial computations. The friction head is only a small part of the total head if the contracted section is short, and it is usually estimated.[6]

The contracted-opening method was used to obtain the flood discharge at four points in New England for the flood of November, 1927. At three of these points no check of the results was practicable, but at Mohawk River near Colebrook, N. H., the results obtained are consistent with those obtained by the slope-area method at points above and below.

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[6] The calculation of discharge from measurements at contracted openings is discussed at considerable length in Miami Conservancy District Tech. Rept., pt. 4, Calculation of flow in open channels, Dayton, Ohio, 1918.

MAXIMUM DISCHARGE

The results of determinations of flood flow at gaging stations, dams, and other points in the area affected by the storm of November, 1927, are shown in the following table, in which the data are arranged by river basins. The length of the records at gaging stations and the maximum discharges previously recorded are shown for purposes of comparison with maximum discharges during this flood. The location of the points of maximum flood flow is shown on Plate 2, and the identification numbers thereon correspond to those given in the table.

The records for about 50 points in the list were obtained by use of rating curves at existing or previously operated gaging stations. At about the same number of points the maximum discharge was computed from data relating to the flow over dams. For these the coefficient C, used in the discharge formula, is given in the table. The coefficient of roughness, *n*, used in Kutter's formula in slope-area determinations, is also presented.

At many points the flood flow was reduced by storage in reservoirs which did not spill until the peak stages had occurred in the rivers below. For such points the total drainage area has been reduced by the area which did not contribute to the peak of the flood, and the effective area thus obtained has been used to compute the maximum rate of discharge for the rest of the basin in second-feet per square mile. At some points the amount of regulated outflow or leakage from reservoirs has been deducted from the maximum discharge before computing the discharge in second-feet per square mile. Attention is called to the fact that rates of discharge in second-feet per square mile for previous floods may not be comparable with rates for this flood unless effective drainage areas and regulated flow are considered.

Maximum discharge and total run-off during the New England flood of November, 1927

No. on map	River and point of measurement	Period of record	Maximum discharge previously recorded		Drainage area (square miles)		Flood of November, 1927				Method of determination
			Date	Discharge (second-feet)	Total	Effective area for flood of November, 1927	Maximum discharge: Time of flood crest	Maximum discharge: Maximum (second-feet)	Maximum discharge: Per square mile (second-feet)	Total run-off Nov. 3–10 (millions of cubic feet)	
	Penobscot River Basin										
1	Penobscot, West Enfield, Me.	1901–1927	May 1, 1923	153,000	6,600	4,690	Nov. 6	60,800	[a] 12.5	23,682	Rating curve.
2	East Branch of Penobscot, Grindstone, Me.	1902–1927	Apr. 30, 1923	35,100	1,070	1,070	Nov. 5	21,300	19.9	5,710	Do.
3	Mattawamkeag, Mattawamkeag, Me.	1902–1927	May 1, 1923	43,900	1,500	1,500	Nov. 6	16,900	11.3	7,628	Do.
4	Piscataquis, Lows Bridge, near Foxcroft, Me.	1902–1927	Sept. 29, 1909	21,700	286	286	Nov. 5	6,740	23.6	1,447	Do.
5	Piscataquis, Medford, Me.	1924–1927	Oct. 21, 1927	24,600	1,170	1,170	Nov. 5	18,200	15.6	5,572	Do.
6	Pleasant, Milo, Me.	1920–1927	Apr. 30, 1923	24,400	325	325	Nov. 5	7,260	22.4	2,300	Do.
	Kennebec River Basin										
7	Kennebec, Waterville, Me.	1892–1927			4,270	3,030	Nov. 5	76,800	[a] 26.3	22,366	Flow over dam, through wheels and gates.[b]
8	Dead, The Forks, Me.	1901–1907, 1910–1927	Apr. 30, 1923	23,800	878	830	Nov. 5	14,700	17.7	5,790	Rating curve.
9	Carrabasset, near North Anson, Me.	1925–1927	May 3, 1926	8,590	351	351	Nov. 4, 10 p. m.	18,600	53	2,407	Do.
	Androscoggin River Basin										
10	Androscoggin, upper plant of Brown Co., Berlin, N. H.	1913–1922			1,380	538	Nov. 4, 8–10 p. m.	12,000	22.3	4,186	Weir formula.[c]
11	Androscoggin, dams of Rumford Falls Power Co., Rumford, Me.	1892–1927			2,090	1,248	Nov. 5	46,700	37.4	9,707	([d])
12	Androscoggin, dam of Central Maine Power Co., Lewiston, Me.		1896	65,000	2,856	2,014	Nov. 5, 7 p. m.	60,000	29.8	14,604	Flow over dam, through wheels and gates.[c]
13	Peabody, above Nineteenmile Brook, near Glen House, N. H.				17.4	17.4		7,330	421		Slope-area; two determinations, n=0.06 and 0.07.
14	Peabody, below Barnes Brook, near Gorham, N. H.				40	40		9,920	248		Slope-area, n=0.07.

[a] Reduced by amount of regulated flow, or leakage.
[b] Record furnished by Hollingsworth & Whitney Co., Waterville, Me.
[c] Record furnished by P. L. Bean, Union Water Power Co., Lewiston, Me.
[d] Record furnished by Charles A. Mixer, Rumford Falls Power Co., Rumford, Me.

Maximum discharge and total run-off during the New England flood of November, 1927—Continued

No. on map	River and point of measurement	Period of record	Maximum discharge previously recorded		Drainage area (square miles)		Flood of November, 1927				
							Maximum discharge			Total run-off Nov. 3–10 (millions of cubic feet)	Method of determination
			Date	Discharge (second-feet)	Total	Effective area for flood of November, 1927	Time of flood crest	Maximum (second-feet)	Per square mile (second-feet)		
	Saco River Basin										
15	Saco, Cornish, Me.	1916–1927	May 2, 1923	23,000	1,300	1,300	Nov. 7	10,800	8.3	4,961	Rating curve.
16	Ellis, above Wildcat Brook, Jackson, N. H.				28	28		14,800	528		Slope-area, n=0.035.
17	Wildcat Brook, 2.1 miles above Jackson, N. H.				15	15		4,080	272		Contracted opening.
18	Ossipee, Cornish, Me.	1916–1927	Apr. 30, 1923	6,740	455	455	Nov. 6	2,320	5.1	1,133	Rating curve.
	Merrimack River Basin										
19	Pemigewasset, below Bakers River, at Plymouth, N. H.	1886–1927	Apr. 29, 1923	28,000	615	599	Nov. 4, 5 p. m.	60,000	100	• 7,156	Flow over Bristol dam reduced by estimated inflow.
20	Pemigewasset, dam at Bristol, N. H.				760	686		62,300	91		Dam; C=3.83.
21	Pemigewasset, dam at Franklin Falls, N. H.				956	791		59,700	75		Dam; C=3.8.
22	Merrimack, Franklin Junction, N. H.	1903–1927	Apr. 30, 1923	43,700	1,460	935	Nov. 5, 2 a. m.	67,000	[a] 71	•10,780	Rating curve.
23	Merrimack, dam at Sewalls Falls, N. H.				2,280	1,755	Nov. 5, 10 a. m.	58,000	[a] 32.7		Dam; C=2.60.[f]
24	Merrimack, dam at Garvins Falls, N. H.				2,340	1,815	Nov. 5, 4 p. m.	58,500	[a] 31.9		Dam; C=3.8 and 3.6.[f]
25	Merrimack, Manchester, N. H.	1924–1927			2,840	2,320	Nov. 5, 9 p. m.	60,300	[a] 26.0		Rating curve.[g]
26	Merrimack, Lowell, Mass.	{1848–1861, 1866–1916}	Apr. 23, 1852	83,000	4,215	3,570	Nov. 6, 4 a. m.	73,000	[a] 20.3		([h]).
27	Merrimack, dam of Essex Co., Lawrence, Mass.	1880–1927	Mar. 3, 1896	86,900	4,663	3,930	Nov. 6, 4 a. m.	70,360	[a] 17.6		Rating curve for dam.[i]
28	Mad, 4 miles above Campton Village, N. H.				47	47		10,200	217		Slope-area; n=0.055.
29	Mad, dam of electric plant, Campton Village, N. H.				59	59		12,000	203		Dam; C=3.33.
30	Beebe, 1 mile east of Beebe River, N. H.				31	31		5,800	187		Contracted opening.
31	Bakers, 2 miles north of Wentworth, N. H.				52	52		15,000	288		Slope-area; n=0.04 and 0.03.
32	South Branch of Bakers, near mouth, West Rumney, N. H.				42	42		9,800	233		Contracted opening.

