UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Water-Supply Paper 836

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GLENN L. PARKER, Chief Hydraulic Engineer

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CORRECTION for Geological Survey Water-Supply Paper 836-E.

In Water-Supply Paper 836-E, "Local overdevelopment of ground-water supplies, with special reference to conditions at Grand Island, Nebr.," the plate numbers and titles as printed on plates 17 and 18 are reversed.

The title of plate 17 (incorrectly printed as plate 18) should read "Map showing contours on the water table in the vicinity of Grand Island on August 1, 1936."

The title of plate 18 (incorrectly printed as plate 17) should have the date "January 1, 1938."

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Water-Supply Paper 836-A

STAGES AND FLOOD DISCHARGES OF THE CONNECTICUT RIVER AT HARTFORD CONNECTICUT

BY

H. B. KINNISON, L. F. CONOVER, AND
B. L. BIGWOOD

Contributions to the hydrology of the United States, 1938
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ILLUSTRATIONS

N. C. Grover, Chief Hydraulic Engineer

STAGES AND FLOOD DISCHARGES OF THE CONNECTICUT RIVER AT HARTFORD, CONNECTICUT

By H. B. Kinnison, L. F. Conover, and B. L. Bigwood

Abstract

Records of stages of the Connecticut River at Hartford, Conn., have been maintained for many years, although the earlier records were for flood stages only. The first record relates to the flood of March 1639. The records of stages and discharges at Hartford are used by the United States Weather Bureau in its flood-forecasting system. Daily records of stages at Hartford have been obtained by the Weather Bureau since November 1, 1904, and a water-stage recorder, giving a graphic record of stage, has been used since September 8, 1908.

Subsequent to the floods of November 1927 the Geological Survey established river-measurement stations on the Connecticut River at Thompsonville and on tributary streams between Thompsonville and Hartford so that the run-off from 98.4 per cent of the drainage area above Hartford was measured at the gaging stations. The run-off from the remaining 1.6 percent of the area was assumed to be the same in second-feet per square mile as that from the tributary area below Thompsonville where records were obtained.

During flood stages the Connecticut River overflows its banks above and below Hartford and forms a reservoir where water is stored in the river channel and on the flood plain. The area of this reservoir at the crest of the flood of March 1936 was about 43.5 square miles, with a volume of 15,580,000,000 cubic feet between a stage of 15.6 feet at the Hartford gage and the peak stage. Of this volume, 5,620,000,000 cubic feet was above Hartford. In computing the discharge past the Hartford gage the rate at which water went into storage on a rising stage or was drawn from storage on a falling stage was applied as a correction to the known inflow into the reservoir. Not only was the flood of March 1936 the greatest one known at Hartford, but it was also the first major flood for which data were available for an accurate determination of the discharge at Hartford throughout the flood period.

INTRODUCTION

The flood of March 1936 was the greatest ever recorded for the Connecticut River at Hartford, Conn. The river rose to a stage 8.6 feet higher than that of November 1927 and 7.8 feet higher than that of May 1854, the maximum known up to that time, and caused unprecedented damage in the city of Hartford and adjacent communities.

Accurate information about the discharge of the river at Hartford and the effects of water storage in the river channel and in the overflow area above Hartford during this record-breaking flood is of greatest importance in connection with studies for the prevention or mitigation of like catastrophes in the future. Not only was the flood of March 1936 the greatest flood that has occurred at Hartford since the first white settlements there but it was also the first major flood for which data were available for an accurate determination of the discharge of the river at Hartford throughout the flood period. Therefore, it is considered desirable to give a fairly complete description of the methods used in arriving at the determinations of the river discharge under the conditions existing at the time of the flood.

Records of previous floods show stages only, and for floods prior to that of 1936 it is not possible to make accurate determinations of the crest discharge at Hartford, because of lack of necessary basic information. However, it is believed that the methods described in this report may be used in future flood-flow computations, provided records are available for the gaging stations used in March 1936.