33	Smith, 3 miles southwest of Bristol, N. H.	1918–1927	Mar. 29–30, 1925	2,260	78.5	78.5		5,800	74	[a] 595	Rating curve and slope-area.
34	Nubanusit Brook, 1½ miles above Peterboro, N. H.	1920–1927	Mar. 10, 1921	1,050	54.3	54.3	Nov. 4, 10 p. m.	1,010	19	276	Rating curve.
35	North Branch of Contoocook, North Branch Village, 4 miles northwest of Antrim, N. H.	1924–1927	Apr. 26, 1926	1,600	59.5	59.5	Nov. 5, 7 a. m.	2,100	35	[a] 430	Do.
36	Suncook, North Chichester, N. H.	1918–1927	Apr. 7, 1923	4,300	157	157		1,860	11.8		Do.
37	Souhegan, Merrimack, N. H.	1909–1927	Apr. 8, 1924	10,400	168	168	Nov. 5, 1 a. m.	6,650	40	952	Do.
	Providence River Basin										
38	Blackstone, Worcester, Mass.	1923–1927	Apr. 7, 1924	740	31.5	31.5	Nov. 4, 6–7 p. m.	790	25	132	Do.
	Pawtuxet River Basin										
39	Pawtuxet, Scituate Dam at Kent, R. I.				92.8	83.8	Nov. 4, 8–10 a. m.	10,900	130		Storage in reservoirs.[j]
40	Ponaganset, Barden Reservoir, Ponaganset.				33	32	Nov. 4, 7 a. m.	4,320	135		Dam; C=3.5.[j]
	Thames River Basin										
41	Quinebaug, Jewett City, Conn.	1918–1917	Mar., 1920	12,000	712	712	Nov. 5, 4 a. m.	12,500	18	3,434	Rating curve.
	Connecticut River Basin										
42	Connecticut, Waterford, Vt.	1927			1,600	1,520	Nov. 6, 8 a. m.	31,100	20.5		Rating curve.
43	Connecticut, South Newbury, Vt.	1918–1927	May 1, 1923	56,700	2,830	2,750	Nov. 4, 12 p. m.	78,000	28	[a] 23,004	Flow over Wilder Dam reduced by estimated inflow.
44	Connecticut, dam at Wilder, Vt.				3,410	3,330	Nov. 5, 12 m.	83,700	25		Dam; C=2.8.
45	Connecticut, White River Junction, Vt.	1911–1927	Mar. 27, 1913	113,000	4,120	4,040	Nov. 4, 7 a. m.	148,000	37	[a] 38,552	Rating curve.
46	Connecticut, Vernon, Vt.				6,300	6,220	Nov. 5, 1 a. m.	155,000	24.9		Rating curve.
47	Connecticut, Turners Falls, Mass.				7,250	7,170		171,000	23.8		Dam; C=3.9.[k]
48	Connecticut, Sunderland, Mass.	1904–1927	Mar. 28, 1913	135,000	8,000	7,740	Nov. 5, 4 p. m.	165,000	21.3	59,132	Rating curve.
49	Connecticut, Holyoke, Mass.				8,390	8,120	Nov. 5, 2.30–4.30 p. m.	169,000	20.8		Flow at Sunderland plus, estimated inflow.
50	Mohawk, 6.15 miles above Colebrook, N. H.				26	26		4,340	167		Slope-area; n=0.03.
51	Mohawk, bridge 5.75 miles above Colebrook, N. H.				30.5	30.5		5,110	167		Contracted opening.
52	Mohawk, 4.9 miles above Colebrook, N. H.				32	32		5,310	166		Slope-area; n=0.03.
53	Israel, dam at Lancaster, N. H.				124	124		8,840	71		Dam; C=3.6.
54	Johns, dam at Whitefield, N. H.				35	35		1,080	31		Dam; C=3.5.
55	Passumpsic, Pierce's mills, near St. Johnsbury, Vt.				237	237		33,000	139		Dam; C=3.9.
56	Ammonoosuc, Bethlehem Electric Co.'s dam near Bethlehem, N. H.				97	97		17,900	185		Dam; C=2.7 and 3.85.

[a] Reduced by amount of regulated flow, or leakage.
[e] Partly estimated.
[f] Record furnished by H. M. Turner, consulting engineer, Boston, Mass.
[g] Record furnished by Amoskeag Manufacturing Co., Manchester, N. H.
[h] Record furnished by Proprietors of Locks and Canals on Merrimack River, Lowell, Mass.
[i] Record furnished by Essex Co., Lawrence, Mass.
[j] Record furnished by W. W. Peabody, Water Supply Board, Providence, R. I.
[k] Record furnished by H. A. Moody, Turners Falls Power & Electric Co.

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Maximum discharge and total run-off during the New England flood of November, 1927—Continued

No. on map	River and point of measurement	Period of record	Maximum discharge previously recorded		Drainage area (square miles)		Flood of November, 1927				
							Maximum discharge			Total run-off Nov. 3–10 (millions of cubic feet)	Method of determination
			Date	Discharge (second-feet)	Total	Effective area for flood of November, 1927	Time of flood crest	Maximum (second-feet)	Per square mile (second-feet)		
	Connecticut River Basin—Continued										
57	Ammonoosuc, upper dam of Littleton Light & Power Co., 2 miles above Littleton, N. H.				124	124		16,600	134		Dam; C=3.74.
58	Waits, Bradford Electric Light Co. dam, Bradford, Vt.				162	162		10,500	65		Dam; C=3.50.
59	White, 2 miles below West Hartford, Vt.				695	695	Nov. 4, 3 a. m.	140,000	202	798	Slope-area; n=0.032.
60	Mascoma, Mascoma, N. H.	1923–1927	Mar. 30, 1925	3,700	148	148	Nov. 5, 4 p. m.	3,230	21.8		Rating curve.
61	Ottauquechee, dam at Taftsville, Vt.				192	192		25,400	132		Dam; C=4.0.
62	Ottauquechee, dam at Deweys Mills, Vt.				208	208		27,200	131		Dam; C=3.8.
63	West, 1¼ miles northeast of Newfane, Vt.	1919–1927	Apr. 12, 1922	12,200	310	310	Nov. 3, 12 p. m.	45,000	145		Rating curve.
64	West, dam at West Dummerston, Vt.				410	410		49,000	120		Dam; C=3.33.
65	Ashuelot, 1 mile below Gilsum, N. H.	1922–1927	Apr. 25, 1926	1,350	68.5	68.5	Nov. 4, 12 m.	2,760	40	507	Rating curve.
66	Ashuelot, dam 1½ miles above Hinsdale, N. H.				431	431	Nov. 4, 11.30 a. m.	6,580	15.3		Dam; C=3.8 and 3.3.
67	South Branch of Ashuelot, dam at Troy, N. H.				8	8		913	114		Dam; C=3.7.
68	South Branch of Ashuelot, at Webb near Marlboro, N. H.	1920–1927	Feb. 12, 1925	1,680	36.6	36.6	Nov. 4, 8.15 a. m.	3,560	97	333	Rating curve.
69	Millers, Erving, Mass.	1914–1927	Mar. 28, 1920	6,020	372	372	Nov. 4, 10.30 a. m.	6,350	17	2,082	Do.
70	Sip Pond Brook, 3 miles northwest of Winchendon, Mass.	1916–1927	May 23, 1919	339	18.8	18.8	Nov. 4, 7 p. m.	340	18	97	Do.
71	Priest Brook, 3½ miles west of Winchendon, Mass.	1916–1927	Mar. 28, 1919	700	18.8	18.8	Nov. 5	1,000	53	[e] 195	Do.
72	East Branch of Tully River, 3½ miles north of Athol, Mass.	1916–1927	Mar. 29, 1920	1,000	50.2	50.2	Nov. 4, 5 p. m.	1,610	32	[e] 360	Do.
73	Moss Brook, Wendell Depot, Mass.	1916–1927	Mar. 28, 1919	190	12.2	12.2	Nov. 4, 4.45 p. m.	775	64	[e] 144	Do.
74	Deerfield, Somerset Reservoir, Vt.				30	30			[l] 165		Storage in reservoir.[k]
75	Deerfield, Davis Bridge Reservoir, Vt.				184	154			[m] 200		Do.[k]
76	Deerfield, Charlemont, Mass.	1913–1927	July 8, 1915	50,600	362	180	Nov. 3, 9.30 p. m.	36,000	200	3,163	Rating curve.
77	Cold, 2¾ miles south of Hoosac Tunnel, Mass.				22.4	22.4		6,870	307		Slope-area; n=0.065.
78	Cold, near mouth, 2½ miles northwest of Charlemont, Mass.				32.2	32.2		7,760	241		Slope-area; n=0.08.

79	Ware, Gibbs Crossing, 3 miles below Ware, Mass.	1912–1927	Apr. 8, 1924	2,950	201	201	Nov. 4, 9 p. m.	2,830	14.1	866	Rating curve.
80	Swift, West Ware, Mass.	1910–1927	Apr. 7, 1923	2,390	186	186	Nov. 6, 3 a. m.	2,230	12.0	839	Do.
81	Quaboag, West Brimfield, Mass.	1909–1927	Mar. 17, 1920	1,980	150	150	Nov. 4, 8.30 a. m.	1,180	7.9	471	Do.
82	Westfield, dam at Cummington, Mass.				53	53		6,020	114		Dam; C=3.3.
83	Westfield, dam at West Chesterfield, Mass.				99	99		8,720	89		Dam; C=2.8.
84	Westfield, dam at Huntington, Mass.				224	224		23,600	105		Dam; C=3.66.
85	Westfield, dam at Russell, Mass.				322	322		30,100	93		Dam; C=3.25.
86	Westfield, Trap Rock Crossing, near Westfield, Mass.	1914–1927	Apr. 7, 1924	32,500	496	496	Nov. 4, 8 a. m.	42,500	86	[a] 5,037	Rating curve.
87	Westfield, dam at Mitteneague, Mass.				512	512		38,000	74		Dam; C=3.8.
88	Stevens Brook, dam at West Chesterfield, Mass.				12	12		1,450	121		Dam; C=3.7.
89	Little, upper and lower dams at South Worthington, Mass.				10.4	10.4		1,230	118		Dam; C=3.8 for each dam.
90	Middle Branch of Westfield, Goss Heights, Mass.	1910–1927	July 8, 1915	4,500	53	53	Nov. 3, 9 p. m.	5,860	111	539	Rating curve.
91	West Branch of Westfield, dam at Huntington, Mass.				95	95		16,000	168		Dam; C=3.5.
92	Walker Brook, dam at Chester, Mass.				18	18		2,080	116		Dam; C=3.6.
93	Westfield Little, diversion dam of Springfield waterworks, 3 miles west of Westfield, Mass.	1905–1922	Mar. 13, 1920	1,940	48.5	48.5		3,940	81		([n]).
94	Westfield Little, Crane Paper Co.'s dam, Westfield, Mass.				81	81		8,500	105		Dam; C=3.6.
95	Farmington, 1 mile south of New Boston, Mass.	1913–1927	Apr. 7, 1924	3,450	92.7	75.1	Nov. 3, 9.30 p. m.	7,900	105	1,145	Rating curve.
96	Farmington, New Hartford, Conn.				231	213		24,750	116		([o]).
97	Farmington, dam at Rainbow, Conn.				581	563	Nov. 5, 4–5 a. m.	22,300	40		Dam; C=3.66.[p]
98	East Branch of Farmington, dam at Barkhamstead, Conn.				61.2	61.2		8,680	142		([o]).
99	Nepaug, above Nepaug Reservoir, near Collinsville, Conn.				23.9	23.9		1,783	74.6		([o]).
100	Phelps Brook, above Clear Brook, near Collinsville, Conn.				2.9	2.9		199	69.5		([o]).
101	Clear Brook, ¼ mile above mouth, near Collinsville.				1.05	1.05		46	43.8		([o]).
	Housatonic River Basin										
102	Housatonic, dam at Dalton, Mass.				54.7	50.4		5,460	108		Dam; C=3.8.
103	Housatonic, dam 1½ miles west of Dalton, Mass.				57	53		4,830	91		Dam; C=3.0.
104	Housatonic, dam at Lee, Mass.				187	161		5,980	37		Dam; C=3.7.
105	Housatonic, dam at South Lee, Mass.				244	218		7,830	36		Dam; C=3.3.
106	Housatonic, Falls Village, Conn.	1912–1927	Mar. 29, 1914	8,830	644	618	Nov. 5, 6 p. m.	11,700	18.9	4,901	Rating curve.