Information about previous floods of the Connecticut River at Hartford, covering a period of nearly 300 years, and for somewhat shorter periods at Springfield and Holyoke, Mass., has been included in this report. From this information some idea may be obtained as to the relative magnitude and frequency of the major floods, and it may be noted that the three greatest floods during the entire period were those of May 1854, November 1927, and March 1936, and that the two later of these floods were separated by less than 9 years.

A description of the general features of the storms causing the floods in the Connecticut River Basin and other river basins in New England in March 1936 may be found in Water-Supply Paper 798. That report also contains acknowledgments for financial cooperation and assistance received from cooperating agencies in the several New England States in connection with the collection of field data and preparation of the report. Those acknowledgments to cooperating agencies in Connecticut and Massachusetts are also applicable for assistance in the collection and compilation of the data used in this report.

HISTORICAL REVIEW

Matthew Grant in his "Windsor Church Records" (original manuscripts preserved by the Connecticut Historical Society) observed:

> I found in the old book that the great flood began the 5th of March, 1639. On the 11th day of March it began to fall but by reason of much rain on the 12th day, it rose very high.* * * On the 15th and 16th days it (the flood) had fallen near 2 feet, but on the 16th day was much rain and great wind out of the southeast, which made it an exceeding great

storm. It indamaged houses and break down many trees, so that by the cause of which rain all the 17th and 18th days the water rose very high, more than had ever before been known by the Indians.

Since that date, which was only three years after the settlement of Hartford, all floods of any consequence have been recorded as to height and date in sundry ways. Flood heights were first indicated by markings on posts, buildings, barns, and other convenient places and then noted in the diaries and miscellaneous manuscripts of the early settlers. The Connecticut Courant (now Hartford Courant), first printed in 1764, early began publication of the flood heights. Many other newspapers and journals established at later dates contain accounts of major floods. A Mr. Chapman who lives near the old tollhouse kept a record for many years prior to 1870. Flood heights also were marked by means of spikes driven into the timbers of a brewery building located in this vicinity. The Army Engineers at the time of the river survey made by them in 1871 investigated these known high-water marks and referred them to mean sea level, thus making them comparable. Since 1871 the crest stages have been read from various gages of the Army Engineers, the Hartford & New York Transportation Co., the Connecticut River Bridge and Highway District, and the United States Weather Bureau. The gages formerly used at the tollhouse, at State Street, and at or near the various bridges are not now in existence, but all were in the vicinity of the present gage used by the Weather Bureau.

The Army Engineers kept daily records from 1871 to 1877 in connection with their study of the improvement of the river for navigation. The Geological Survey has published records for the years 1871-81, 1884-86, and 1896-1908, based on daily observations. Except for the periods mentioned above, records were obtained only during periods of high water, with occasional readings at other times. A compilation of these old records was prepared by W. W. Neifert, former official in charge of the Hartford office of the Weather Bureau, and published in part in a paper by Alfred J. Henry, "Floods in New England rivers," in the Monthly Weather Review, December 1914. A complete and amended list of floods of the Connecticut River at Hartford for which records are now available appears elsewhere in this report.

The Weather Bureau's New England Flood Service, with headquarters at Boston, Mass., was established November 1, 1902, for the purpose of forecasting floods, and provided for the observation of river stages at Hartford daily during the period November 1 to April 30 of each year and at other times during periods of high water. Daily gage readings have been obtained at the Hartford gage since November 1, 1904, and beginning September 16, 1905, these records have been collected under the supervision of the Hartford river district of the Weather Bureau, which was established on that date and comprised the Connecticut River and Housatonic River drainage basins. The observations of river stages at Hartford were made on the staff gage of the Hartford & New York Transportation Co. at the dock at the foot of State Street until January 10, 1908, when readings were begun on a board gage placed on the west pier of the temporary highway bridge. After the completion of the new Bulkeley Memorial Bridge a water-stage recorder was placed in pier 1, and records have been obtained there since September 8, 1908. The stilling well, 3 feet 6 inches in diameter, over which the recording gage is placed, is connected with the river by two intake pipes, 2 inches and 4 inches in diameter, placed at an angle to each other and at different heights. The recorder first installed was of the 8-day type and was in operation until October 11, 1935, when it was replaced by a recorder of the continuous type, which has been in operation to the present time. A float-tape gage was installed inside the well July 22, 1936, for reference, and a wire weight gage, for measurements to the water surface outside the well, was placed on the bridge May 7, 1937. Records of stages are published by the Weather Bureau in its annual series of "Daily river stages."