[a] Partly estimated.
[k] Record furnished by H. A. Moody, Turners Falls Power & Electric Co.
[l] Based on increase in storage from 4 p. m. Nov. 3 to 5 a. m. Nov. 4.
[m] Based on increase in storage from 2 to 5 a. m. Nov. 4.
[n] Record furnished by Springfield Waterworks, Springfield, Mass.
[o] Record furnished by C. M. Saville, Board of Water Commissioners, Hartford, Conn.
[p] Record furnished by P. W. Fairbanks, hydraulic engineer, New Britain, Conn.

Maximum discharge and total run-off during the New England flood of November, 1927—Continued

No. on map	River and point of measurement	Period of record	Maximum discharge previously recorded		Drainage area (square miles)		Flood of November, 1927				
			Date	Discharge (second-feet)	Total	Effective area for flood of November, 1927	Maximum discharge: Time of flood crest	Maximum discharge: Maximum (second-feet)	Maximum discharge: Per square mile (second-feet)	Total run-off Nov. 3–10 (millions of cubic feet)	Method of determination
	Hudson River Basin										
107	Batten Kill, 1 mile southwest of Battenville, N. Y.	1922–1927	Feb. 12, 1925	7,350	397	397		20,000	50.7		Rating curve.
108	Hoosic, ¼ mile above North Branch, North Adams, Mass.				74	74		7,770	105		Dam; C =3.45.
109	Hoosic, Greylock Mills, dams 2 miles west of North Adams, Mass.				124	124		12,400	100		Two dams; C=3.33 for each.
110	Hoosic, Greylock Mills dam at North Pownol, Vt.				223	232		14,600	66		Dam; C=3.3.
111	Hoosic, 1½ miles southeast of Eagle, Bridge, N. Y.	1910–1927	July 9, 1915	16,700	512	512		29,700	58		Rating curve.
112	North Branch of Hoosic, Hoosic Mills dam, North Adams, Mass.				40	40		12,200	305		Dam; C=3.3.
113	Green, Boyd's dam, Williamstown, Mass.				42.3	42.3		3,870	92		Dam; C=3.5.
114	Poesten Kill, 4½ miles above mouth, 3 miles east of Troy, N. Y.	1923–1927	Feb. 12, 1925	3,280	88	88		7,150	81		Rating curve.
	Lake Champlain Basin										
115	Otter Creek, Middlebury, Vt.	1923–1907 1910–1920	Mar. 30, 1913	10,000	615	590		13,600	23.1		Do.
116	Otter Creek dam at Huntington Falls, above Weybridge, Vt.				739	714		18,800	26.3		Dam; C=2.64.
117	East Creek, Patch Dam, 2 miles above Rutland, Vt.				51	26.1		4,750	182		Dam; C=3.2.
118	Tenney Brook, Dunklee Pond Dam, near Rutland, Vt.				5.2	5.2		900	173		Dam; C=3.37.
119	Winooski, above Dog River, Montpelier, Vt.	1909–1923	Apr. 7, 1912	20,200	420	397	Nov. 3, 12 p. m.	57,000	144		Rating curve.
120	do.				420	397		60,600	153		Slope-area; n=0.04.
121	Winooski, 4½ miles above dam at Essex Junction, Vt.				1,034	1,010	Nov. 4, 2 p. m.	110,000	109		Slope-area; n=0.03.

122	Winooski, Burlington Light & Power Co.'s dam, Essex Junction, Vt.				1,044	1,020	Nov. 4, 2 p. m.	116,000	114		Dam; C=4.00.
123	Mollys Brook, dam of Montpelier & Barre Light & Power Co., Mollys Falls, Vt.				24	24	Nov. 5, 7 a. m.	581	14.2		Dam.
124	Jail Branch, East Barre, Vt.	1920–1923	Apr. 10, 1822	1,350	38	38		11,500	303		Rating curve.
125	North Branch of Winooski, dam at Wrightsville, Vt.				67	67	Nov. 3, 11 p. m.	17,200	257		Dam; C=3,33.
126	Dog, ¾ mile above Union Brook, Northfield, Vt.	1909–1920	Mar. 25, 1913	3,400	52	52	Nov. 3, 6.30 p. m.	8,000	154		Rating curve.
127	Dog, dam of Cross Bros. plant, Northfield, Vt.				60.5	60.5		9,160	151		Dam; C=3.9.
128	Mad, dam, No. 8 of Peoples Electric Co., near Middlesex, Vt.				143	143	Nov. 3, 12 p. m.	23,000	161		Dam; C=3.00.
129	Lamoille, dam of Morrisville Electric Light & Power Co., Cadys Falls, Vt.				280	280		36,600	131		Dam; C=4.0
130	Lamoille, dam at Public Electric Light Co., Fairfax Falls, Vt.				559	559	Nov. 4, 3–4 p. m.	66,900	120		Dam; C=3.90.
131	Missisquoi, 2 miles above Trout River, 3 miles below Richford, Vt.	1909–1923	Apr. 7, 1923	16,000	445	445		45,000	101		Rating curve.
132	Missisquoi, dam at Sheldon Springs, Vt.				809	809		62,900	78		Dam; C=4.00.
	St. Francis River Basin										
133	Clyde, dam of Newport Electric Light Co., West Derby, Vt.	1909–1924	March, 1913	4,500	150	150		3,660	24.4		Dam; C=3.30.
134	Tomifobia, Butterfields Co.'s dam at Derby Line, Vt.				58	58		8,700	167		Dam; C=3.8.[f]

[f] Record furnished by H. M. Turner, consulting engineer, Boston, Mass.

EFFECT OF RESERVOIRS ON FLOOD FLOW

One method often proposed for controlling or reducing flood flows is the construction of reservoirs on the headwater or tributary streams. If the reservoirs can be made to serve other purposes, such as regulation of flow for power, the cost for each purpose is thereby reduced. Difficulties may be encountered, however, in the operation of reservoirs that serve more than one purpose.

Reservoirs in the New England area affected by the storm of November, 1927, were built for the development of power. Fortunately at the time of the storm many of them had storage capacity available and were therefore able to retain the flood flows from their drainage areas at least until peak stages in the main rivers had passed. In the preparation of records of maximum discharge and discharge in second-feet per square mile, the effect of such reservoirs has been considered.

In the Merrimack River Basin the total drainage area for the Pemigewasset River at Plymouth was reduced by 16 square miles tributary to Bakers Ponds, which did not spill until the peak on the main river had passed. For the same river at Bristol an additional area of 58 square miles for Squam Lake was deducted, and at Franklin Falls an area of 91 square miles for Newfound Lake, making the controlled area at this point 165 square miles. For the points on Merrimack River at Franklin Junction, Sewalls Falls, Garvins Falls, and Manchester, the area tributary to Lake Winnepesaukee, 360 square miles, is also deducted, making the controlled area 525 square miles. For Lowell 118 square miles additional was deducted because of diversion for water supply of Boston, and for Lawrence 93 square miles for the same purpose, making the total reduction at Lawrence 736 square miles.

In the Connecticut River Basin the drainage areas for all points on the main stream from Waterford to Turners Falls, inclusive, were reduced by 81 square miles, the area controlled by the dam on First Connecticut Lake. The areas for Sunderland and Holyoke were further reduced by 184 square miles tributary to the Somerset and Davis Bridge Reservoirs, on the Deerfield River. These reservoirs had, respectively, 16 and 28 per cent of their capacities unfilled after the flood and furnish an excellent example of what power storage will do toward flood control. The drainage areas for points on the Farmington River were reduced by 17.6 square miles controlled by Otis Reservoir, which probably did not contribute to the peak stage. At points on the Housatonic River near Dalton the drainage areas were reduced by 4.3 square miles controlled by Ashmere Reservoir, and at Lee, South Lee, and Falls Village by 21.7 square miles additional, controlled by Pontoosuc Lake.

The drainage areas for Otter Creek at Middlebury and near Weybridge were reduced by 25 square miles and that for East Creek near Rutland by 24.9 square miles for areas controlled by dams that did not spill. In the Winooski River Basin the areas for Montpelier and Essex Junction were reduced by 24 square miles controlled by Mollys Falls Reservoir, on Mollys Brook, which did not spill until the peak of the flood had passed on the main stream. It is estimated that if there had been no storage on Mollys Brook the flood flow at Montpelier would have been increased by 6,000 second-feet, or about 10 per cent.

The lakes and reservoirs on the headwaters of the rivers in Maine undoubtedly had some effect in reducing the peaks of the floods on those rivers. The Carrabasset River near North Anson, Me., however, had a higher discharge in second-feet per square mile than streams at other points in Maine. This is explained by steep slopes and few ponds in the drainage area above the section.

The following table shows for a group of reservoirs in New England the amounts in storage before and after the flood and the additional storage that would be available if the spillway crests were raised 5 feet. The data were furnished by H. A. Moody, hydraulic engineer, Turners Falls Power & Electric Co.