USEFULNESS OF RECORDS

Throughout the modern history of the Connecticut River Valley records of river stages and discharges at Hartford have been of great value in problems of navigation, flood forecasting, flood control, water-front improvements, bridge, railroad, and highway construction, river pollution, interstate use of water, power development, industrial and recreational activities, and general hydraulic research.

The river survey made by the Army Engineers in 1871, which marked the establishment of a permanent gage at Hartford, was carried out in the interests of improvement of navigation. Transportation of passengers and freight by water was at that time an important commercial activity and continued to increase in importance for several decades. Records of river stages have found constant use in connection with the successful operation of river boats and the maintenance of adequate navigation channels. Prior to 1870 the value of river records was recognized only as a matter of historical significance.

The record of stages and discharges at Hartford is an essential element in the flood-forecasting system established by the Weather Bureau in 1904 by authorization of Congress. With the increase of population and wealth in the Connecticut River Valley, timely forecasting of flood heights has become increasingly important.

The flood of 1927, with its attendant damage and destruction, emphasized the necessity for protection of the great population and wealth which had become concentrated in the valley. In the design and operation of flood-control works the river records are of vital importance. The flood of 1936 further emphasized the immediate need of a comprehensive plan for flood control and protection.

The concentration of population in the Connecticut River Valley has brought with it many intricate problems of modern civilization, all of which demand a comprehensive knowledge of river stage and discharge.

COMPUTATION OF FLOOD DISCHARGE AT HARTFORD

The flood of November 1927 was the greatest known flood on the Connecticut River at Hartford up to that time with the single exception of that of May 1, 1854. After the flood of 1927 the Geological Survey established a river-measurement station on the Connecticut River at Thompsonville (the measurements, including the flow in the canal of the Northern Connecticut Power Co.), and also established measurement stations on the two principal tributaries of the Connecticut River between Thompsonville and Hartford -- namely, the Farmington River at Tariffville and the Scantic River at Broad Brook. The total drainage area of the Connecticut River at Hartford is 10,480 square miles, and at Thompsonville it is 9,637 square miles. The drainage area of the Farmington River at Tariffville is 578 square miles, and that of the Scantic River at Broad Brook is 98.4 square miles. Therefore, of the discharge from the 10,480 square miles of drainage area at Hartford, that from 10,313 square miles, or 98.4 percent of the total area, is measured at the gaging stations named above. The records of flow at these stations, together with the records of stages at the Weather Bureau's gage at Hartford, form the basis for the computation of the discharge at Hartford.

From time to time during past years the lower Connecticut River has been the subject of studies and investigations, some of which have involved the determination of the discharge of the river at Hartford. Recent studies by the Geological Survey indicate that the rating curve for the stage-discharge relation at Hartford is not a single curve but a broad loop curve showing a much greater discharge for a given gage height on a rising stage than for the same gage height on a falling stage. Loop curves have been developed and used for many years in the work of the Geological Survey. (See "River discharge," by J. C. Hoyt and N. C. Grover, p. 97.) The looping of a rating curve is accentuated in flat, sluggish reaches of rivers and is always developed when a considerable amount of overflow occurs between the gaging station and the high-water control, especially if the river channel at the high-water control is relatively narrow. It is not necessarily true that the loop developed for one flood will be the same as the loop for another flood, even though the floods attain the same crest stage; the controlling factor is the relative rate of rise and fall of the flood stages.