Storage in reservoirs during flood of November, 1927

Reservoir	Drainage area (square miles)	Total storage capacity		Storage capacity available on Nov. 3 (inches on drainage area)	Quantity stored			Storage capacity available Nov. 5		Additional storage capacity 5 feet above crest	
					Maximum day		Two days (inches on drainage area)				
		Millions of cubic feet	Inches on drainage area		Inches on drainage area	Second-feet per square mile		Inches on drainage area	Per cent of total	Inches on drainage area	Second-feet per square mile for one day
Pawtuxet River Basin:											
Scituate Reservoir	93	4,950	22.9	5.6		[a] 122	±5.6	([b])		3.6	96
Connecticut River Basin:											
First and Second Lakes	83	3,865	20.3	7.74	1.79	47.5	2.36	5.38	26.5	5.89	158
Miles Pond	5	80	6.9	[c] 1.55			[d] 1.55				
Indian Pond	1.5	41	11.75	[c] 3.05			[e] 3.05				
Goose Pond	15	480	13.8	8.25	.66	17.8	1.18	7.4	54.0	4.3	116
Grafton Pond	3.2	139	18.7	18	2.83	76.0	2.83	15.4	82.0	9.7	260
Crystal Lake	10.5	140	5.75	1.68	1.89	50.7	2.10	([f])		3.9	103
Mascoma Lake	152	500	1.42	.23	.58	15.6	.93	([f])		1.14	30.5
Somerset Reservoir	30	2,714	38.94	11.72	4.78	129	5.44	6.28	16.2	5.48	145
Davis Bridge Reservoir	[g] 154	5,036	14.08	9.21	4.53	121	5.2	4.01	28.5	1.36	37
Otter Creek Basin:											
Chittenden Reservoir	17			4.87	4.00	107	4.87			4.14	111

[a] Rate for 4 hours.
[b] Spilling Nov. 19.
[c] Capacity available Nov. 1.
[d] Nov. 1–5.
[e] Nov. 1–7.
[f] Spilling.
[g] Net drainage area.

DAMAGE CAUSED BY THE FLOOD

A storm and flood of the magnitude that visited New England in November, 1927, is capable of nullifying the usefulness of most of the facilities and conveniences upon which modern civilized life depends. Damage to bridges and roadbeds of railroads and highways stops transportation and communication. Industries in towns and cities are affected by lack of transportation of materials and products or by actual flooding of plants, and agricultural lands are destroyed by erosion or rendered useless by deposition of sand and gravel. Public utilities furnishing gas, electric, telephone, telegraph, and street railway service are handicapped, if not stopped entirely, and public health is threatened by the flooding or destruction of water supply and sewerage systems.

An attempt was made to summarize property losses and damages caused by the flood of November, 1927, for the whole of New England, but it was found that, except in the State of Vermont, no organization had been given authority and funds to gather the data for a comprehensive survey.

In Vermont estimates of the losses and damages of various kinds were made by the Vermont Flood Survey, of which Robert M. Ross, Commissioner of Forestry, was chairman. The highway departments of all the States but Connecticut prepared estimates of losses and damages to highways and highway bridges, and the New England Flood Committee of the American Railway Engineering Association, W. J. Backes, chief engineer, Boston & Maine Railroad, chairman, has compiled data of the railroad losses and damages for the railroads in New England, though it was impracticable to segregate the data by States.

The Vermont report makes it appear that in a flood of such severity the financial losses in highways, railroads, industries, and municipalities are about equal, each being roughly 23 per cent of the total. Early reports overlooked the heavy losses to industries and municipalities. Accurate estimates of flood losses are, at best, difficult to obtain, but the estimates given are believed to be reliable as far as they go, and they should be of considerable value in showing the vast amount of money lost because of a single flood, thus giving some idea of the amount that it is wise and proper to expend in order to prevent the recurrence of such losses.

The total number of reported lives lost in New England was 85, one in Rhode Island and the rest in Vermont.

The following tabulation is taken from the report of the Vermont Flood Survey:

Losses in Vermont caused by the flood of November, 1927

Agricultural, 690 farms	$1, 350, 156
Roads and bridges, 1,258 bridges	7, 062, 998
Industries, 264 establishments	5, 558, 900
Municipalities, 137 cities and villages	6, 403, 651
Railroads and electric railways, 12 lines	7, 019, 200
State Hospital at Waterbury	400, 000
Telephone and telegraph companies	319, 050
Gas companies, 3	30, 400
	28, 144, 355

Estimates of damages to highways and highway bridges in four of the New England States, prepared by the State highway departments, are shown below. In Maine there was practically no damage, and in Connecticut the damage was not reported.

Damages to highways and highway bridges caused by the flood of November, 1927

New Hampshire	$2, 710, 139
Vermont	7, 062, 998
Massachusetts	936, 000
Rhode Island	75, 000
	10, 784, 137

The damages to railroad property and the losses due to suspension of traffic, operation, and miscellaneous losses as reported to the New England Flood Committee of the American Railway Engineering Association are shown by the following tabulation:

Railroad losses caused by the flood of November, 1927

Property damage:	
Bangor & Aroostook Railroad	$4, 000
Boston & Albany Railroad	350, 000
Boston & Maine Railroad	2, 500, 000
Canadian Pacific Railway	1, 250, 000
Central Vermont Railway	2, 750, 000
Delaware & Hudson Co	283, 000
Maine Central Railroad	200, 000
Montpelier & Wells River Railroad	190, 000
New York, New Haven & Hartford Railroad	100, 000
Rutland Railroad	750, 000
St. Johnsbury & Lake Champlain Railroad	291, 000
	8, 668, 000
Traffic, operating, and miscellaneous losses (not complete)	4, 131, 000
Grand total	12, 799, 000

PREVIOUS NEW ENGLAND STORMS

From time to time storms of unusual severity occur in New England. From a study of the frequency of the occurrence of these storms, it is evident that in some sections of New England a storm of great intensity may be expected to occur on the average about once in 20 years.

Prof. H. K. Barrows, of the Massachusetts Institute of Technology, writes as follows in an unpublished article entitled "Great storms in New England and their frequency":

A study of great storms in New England indicates the following list of exceptional storms:

November 3–4, 1927.	March 24–25, 1826.
July 12–14, 1897.	March 5–6, 1823.
October 12–14, 1895.	May 13–19, 1814.
February 11–14, 1886.	March 18–22, 1801.
October 3–4, 1869.	October 20–22, 1785.
July 24–25, 1830.	January 7–8, 1770.

Brief descriptions of these storms prior to that of 1927 follow:

July 12–14, 1897.—Memorable and destructive in Connecticut and western Massachusetts, lasting 30 to 36 hours. Rainfall 5 to 9 inches with a maximum of 10.3 inches at Southington, Conn.

October 12–14, 1895.—In southeastern New England, lasting about 36 hours. Rainfall 5 to 8 inches, but owing to previous dry weather no marked damage resulted.

February 11–14, 1886.—In southeastern New England, lasting about 48 hours. Rainfall 5 to 8 inches, but owing to deep snow, which melted, about 2 inches more of water was released. Records of this storm have served as a basis for waterway design in this district since that time.

October 3–4, 1869.—Covered most of New England and extended as far south as Virginia. Lasted 36 hours and resulted in one of the greatest freshets that has ever occurred in New England. Rainfall 6 to 12 inches with a maximum recorded of 12.35 inches at Canton, Conn.

July 24–25, 1830.—Centered in Vermont and resulted in floods and conditions similar to those of November, 1927. Lasted four or five days, with 7 inches of rain at Burlington, one-half of this in one day. Many lives were lost, and bridges, buildings, and other structures washed away. The worst floods were on Otter Creek and Winooski and White Rivers.

March 5–6, 1826.—Centered in northern New England and extended into New York and Canada. No records of rainfall are available, but it was stated as being "torrential." In Vermont much damage was done to roads, bridges, and buildings along the rivers, and some loss of life occurred. Montpelier—then a village—was almost entirely inundated, and much loss of farm stock resulted. This storm also caused very serious ice jam floods on the Kennebec River in Maine.

March 5–6, 1823.—Centered in Rhode Island and Connecticut. A very heavy 24-hour rainfall at a time when deep snow prevailed. Many bridges and buildings lost.

May 13–19, 1814.—In Maine the month was very wet, culminating in a four-day storm, with some further rain during two more days. Resulting freshet characterized as greatest in 30 years. Many bridges, mills, houses, and logs lost, particularly on the Androscoggin and Saco Rivers.

March 18–22, 1801.—A four-day rain, causing a great flood in southeastern Vermont, Massachusetts, and Connecticut. Much damage to mills, bridges, houses, etc., and loss of several lives.

October 20–22, 1785.—Preceded by a wet period. Rainfall totaled 9 inches in three days. Centered in southeastern New Hampshire and resulted in great freshets on the Merrimack and other rivers in New Hampshire. Much damage also on the Saco and Monsam Rivers in southwestern Maine.

January 7–8, 1770.—A 24-hour rainfall with loss of many mills and dams on the Kennebec and Androscoggin Rivers in Maine, owing particularly to heavy ice going out. Great damage also on the Connecticut River.

Available data.—Data for the above storms subsequent to and including that of 1869 are fairly complete and accurate. No comprehensive rainfall data are available for the earlier storms, and their severity must be judged mostly from the statements of resulting damage. There were other storms in this period that perhaps were of importance, but it is believed that those listed are the outstanding ones in this period of about 160 years.

Time of occurrence.—The 12 great storms listed occurred in the months of the year as follows: January, 1; February, 1; March, 3; May, 1; July, 2; October, 3; November, 1.

Location.—The general location of these storms was as follows: Northern New England, 5; southern New England, 4; general in New England, 3. The storms included as general in New England are those of 1869, 1897, and 1927. It is of interest to note that these were all storms of the Atlantic coast type, all occurring either in the summer or fall. These three are the outstanding great storms in New England in this period of about 160 years.

Frequency of great storms in New England.—The average great storm frequency has been as follows:

Location in New England	Number of storms in 160 years	Average frequency of occurrence (years)
Northern	5	32
Southern	4	40
General	3	53
	12	13

It is noteworthy, however, that the three greatest storms actually occurred within a period of the last 58 years, or one about every 20 years, on the average, in this time. If these three greatest storms are included as occurring in both northern and southern New England, as was the case, this would give northern New England 8 storms, or one every 20 years, and southern New England 7 storms, or one every 23 years.

It may, therefore, be concluded that, on the average, storms of sufficient magnitude to cause serious flood damage may be expected to occur about every 20 years anywhere in New England, except perhaps in the extreme northerly portions. Outstanding or general great storms covering most of New England may be expected every 30 or 40 years.

It must be clearly kept in mind, however, that these are average figures. No one can foretell when such storms may occur or the actual time intervals between them. They may of course occur even in two successive years.

The storm of 1869 was probably the greatest storm both in extent and intensity that has occurred in New England within the last century. Plate 2 shows the rainfall of this storm, from a map prepared by George V. White.[7] The late James B. Francis fully described this storm in a paper presented to the American Society of Civil Engineers at a meeting held in Boston in June, 1878. This storm centered over north-central Connecticut, with a maximum recorded rainfall of 12.35 inches at Canton, Conn., but heavy rains covered a more extensive area than during the storm of 1927. As indicated in the following table, the rainfall exceeded 9 inches over an area of 900 square miles, as compared to 500 square miles in 1927, and exceeded 6 inches over an area of 13,600 square miles, without including large areas in New York and Maine, as compared to 8,500 square miles in 1927.

Areas in which rainfall exceeded amounts indicated during storm of October, 1869

	Square miles
Over 12 inches: Connecticut	40
Over 11 inches: Connecticut and Massachusetts	255
Over 10 inches: Connecticut and Massachusetts	370
Over 9 inches:	
Connecticut	667
Massachusetts	235
	902
Over 8 inches:	
Connecticut	1, 450
Massachusetts	814
	2, 26
Over 7 inches:	
Connecticut	2, 333
Southwest Massachusetts and New York	1, 568
Central Massachusetts	333
New Hampshire	2, 508
Vermont	412
	7, 154
Over 6 inches:	
Connecticut	3, 314
Massachusetts	3, 304
Vermont	1, 804
New Hampshire	5, 150
	13, 572

As comparatively few rainfall stations were in operation in 1869, it is difficult to determine accurately the extent of the storm, but from contemporary press reports it is evident that widespread damage resulted over much of New England. At Concord, N. H., the rain

[7] Goodnough, X. H., Rainfall in New England during the storm of November 3 and 4, 1927: New England Waterworks Assoc. Jour. vol. 42, pl. 4, p. 170, 1928.

began falling during the night of October 2. By daylight on October 5 the precipitation had amounted to over 2 inches and by the afternoon of the same day 6 inches more had fallen. From this report it is evident that the precipitation was very heavy.

PREVIOUS FLOODS

Water was the only source of power readily available in the early period of American history, and the rivers became a very influential feature in the development of the country. Mills, located on the river banks adjacent to power sites, formed the center of growing communities, and crops were cultivated in the fertile river valleys. Thus it was that the behavior of the rivers was of vital importance to the early settlers, and as a result some of the longest records of river stages in the United States have been obtained on New England rivers.

In studying the periodicity of floods of certain magnitude, it is essential that a complete record of river stages be available over as long a period of time as possible. The following table is of great value in determining the periodicity of the principal floods on the Connecticut River, and has been taken from a paper by C. H. Pierce.[8] Peak stages for the years 1925 to 1927 have been added, and the peak discharges at Sunderland, Mass., have been revised.

Comparative heights of principal floods of the Connecticut River, 1639–1927

Year	Date	River stage (feet)			Peak discharge at Sunderland, Mass. (second-feet)
		Hartford, Conn.	Springfield, Mass.	Holyoke, Mass.	
1639	Mar. 18	(a)			
1642	May-June	(a)			
1683	July-August	26.0			
1692	February-March	26.2			
1767	Jan. 12	(a)	(a)		
1793	Feb. 21	(a)	(a)		
1798	Mar. 25	(a)	(a)		
1801	Mar. 20	27.5	21.2	(b)	
1807	Feb. 1	(a)	(a)		
1818	Mar. 3	(a)	(a)		
1824	Feb. 24	(a)	(a)		
1827	Mar. 30	(a)	(a)		
1838	Jan. 28	23.0			
1839	Jan. 29	24.2			
1841	Jan. 9	26.3			
1843	Mar. 29	27.2	20.7		
1852	Apr. 24	23.2	19.5		
1854	May 1	29.8	22.2		
1856	Aug. 21–22	23.3	18.9		
1859	Mar. 19–20	26.4	20.5		
1862	Apr. 20–21	28.7	22.0		
1865	Mar. 18–20	24.8	18.0		
1869	Apr. 22–23	26.7	20.5	11.2	
1869	Oct. 5–6	26.3	21.0	12.7	
1870	Apr. 20–21	25.3	19.0	9.5	
1874	Jan. 9	23.9	17.5	8.0	
1878	Dec. 11–13	24.5	18.5	9.2	
1893	May 5–6	24.0	18.1	8.4	
1895	Apr. 16–17	25.7	20.2	9.6	

[a] Great flood. [b] Jefferson flood.

[8] Flood flows of New England rivers: Boston Soc. Eng. Jour., vol. 11, pp. 327–375, 1924.

Comparative heights of principal floods of the Connecticut River, 1639–1927—Continued

Year	Date	River stage (feet)			Peak discharge at Sunderland, Mass. (second-feet)
		Hartford, Conn.	Springfield, Mass.	Holyoke, Mass.	
1896	Mar. 2–3	26.5	20.2	9.5	
1900	Feb. 14–15	23.4	17.0		
1901	Apr. 8–10	25.8	19.7	11.4	
1902	Mar. 4	25.3	19.2	10.8	
1903	Mar. 24–25	23.4	17.4	10.6	
1904	Apr. 30	21.4			73,400
1905	Mar. 31–Apr. 2	24.0	17.5	10.6	111,000
1906	May 29–30	18.5			71,700
1907	Nov. 8–9	20.3	15.4	9.0	78,100
1908	Mar. 30–31	18.2	13.1	7.6	66,300
1909	Apr. 16–17	24.7	18.5	10.6	113,000
1910	Jan. 23	20.0	15.0	7.5	57,800
1911	Apr. 16–17	15.5	11.9	7.2	60,100
1912	Apr. 9–10	21.2	16.1	9.3	93,200
1913	Mar. 28–29	26.3	20.9	12.0	135,000
1914	Apr. 21–23	21.9	17.0	9.9	102,000
1915	Feb. 26–27	20.6	15.6	8.8	82,100
1916	Apr. 2–3	20.8	15.6	8.9	79,000
1917	Mar. 29–30	18.3	13.5	7.4	65,000
1918	Apr. 3–4	18.8	14.0	7.9	73,000
1919	Mar. 29–30	19.8	15.0	9.2	83,600
1920	Mar. 28–30	22.5	17.3	9.83	114,000
1921	Mar. 10–12	19.9	15.5	8.86	81,300
1922	Apr. 13–14	24.5	19.4	11.35	127,000
1923	Apr. 7–8	22.0	16.8	9.35	94,000
1924	do	20.7	14.5	7.8	61,800
1925	Mar. 30–Apr. 1	20.5	16.0	9.47	97,400
1926	Apr. 26–27	20.8	16.03	9.14	92,400
1927	Nov. 3–6	29.0	22.45	14.75	165,000

NOTE.—Zero of gage at Hartford is mean tide at Saybrook, Conn. Stages at Springfield referred to a datum 37.8 feet above Hartford base. Zero of gage at Holyoke is crest of dam, which, since 1901, is 97.975 feet above Hartford base.

A comparison of the flood stages of 1927 with those recorded in previous years at several points on the Connecticut River is shown by the following table. The stages for Hartford, Springfield, and Holyoke are taken from the preceding table and are for those years in which the stage was 24 feet or more at Hartford.

In using this table it should be borne in mind that there is a tendency during the development of a river to increase the obstructions to the passage of floods down a river. New dams are built, old dams are raised, and bridge abutments and other structures encroach upon the stream bed to such an extent that a flood may have a tendency to reach a higher stage than equal floods of earlier years. The Connecticut River floods have been affected in this manner at some of the localities given in the table, so that the stages in the table not only serve as a comparison of stages for the principal floods but may be an indication of the effect produced by channel encroachments or river developments below.

Flood stages, in feet, at points on Connecticut River during years in which stage was 24.0 feet or more at Hartford

Year	Month	Hartford	Springfield	Holyoke	Sunderland	French King Rapids [a]	Connecticut River power Co. gage [b]	Bellows Falls	Ascutneyville	White River Junction	Orford	South Newbury	Wells River
1683	July-August	26.0											
1692	February-March	26.2											
1801	March	27.5											
1839	January	24.2											
1841	January	26.3											
1843	March	27.2	20.7										
1854	May	29.8	22.2										
1859	March	26.4	20.5										
1862	April	28.7	22.0			203.3	152.0	121.4					
1865	March	24.8	18.0										
1869	April	26.7	20.5	11.2									
1869	October	26.3	21.0	12.7								33.3	
1870	April	25.3	19.0	9.5									
1878	December	24.5	18.5	9.2									
1893	May	24.0	18.1	8.4									
1895	April	25.7	20.2	9.6						26.3			
1896	March	26.5	20.2	9.5									
1901	April	25.8	19.7	11.4									
1902	March	25.3	19.2	10 8							27.5		
1905	March-April	24.0	17.5	10.6	27.7					20.2	24.8		31.4
1909	April	24.7	18.5	10.6	27.9					22.6	30.3		35.0
1913	March	26.3	20.9	12.0	30.7	198.0	150.6	119.0	139.4	30.0	33.4		36.0
1922	April	24.5	19.4	11.35	29.7					26.8	31.0		
1927	November	29.0	22.45	14.75	34.1	203.4	156.5	125.8	145.2	35.0		35.4	

[a] 5 miles above Turners Falls. [b] 10 miles below dam at Bellows Falls.

Of the peaks in the 24 flood years 18 came in January to April, 1 in December, 2 in May, and 3 in summer or fall. The floods during December to May were due to combinations of accumulated precipitation, current precipitation, and temperature. Those occurring during the summer and fall are caused by current precipitation.

It is of interest also to note that of the 12 exceptional storms in New England listed on page 84, only 3 were coincident with great floods on the Connecticut River; these occurred in March, 1801, October, 1869, and November, 1927.

The flood of 1854 is the highest on record at Hartford, and it was practically equal to the flood of 1927 at Springfield. Pierce[9] writes as follows on the causes of this flood:

The greatest flood within authentic record at Hartford was in May, 1854, with a gage reading of 29.8 feet. This was at a period when all the forests of the upper watershed were still intact. It was, however, not a remarkable flood in the Merrimack, the only other New England river for which dependable records for that time are available. This was due to the prevalence of heavy rain, which began on the evening of April 27 and continued, practically without intermission, until noon of May 1, a period of about 90 hours. There is some evidence showing that a week prior to the rain a foot of wet snow fell over the upper watershed, and it is possible that there was still some of the winter's snow on the north slopes in New Hampshire and Vermont at the beginning of the warm spell that immediately preceded the heavy rain, which deposited nearly 7 inches at Hartford.