Character of the river valley from Windsor Locks to Hartford

Windsor Locks, at the head of tidewater and at the foot of the rapids around which the canal of the Northern Connecticut Power Co. is constructed, lies at the upper end of a broad flood plain over which the water flows during periods of high water. This flood plain, which is in places 2½ miles wide, extends downstream about 18 miles below Hartford to the relatively narrow gorge in the river in the vicinity of Middletown. The flood plain has a decided slope downstream and carries so large a volume of water during flood periods that the slope of the river closely approximates the slope of the flood plain, the water rising or falling about the same amount at all points within the flooded area. Therefore, the great inundated river valley acts in a manner similar to a detention reservoir, with the city of Hartford situated about a third of its length below its upper end.

At the crest of the flood of March 1936 the area of this reservoir, as measured on the Geological Survey topographic maps, was 43.5 square miles, of which 16.74 square miles, or 38.5 percent, was above the Hartford gage. By means of river cross sections taken from recent surveys made by the Army Engineers, the capacity of the entire reservoir between a stage of 15.6 feet at the Hartford gage and the peak stage was determined to be 15,580,000,000 cubic feet. Of this volume, 5,620,000,000 cubic feet was in the part above Hartford. A capacity curve was prepared showing storage at different stages for that part of the valley reservoir above Hartford, and the effect of this storage was taken into consideration in the computation of the flow at Hartford.

Flood discharge at Thompsonville

The drainage area of the Connecticut River at Thompsonville is 92 percent of the total drainage area above Hartford. The Thompsonville gage is in the pool above the Enfield Dam, about 150 feet above the head gates of the Northern Connecticut Power Co.'s canal. Water diverted into this canal is returned to the river at Windsor Locks and is included in the flow above Hartford.

A continuous record of stage during the flood was obtained at this gaging station by means of a water-stage recorder of the latest type. The rating curve had been well defined to high stage previous to the flood by means of current-meter measurements. The following discharge measurements were obtained during and after the flood, so that the rating curve to the peak stage was determined with a high degree of accuracy. Figure 1 shows the rating curve for this station.

Discharge measurements of the Connecticut River at Thompsonville, Conn.

Date (1936)	Gage height (feet)	Discharge (second-feet)
March 20	16.34	277,000
22	13.39	214,000
25	8.30	119,000
29	6.46	87,100
April 10	5.10	60,200
30	2.68	18,600

The gage height at the end of each 2-hour period throughout the flood was read from the continuous-recorder graph, and the corresponding discharge was determined from the station rating curve. These bihourly discharges during the flood of March 1936, together with the mean daily discharge for the 3 months' period ending April 30, 1936, are shown in the table on page 9.

The discharge at the end of each 2-hour period was determined in a similar manner for the stream-gaging stations on the Farmington River at Tariffville and on the Scantic River at Broad Brook, except that the discharge at the Broad Brook station March 20-21, when the stage-discharge relation was affected by backwater from the Connecticut River, was determined from a gage-height graph corrected for backwater.