[9] Pierce, C. H., op. cit., p. 372.

The records for points upstream on the Connecticut River indicate that the flood of March, 1913, was probably the greatest between 1869 and 1927. Pierce[10] writes as follows about this freshet:

The high water of 1913 was entirely a heavy rain flood. The mild rainy weather of March 20 to 22 reduced to water the snow and ice yet remaining in the woods and mountains, and, there being considerable frost in the ground, conditions were favorable for a rapid run-off. Hence the smaller streams soon filled to overflowing banks and were augmented by heavy rains two days later, falling on thoroughly saturated ground where not frozen. A sharp rise in the larger streams quickly followed. In addition these larger streams were still running relatively high in connection with freshet conditions of the previous week. An immense volume of water was soon sweeping down from the north with irresistible force, inundating thousands of acres of land, and doing damage of such extent that the total value could not be estimated in a monetary sense. It produced at Hartford the highest water since 1896, and in the upper valley, where the rainfall was the heaviest, the greatest flood since 1869. It is further claimed by elderly people in upper Vermont that the crest wave was even higher than during the 1854 flood.

NEW ENGLAND FLOODS AND HIGHWAYS

By G. G. Clark, J. V. McNary, and C. S. Jarvis[11]

For many years prior to November, 1927, New England rivers had been regarded as outstanding examples of stabilized streams, with habits fairly well defined and moderated. These impressions were strengthened by the great number of old structures, such as timber crib dams and wooden truss bridges, which had survived the test of half a century or more; likewise by the lumber yards, the manufacturing plants, and the homes located much nearer the main channels than would be advisable where torrential flow is expected.

Apparently authentic accounts of devasting storms and floods in various parts of New England during the last 200 years would lead us to expect recurrence; yet the uninterrupted service of many timber bridges and dams for more than 50 years could not be disregarded. The record of those old structures seemed to justify the assumption that they might remain indefinitely, or until replaced by more modern types. It was difficult to conceive of more aggravated conditions than those which prevailed during October of both 1785 and 1869. Every new storage development should exert a regulating influence. Perhaps this was overestimated by those who have made encroachments within the natural channels and flood plains for enlargements of their plant facilities and storage yards. The losses of both life and property during the flood of November 3–5, 1927, were no doubt multiplied because of the feeling of security against a recurrence of the highest known stages that had prevailed. This catastrophe produced flood heights from 3 to 5 feet higher than previously recorded

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[10] Pierce, C. H., op. cit., p. 373.

[11] Bureau of Public Roads, U. S. Dept. Agriculture.

on the Winooski and its major tributaries, also in various sections of the Connecticut Valley; while on many other rivers new records were established at one or more stations. Intervening among these areas so severely devastated were others that escaped with only minor damage, owing to the positive regulation by adequate storage reservoirs for flood control, usually in combination with water supply or hydroelectric developments.

In addition to the misplaced confidence regarding attainable flood heights, the suddenness with which the crests invaded the unwarned valleys during those stormy nights may account in a large measure for the loss of personal property, livestock, and human life. Nearly 3 per cent of the entire population of Vermont were deprived of shelter when more than 9,000 people were driven from their homes. Houses badly damaged were reported as numbering 1,339, and 264 were totally destroyed. The 54 deaths occurring in the Winooski Valley alone represented approximately two-thirds of the known fatalities in New England directly traceable to the flood of November, 1927. There is abundant evidence that the indirect toll of human life may exceed the direct, because of the privations and hardships imposed.

SURVEY OF FLOOD DAMAGE TO HIGHWAYS AND BRIDGES

Within the week following the flood, the several State highway organizations, representatives of the War Department, of the United States Geological Survey, representing the Interior Department, and of the Bureau of Soils and Chemistry and the Bureau of Public Roads, representing the Department of Agriculture, were engaged in making preliminary surveys of the devasted areas, where relief work under the direction of the Red Cross was already in full swing.

In response to requests from the governors of Vermont and New Hampshire, the Bureau of Public Roads undertook and completed a rapid survey of the flood damage to highways and bridges in those States. This prompt action insured the advantage of first-hand information concerning the extent and nature of the damage before the evidence had been obliterated by reconstruction or repairs.

Highway improvement in the two States has been and is, to a considerable extent, a cooperative procedure—that is, Federal routes are improved with Federal and State funds, State aid and trunk-line routes with State and town funds, State roads (limited to a small mileage) with State funds, and town roads with town funds, the town unit being approximately comparable with the township of the Middle West.

The district engineer who had jurisdiction over the field operations of Federal highway work in these two and adjoining States was placed in charge of the survey. An organization comprising a statistical force and engineers from the district and Washington offices for field duty collected and compiled the required data in about one month, in spite of inclement weather and impaired transportation facilities.

Vermont and New Hampshire are administratively divided into twelve and ten districts, respectively, each under the supervision of a commissioner or district engineer, who reports to the State highway commissioner. A representative of the Bureau of Public Roads was assigned to each district to work in cooperation with the State representative, who served as an adviser in regard to the location of the damaged sections and ways and means of reaching and appraising them. As rapidly as inspections were completed, the appraisal sheets were mailed to Montpelier or Concord. On completion of the work in one district, the appraiser was assigned to another. Inspections were made in each of the twelve districts in Vermont, but only seven were covered in New Hampshire, as three in the southern part of the State suffered little or no damage.

ESTIMATED COST OF REPAIRS AND REPLACEMENTS

Although a large amount of detailed information was procured concerning bridges destroyed, it was not contemplated that the data sheets for a particular project would be used as the sole basis for planning new work. The estimates of damages to bridges were prepared on the basis of the present replacement cost of an adequate structure, as in general no data were available to show the original cost. Many of the old bridges were completely destroyed. Several of them were of antiquated design and scheduled for early replacement, as they were not well adapted to the requirements of present-day traffic.

Damage to the roads was estimated on the basis of reconstruction or relocation of the roadway, with materials similar to those previously existing in the damaged sections.

All appraisal reports from the field were reviewed and coordinated by the supervisors at the central office for each State, and the sites of all major structures were investigated by a bridge engineer from the Washington office.

Reports were entered on a schedule made up by State districts, showing the identification number of the report, the new work to be done, the length of the damaged section, and the estimated cost of replacement, chargeable to either highway or bridge damage, and listed under the appropriate column heading, whether Federal, State aid, or town routes. As rapidly as the reports were received by the statistical force, the review, classification, and posting were completed.

A brief summary of the estimated cost of repairs and replacements is as follows:

Estimated cost of repairs and replacement of roads and bridges damaged by the flood of November, 1927

[Based on survey by the Bureau of Public Roads]

	Roads	Bridges	Total
VERMONT			
Federal aid projects	$97, 913. 00	$122, 200. 00	$220, 113. 00
Federal aid routes, outside of limits of places having more than 2,500 population	885, 300. 00	1, 206, 720. 00	2, 092, 020. 00
Federal aid routes excluded as above		341, 600. 00	341, 600. 00
Total Federal system	983, 213. 00	1, 670, 520. 00	2, 653, 733. 00
State aid system	690, 930. 00	2, 263, 122. 00	2, 954, 052. 00
Town system	399, 288. 00	1, 370, 396. 00	1, 769, 684. 00
Grand total	2, 073, 431. 00	5, 304, 038. 00	7, 377, 469. 00
NEW HAMPSHIRE			
Federal aid projects	5, 790. 50	28, 095. 00	33, 885. 50
Federal aid routes, outside of limits of places having more than 2,500 population	136, 287. 50	433, 145. 00	569, 432. 50
Federal aid route in the town of Walpole, which may contain more than 2,500 population [a]		50, 000. 00	50, 000. 00
Total Federal system	142, 078. 00	511, 240. 00	653, 318. 00
State roads	148, 240. 00	83, 500. 00	231, 740. 00
State aid and trunk-line roads	230, 584. 75	326, 027. 00	556, 611. 75
Town roads	706, 618. 46	524, 426. 00	1, 231, 044. 46
Forest projects	17, 595. 00	19, 830. 00	37, 425. 00
Grand total	1, 245, 116. 21	1, 465, 023. 00	2, 710, 139. 21

[a] Damages in the town of Walpole consisted of the destruction of the approach and underpass at the east end of an interstate bridge to Bellows Falls, Vt. Total damage estimated to be $100,000, one-half to be paid by the railroad.

On the basis of these estimates the following appropriations were made by Congress in an act approved May 16, 1928:

For the relief of the following States as a contribution in aid from the United States, induced by the extraordinary conditions of necessity and emergency resulting from the unusually serious financial loss to such States through the damage to or destruction of roads and bridges by the floods of 1927, imposing a public charge against the property of said States far beyond its reasonable capacity to bear, and without acknowledgment of any liability on the part of the United States in connection with the restoration of such local improvements, namely: Vermont, $2,654,000; New Hampshire, $653,300; Kentucky, $1,889,994; in all, $5,197,294, to be immediately available and to remain available until expended: *Provided,* That the sums hereby appropriated shall be expended by the State highway departments of the respective States with the approval of the Secretary of Agriculture for the restoration, including relocation of roads and bridges so damaged or destroyed in such manner as to give the largest measure of permanent relief, under rules and regulations to be prescribed by the Secretary of Agriculture: *Provided further,* That the amount herein appropriated for each State shall be available from State funds for the purposes contained herein.

Subdivision according to drainage basins showed that nearly one-fourth of the estimated highway damage in Vermont occurred within the Winooski Basin, and an equal amount along White River and its tributaries; nearly one-tenth occurred within the Lamoille drainage area. Similarly, in New Hampshire the Ammonoosuc Basin, on the windward slopes of the Presidential Range, is charged with fully one-fourth of the total, or nearly five times the amount reported for a much greater area on the leeward slopes of the same range, draining into the Androscoggin.

RELATION OF HIGHWAY DAMAGE TO THE TOTAL

The official estimates of direct damage to agriculture in Vermont alone were approximately $1,500,000, the railroads sustained about $7,000,000, and other industries reported more than $5,500,000. In addition, there were indirect losses capable of fair appraisal which exceeded $7,000,000, and other deleterious effects due to the flood which can not be adequately expressed in monetary values. Of the total of direct or indirect damages in Vermont exceeding $28,000,000, the portion chargeable to the highway system is fully 25 per cent.