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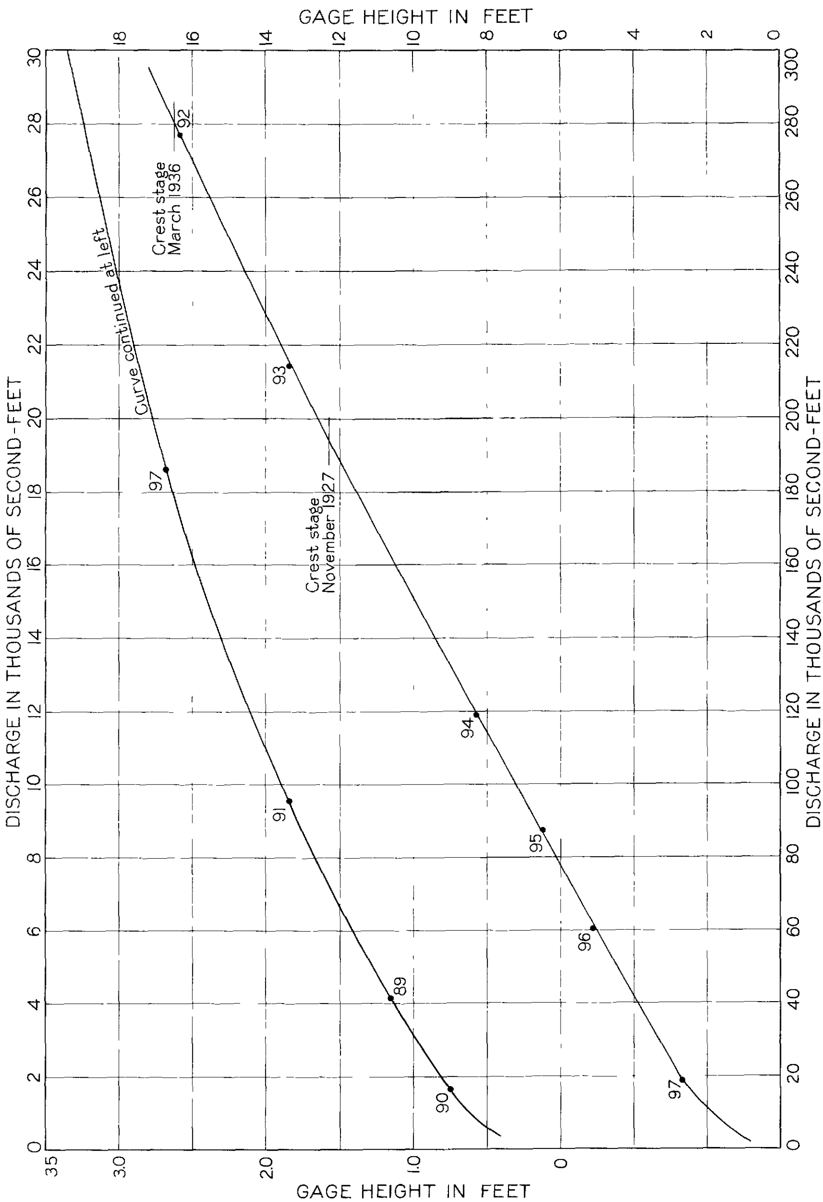


FIGURE 1.—Rating curve for Connecticut River at Thompsonville, Conn.

Discharge of the Connecticut River at Thompsonville, Conn., during the flood of March 1936

Location.- Lat. 41°59'20", long. 72°36'15", in pool above Enfield Dam, 1 mile below Thompsonville, Hartford County. Zero of gage is 38.48 feet above mean sea level.
Drainage area.- 9,637 square miles.
Gage-height record.- Water-stage recorder graph except for period 12 p.m. Mar. 18 to 7 a.m. Mar. 23, when it was based on flood marks and shape of stage graphs at nearby stations. Gage heights given to half tenths between 2.10 and 4.20 feet; hundredths below and tenths above these limits.
Stage-discharge relation.- Defined by current-meter measurements below 277,000 second-feet; verified by drainage-area comparison of instantaneous and total yield of flood at other gaging stations on Connecticut River.
Maxima.- 1936: Discharge, 282,000 second-feet 2 to 10 a.m. Mar. 20 (gage height, 16.6 feet).
1928-35: Discharge, 153,000 second-feet Apr. 20, 1933 (gage height, 10.47 feet).
Maximum discharge previously known, 190,000 second-feet (revised) Nov. 6, 1927 (gage height, 12.1 feet).
Remarks.- Flood run-off affected by 19,500,000,000 cubic feet of storage capacity above station. Tables of daily and monthly discharge include water diverted by canal of Northern Connecticut Power Co. Bihourly stages and discharges as shown in table are for Enfield Dam only, except for period March 18-25, when flow in canal is included.