As partial compensation for these damages, some of the tests, training, and experiences associated with the recent flood may eventually be worth a large part of the cost, in leading to effectual preventive or control measures that may be undertaken by the stricken communities and others to prevent the recurrence of such disasters. Flood prevention and control have ceased to be regarded as merely local problems; to be effective, they demand either State or Federal supervision.

REOPENING ROADS TO TRAFFIC

Among the first activities undertaken by the stricken communities were the clearing and repair of highways and bridges. Where large structures had been destroyed, as between Middlesex and Waterbury, the prescribed detours to cover a few miles, which normally would be traversed in half an hour, amounted to 60 or 70 miles, which required from 10 to 20 hours on the precarious roads.

The State and town forces, by clearing off débris, filling holes, and graveling detours around bad washes, made traffic possible within a few days. This work was carried on as a continuous operation until the closing down of winter, but by that time the condition of the roads had been sufficiently improved for essential traffic to move with a reasonable degree of facility. (See pl. 10, *B*.)

The stream crossings, however, presented a more difficult problem. Throughout the devastated area practically all dimension lumber was swept away, and owing to the nature of the industries of the two States, there were no stocks of steel beams that could be utilized. Moreover, the complete interruption of railroad traffic over the greater part of the area prevented the bringing in of suitable materials. The only solution possible appeared to be temporary construction with whatever materials could be procured in the vicinity.

The smaller structures were replaced by the towns. The substructures were log cribs or dry-laid masonry; the superstructures consisted of log stringers for spans up to about 25 feet and log trusses with log stringers for spans of 25 to 60 feet. The floors were made of plank sawed by small local mills from timber cut near by. Every possible use was made of salvaged materials, such as timbers from wrecked barns and bridges. Considering the labor shortage and general conditions, the work was rapidly executed in most localities, bridges with spans as great as 60 feet being opened to traffic within 10 days after the flood.

For the larger crossings, wherever possible, arrangements were made to defer operations until the construction of permanent bridges during the following season. This was accomplished in some places by providing a footbridge for pedestrians, where conditions required it, and reconditioning minor roads for a detour to carry vehicular traffic. In a few places it was possible to floor railroad bridges for use until a new structure was built. Where no other course was open, temporary bridges of log trusses on log-crib abutments and piers were constructed. A number of such structures were built with the full expectation that they would be carried away by the ice in the spring, when it would be necessary to build another temporary bridge to serve while the permanent structure was being erected.

Crossings that are so essential to the traffic flow that no unavoidable interruption could be countenanced were given special consideration. The three main bridges over the Winooski River will serve as examples.

Winooski Bridge: A pontoon bridge was provided and installed by the Army Engineers for temporary use; meanwhile a contract was awarded for the permanent structure, on which work was to be carried on during the winter to insure completion and opening to traffic before the break-up of the ice. (See pl. 11.)

Waterbury Bridge: A contract was awarded for a new bridge to be completed March 1, 1928; in the meantime the State undertook to install and maintain a pile trestle bridge.

Middlesex Bridge: The Bureau of Public Roads designed and supervised the construction of a temporary bridge of a type free from menace by ice and high water.

NOTES FROM THE SURVEY

The field inspection of damages sustained by highways in the devastated areas brought out the fact, so often disclosed elsewhere under similar tests, that the better types of highway suffer the least. Compared with the total investment involved, the damages ranged from less than 5 per cent on the Federal aid projects to more than 30 per cent on many of the less important roads. In extreme cases the only remaining vestiges for considerable distances were the right of ways; and for many of these abandonment in favor of higher ground, to insure against recurrence of the damage, is warranted. The rarity of such examples on the State trunk highways and the Federal aid system in comparison with the poorer types of roads indicates that highways built under the higher standards prevailing in recent location and construction are both trustworthy and economical. Paved highways, for example, withstood current velocities that produced total destruction of untreated gravel roads under equal tests. However, where lateral erosion is so severe as to remove the subgrade, as occurred along Jail Branch near Barre, Vt. (pl. 12), and along Olivarian Brook near Haverhill, N. H., the undermining accomplishes complete destruction of any type of surfacing. The lowered stream bed resulting from failure of a stone masonry dam on Jail Branch no doubt permitted attack below the belt of protective riprap, and thus the armor was ineffective. The obvious remedy or insurance to be provided for such conditions must depend on some form of stream control and channel stabilization.

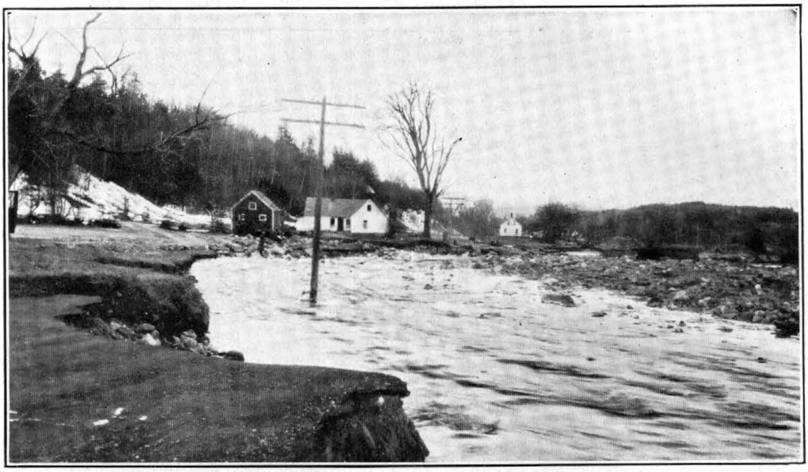
Federal aid project No. 68, in the Winooski Valley (pl. 13, *A*), sustained unusually heavy damage, yet it remained passable. The concrete pavement conformed to the new subgrade where it was undermined, with a surprisingly small amount of cracking. The sand and silt deposit, which covered nearly a mile of the highway grade, completely buried the construction equipment, including trucks and concrete mixer. The 50-foot dam at Bolton Gorge produced impoundage for several miles upstream during the height of the flood and contributed to the depth of inundation at Waterbury, at the same time checking the velocity and erosion. Seeking an additional outlet, the flood waters followed the Central Vermont Railway cut through a great deposit of glacial till, mainly sand and rock flour. Where an approach fill once sustained the track 40 feet above the valley, the newly eroded channel has dimensions comparable with great cuts on ship canals. Several hundred thousand cubic yards of this material, suddenly removed by the Winooski River flood, was thus deposited in the widened parts of the valley immediately below. The damage accruing to Federal aid project No. 68 is thus largely traceable to the failure of a natural barrier where the railway cut was enlarged and swept to bedrock.

The fact that the railway was out of commission for several months and the highway was restored to good working order within a few days after the flood subsided near Richmond, Vt. (pl. 14, *A*), emphasizes the reliability of highway service when all other means of transportation are interrupted.

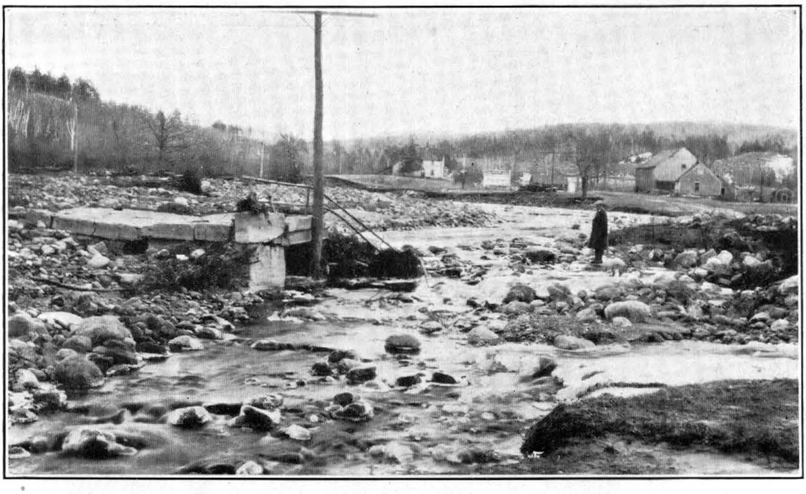
SPILLWAYS AND RELIEF CHANNELS

With the improvement of standards governing highways and bridges there has been an unfortunate disregard of past experience at many river crossings. Our forefathers wisely placed the structures considerably higher than the approaches and thus provided what might be termed emergency spillways or relief channels to accommodate portions of the highest floods. Although traffic was interrupted during the brief periods of overflow and until minor repairs could be made, the main structure was more likely to remain in place by reason of such relief. The raising of the grades to make level approaches in

AERIAL VIEW OF THE PONTOON BRIDGE AT WINOOSKI, VT.