Mean discharge, in second-feet, 1936

Day	Feb.	Mar.	Apr.	Day	Feb.	Mar.	Apr.	Day	Feb.	Mar.	Apr.
1	7,350	6,200	57,200	11	6,220	11,900	59,000	21	7,580	249,000	31,000
2	6,120	6,900	55,400	12	6,600	57,400	57,200	22	6,340	220,000	31,900
3	7,240	7,420	55,400	13	7,200	98,600	55,400	23	5,550	189,000	31,000
4	7,790	7,800	55,400	14	6,810	120,000	53,600	24	6,350	154,000	29,200
5	7,800	9,260	51,800	15	5,770	114,000	44,500	25	6,590	118,000	28,300
6	7,730	9,420	53,600	16	4,180	101,000	45,400	26	7,350	101,000	24,700
7	7,560	7,880	71,900	17	5,290	86,800	44,500	27	7,870	87,700	23,000
8	7,300	5,830	79,300	18	6,230	135,000	41,800	28	7,950	87,400	20,500
9	4,440	7,780	68,300	19	6,600	256,000	38,000	29	7,550	86,800	18,300
10	5,160	8,970	62,700	20	7,200	278,000	34,600	30		73,800	17,600
								31		62,800	
Mean monthly discharge, in second-feet.......................									6,680	89,200	44,680
Run-off, in inches..									0.75	10.68	5.18

Gage-height, in feet, and discharge, in second-feet, at indicated time, 1936

Hour	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.
	March 8		March 9		March 10		March 11		March 12		March 13	
2	1.33	5,420	1.28	5,060	1.58	7,340	1.69	8,260	2.6	17,600	6.4	85,000
4	1.31	5,280	1.28	5,060	1.55	7,100	1.68	8,180	2.95	23,000	6.4	85,000
6	1.30	5,200	1.26	4,920	1.51	6,780	1.68	8,180	3.4	31,000	6.5	86,800
8	1.30	5,200	1.30	5,200	1.50	6,700	1.75	8,780	3.7	36,400	6.6	88,600
10	1.27	4,990	1.40	5,950	1.55	7,100	1.84	9,560	4.0	41,800	6.7	90,400
N	1.27	4,990	1.48	6,550	1.62	7,670	1.97	10,700	4.3	47,200	6.8	92,200
2	1.27	4,990	1.55	7,100	1.66	8,010	2.03	11,300	6.0	77,800	6.9	94,400
4	1.28	5,060	1.61	7,580	1.69	8,260	2.07	11,700	5.9	76,000	7.2	99,400
6	1.28	5,060	1.67	8,100	1.72	8,520	2.1	12,000	6.0	77,800	7.6	107,000
8	1.29	5,130	1.68	8,180	1.72	8,520	2.15	12,500	6.2	81,400	7.9	112,000
10	1.29	5,130	1.66	8,010	1.72	8,520	2.25	13,500	6.2	81,400	8.0	114,000
M	1.29	5,130	1.62	7,670	1.70	8,350	2.3	14,000	6.3	83,200	8.0	114,000
	March 14		March 15		March 16		March 17		March 18		March 19	
2	8.1	116,000	8.4	121,000	7.8	110,000	6.6	88,600	6.6	88,600	13.1	210,000
4	8.2	118,000	8.3	119,000	7.7	108,000	6.5	86,800	6.7	90,400	13.7	222,000
6	8.3	119,000	8.2	118,000	7.6	107,000	6.5	86,800	6.8	92,200	14.3	234,000
8	8.3	119,000	8.1	116,000	7.5	105,000	6.4	85,000	7.1	97,600	14.8	245,000
10	8.3	119,000	8.0	114,000	7.4	103,000	6.4	85,000	7.5	105,000	15.2	253,000
N	8.2	118,000	7.9	112,000	7.3	101,000	6.4	85,000	8.2	118,000	15.6	261,000
2	8.2	118,000	7.8	110,000	7.2	99,400	6.4	85,000	9.1	134,000	15.9	268,000
4	8.2	118,000	7.7	108,000	7.0	95,800	6.4	85,000	10.0	151,000	16.1	272,000
6	8.4	121,000	7.7	108,000	6.9	94,400	6.4	85,000	11.0	169,000	16.2	274,000
8	8.4	121,000	7.6	107,000	6.8	92,200	6.4	85,000	11.7	183,000	16.4	278,000
10	8.5	123,000	7.8	110,000	6.8	92,200	6.5	86,800	12.1	190,000	16.5	280,000
M	8.5	123,000	7.8	110,000	6.7	90,400	6.5	86,800	12.5	198,000	16.5	280,000
	March 20		March 21		March 22		March 23		March 24		March 25	
2	16.6	282,000	15.8	266,000	14.3	234,000	12.8	204,000	11.1	171,000	9.0	132,000
4	16.6	282,000	15.7	264,000	14.2	232,000	12.6	200,000	10.9	167,000	8.9	130,000
6	16.6	282,000	15.5	259,000	14.1	230,000	12.5	198,000	10.8	166,000	8.7	127,000
8	16.6	282,000	15.3	255,000	13.9	226,000	12.3	194,000	10.6	162,000	8.5	123,000
10	16.6	282,000	15.2	253,000	13.8	224,000	12.2	192,000	10.4	158,000	8.4	121,000
N	16.5	280,000	15.0	249,000	13.7	222,000	12.1	190,000	10.3	156,000	8.3	119,000
2	16.4	278,000	14.8	245,000	13.5	218,000	12.0	188,000	10.1	153,000	8.2	118,000
4	16.4	278,000	14.7	242,000	13.4	216,000	11.8	184,000	9.9	149,000	8.0	114,000
6	16.3	276,000	14.7	242,000	13.3	214,000	11.7	183,000	9.7	145,000	7.9	112,000
8	16.2	274,000	14.6	240,000	13.2	212,000	11.6	181,000	9.5	142,000	7.8	110,000
10	16.0	270,000	14.5	238,000	13.0	208,000	11.4	177,000	9.4	140,000	7.7	108,000
M	15.9	268,000	14.4	236,000	12.9	206,000	11.2	173,000	9.2	136,000	7.6	107,000