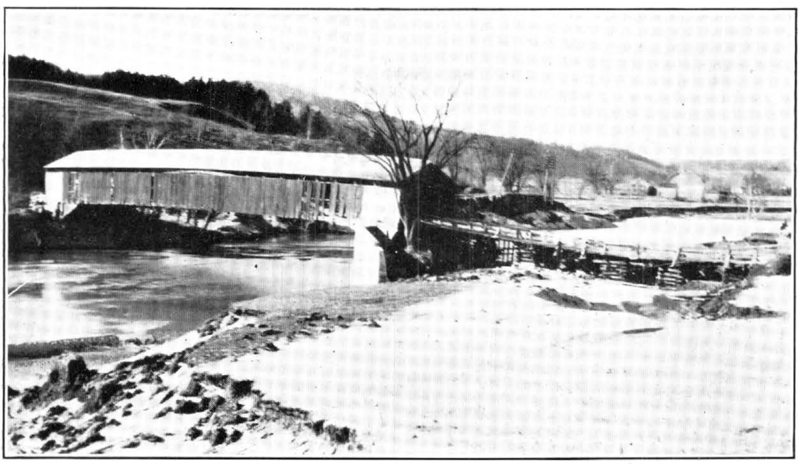
A. HIGHWAY EROSION



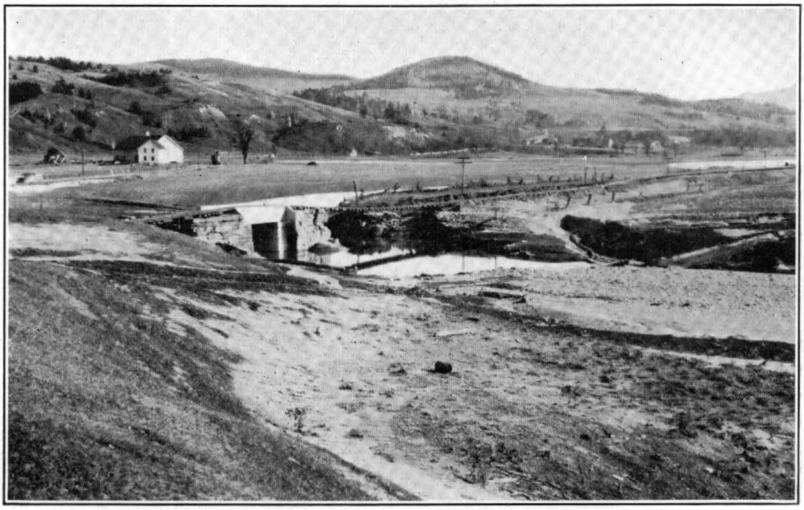
B. CHANNEL CHANGE

OLIVARIAN BROOK NEAR HAVERHILL, N. H., NOVEMBER, 1927

A. FEDERAL AID PROJECT 68, WINOOSKI VALLEY, VT.



B. CHECKER HOUSE BRIDGE, NEAR RICHMOND, VT., AFTER FLOOD OF NOVEMBER, 1927



A. HIGHWAY NEAR RICHMOND, VT., IN SERVICE WITHIN A WEEK AFTER THE FLOOD OF NOVEMBER, 1927

B. SITE OF BRIDGE ON THE CONNECTICUT RIVER AT PIERMONT, N. H., AFTER THE FLOOD OF NOVEMBER, 1927 accordance with what has been erroneously considered necessary to meet the demands of present-day traffic, with no compensating provision for the emergency waterway thus obstructed, definitely accounts for the loss of many major structures. In addition to the increased velocities under bridges that are thus called upon for added duty, the higher pondage required upstream, the routing of all débris toward the structure instead of allowing the quiet spreading and lodgment of floating material, and the danger of sudden release of impounded water if the high embankments are overtopped are all valid arguments for auxiliary channels near every important crossing of a flood way.

To the retention of lateral spillways is due the credit for saving the main bridges in the Connecticut Valley. When the two-span covered timber truss bridge, 350 feet in length, was floated from its place at Piermont, N. H. (pl. 14, *B*), it threatened the Orford (pl. 10, *A*), the Hanover, and other old structures that would have yielded readily to such a battering ram. (See pl. 13, *B*.) In such an event, the modern steel spans would have been in imminent danger, and the timber jam at White River Junction would have assumed quite different proportions. Fortunately for everyone, the spillway channels for a few miles below Piermont have never been obstructed by solid-fill approaches. The two spans, still coupled together, drifted into the shallow lateral channel and lodged intact.

Although the fields and pastures subjected to occasional overflow as flood ways become littered with silt and débris, the damage is relatively slight where the velocities are not excessive. When erosion occurs on bare soil or along highways to the extent of removing gravel and field stone of moderate sizes, it is remarkable what protection is afforded by sod and undergrowth on pasture lands under the same test. A notable example is furnished by the view of the White River Valley below Sharon, Vt., furnished by the Army Air Service. There the old highway has been converted into a nearly rectangular channel fully 10 feet in depth, whereas the sod on each side is undisturbed.

STRUCTURES LOST DURING THE FLOOD

A survey by the State Highway Department of Vermont showed that 1,214 highway bridges with spans of 4 feet or more had been either destroyed or seriously damaged. Of this number, 542 had spans of less than 20 feet, 305 ranged between 20 and 40 feet, and the other 367 between 40 and 450 feet.

Only a few of the lost structures were modern, less than 10 per cent of them having been built within the last 20 years, and only about 1 per cent within the last 5 years.

Most of the smaller structures with spans of 30 feet or less were constructed on dry rubble masonry substructures founded on the stream-bed gravel, boulders, or bedrock. Log stringers, or in a few structures I-beams, supported the floors, which usually consisted of plank, or in some bridges of concrete.

Bridges from 30 to 60 feet in span were mostly timber trusses, with a few light steel trusses and I-beam spans. The substructures differed from those of the shorter spans only in the use of heavier stone and better workmanship in laying. A greater number of the sites had been chosen so that at least one abutment was on bedrock.

In general, failure of the structures was due to the pressure of water and floating débris. Here and there an abutment was undermined where the structure was high enough to clear the flood surface. Where substructures failed it will always remain an open question as to the part played by uprooted trees, débris, and outbuildings in constricting the waterway and causing scouring of the channel to great depth. Abutments that were founded on rock, unless they were previously in need of repair, are still standing, and in general they have retained the approach fills in good condition. Substructures that were not founded on bedrock were completely destroyed, as were also in most places the approach fills.

The greater number of long-span and multiple-span bridges were housed timber trusses. Many of these were floated away bodily. As they were borne along by the current they acted as battering rams, destroying other structures that might have withstood the pressure of less massive débris. When a floating span lodged against another structure, it collected other materials rapidly until the entire obstruction was swept away, releasing a new flood crest to carry on the work of destruction. Such timber jams account for the loss of most of the steel bridges that failed.

The Waterbury Bridge, Federal aid project No. 61–A, consisted of an 80-foot steel truss and a 160-foot span. Débris lodged against the structure in such quantities that the longer-span steel truss was finally swept away. It lodged on its back about 150 feet below the site. All other modern highway structures that failed in the stricken area were undermined, so far as this survey disclosed.

The Spaulding Bridge, Federal aid project No. 84–A, consists of a single 50-foot span reinforced-concrete T-beam bridge. This structure settled vertically about 15 feet so that only the tops of the railings were visible, and these were seen only when the water was low. The foundations were described as having been carried into gravel about 4 feet below the stream bed.

Randolph Bridge, on the Third Branch of the White River, Federal aid project No. 67–A, was destroyed by the breaking of a dam about 75 feet above the bridge. The break occurred directly in line with the right abutment and wing wall of the dam, concentrating an enormous flow at great velocity against this part of the foundations.

It was reported that in the course of half an hour after the failure of the dam the undermined wing wall fell forward, so that it deflected the flow against the abutment; and this in turn slowly settled about 12 feet at the upstream end and 4 feet at the downstream end. The channel was widened nearly 200 feet back of this abutment to a depth of about 35 feet through the natural valley fill. The foundations of this structure were in heavy gravel about 8 feet below the bed of the stream.

Other bridges failed in much the same manner because of being located too near curves in the stream channels. (See pl. 11.) As might be expected, the abutments on the inside of bends were not damaged.

PROBABILITY OF RECURRENCE

The plans for reconstruction must take account of the previous rainfall and run-off records if adequate provision is to be made for future demands. If we may credit the fragmentary accounts of early historians and the continuous records of several stations for more than a hundred years, storms of equal or greater intensity but probably covering smaller areas have visited various sections of New England at intervals ranging from 10 to 40 years. They have usually occurred between May and late October, when both the soil and the foliage would intercept and retain a greater proportion of the moisture than was held in November, 1927, after an October of nearly double the normal rainfall. Nearly one-half of the area of Vermont, including practically all the high mountainous districts, received 8 inches or more of rainfall within two days. It is probable that fully double this amount fell on Mount Washington, in New Hampshire. The divergent courses and narrow strips tributary to the rivers that head in the Presidential Range contiguous to Mount Washington provide a fair distribution and the beginning of regulation; yet the run-off from this high area plays an important part in every great flood affecting the Connecticut, the Merrimack, the Saco, or the Androscoggin River.

Analysis and comparison of meteorologic and hydrographic records for the entire area warrant the conclusion that the flood of 1927 was of the same order as others that have occurred in considerable portions of the same districts from three to four times in a century. There is no adequate reason for expecting any wide variation from that behavior in the future, except as the result of control works that may be installed.

The property losses and the indirect damage far exceeded those of any previous flood since colonization; probably the same is true regarding fatalities. Such results naturally follow intense industrial development within the flood plains and adjacent to the river channels, unless flood-control projects are made to keep pace with the valley encroachments.

Immediately after such torrential run-off the surface conditions are favorable to recurring floods as the result of less severe storms. The high moisture content of the soil when winter sets in, the torn and gullied condition of the ground, which favors rapid drainage, and the raw banks partly undercut by the meandering streams in surcharged channels, where great masses of earth and rock waste are seemingly poised ready to slough off when the spring thaw begins, all contribute to the higher stages and destructiveness of the next floods. The heavy burden of stones and gravel in motion along the stream beds, besides retarding the normal velocity and thereby causing overflow, adds greatly to the dynamic power of the flood for battering obstructions. At each widened section or reduction of slope a temporary rock-fill dam or bar is formed, around which the streams make wide detours by eroding the less resistant valley soil; and thus new chapters are begun in the record.

Because the same accumulation of rock waste may lodge at successive sections downstream, the stabilization of banks and channels must be recognized as a major problem in flood-control projects, requiring coordination and supervision. Otherwise the protection of one community will be accomplished at the expense of others subjected to the same perils.

Without a system of control based upon a well-matured and unified plan for flood control, recurrence of disasters such as the New England States sustained in 1927 seems to be inevitable not only in the Eastern States but in practically every intensely developed region and wherever the effects are cumulative, as on some of the Winooski tributaries and along other streams in the devastated areas. In several places the release of a small millpond proved to be of tremendous effect, for it produced an additional wave just sufficient to remove large stocks of lumber, houses, barns, and bridges which otherwise would have remained in place. Armed with such wreckage and battering rams, the stream swept all before it, occasionally halting at some obstruction long enough to inundate sections of the valley to depths never before known, drowning livestock herds that were supposedly safely housed, and then resuming progress beyond the shattered barrier with redoubled fury. Thus the maximum damage due to both inundation and torrential velocity was sustained where a relatively small storage dam of reliable construction would have kept the stream within prescribed bounds.

Utilization of the best available sites for the detention and smoothing out of flood crests on the wild, torrential branches, or at some place below their junction with the main stream, would afford ample insurance against recurrence under any conceivable conditions that are indicated by a century of continuous records, at a cost less than one-half of the physical damage sustained in the regions recently devastated.