Inflow to the valley reservoir

By determining continuously the discharge past the three river-measurement stations at Thompsonville, Tariffville, and Broad Brook, practically the entire flow into the reservoir above Hartford could be determined at all times during the flood of March 1936. A small amount was added to the inflow measured at the three gaging stations because of the flow from the 1.6 percent of ungaged drainage area above the Hartford gage. This additional amount was estimated by assuming it to be the same in second-feet per square mile as that measured at the Broad Brook gaging station. A reasonable time interval was allowed for the water to enter the reservoir after it had passed the Thompsonville and Tariffville gages.

These measuring facilities provided means for determination of the inflow to the reservoir above Hartford at all times during the flood. The accuracy of these determinations depends almost entirely upon the accuracy of the determination of the flood flow past the gaging stations.

Determination of gain or loss in storage

When the inflow into a reservoir increases and the reservoir begins to fill, part of the inflow necessarily goes into storage, and the discharge out of the reservoir is less than the inflow by the amount of water thus stored. After a rise, when the inflow is decreasing and the reservoir begins to empty, the discharge out of the reservoir is greater than the inflow by the amount of water coming out of storage. If the rate of inflow into the reservoir is known, it only becomes necessary to determine the rate at which the water goes into or comes out of storage to determine the discharge from the reservoir. These rates depend upon two factors -- first, the capacity of the reservoir; and second, the rate of rise or fall in the surface of the reservoir. The method of determining the capacity of the reservoir has been given above. The second factor was determined from three gages, as follows:

(a) The recording gage on the Connecticut River at the highway bridge in Hartford.

(b) The recording gage on the Scantic River at Broad Brook. This gage, being in backwater from the Connecticut River during the period from 5 p.m. March 19 to 3 p.m. March 25, accurately recorded the rise and fall of the Connecticut River during most of the peak.

(c) A nonrecording gage on the Connecticut River at Windsor Locks.

Graphs from these gages are shown in figure 2, where it may be seen that the stages rose and fell by practically the same amounts at all three gages.

The bihourly stage at the Hartford gage and the corresponding computed discharge at that place are shown in the table on page 13. The table also shows the mean daily discharge for the period March 1 to April 30.

The accuracy of the determinations of the bihourly discharges at Hartford depends upon several factors, of which the principal two are:

(a) The accuracy of the measurement of the inflow above Hartford. This was measured at three standard river-measurement stations, each equipped with a water-stage recorder and considered to measure the river discharge with a high degree of accuracy. An exception may be the Broad Brook station during periods of backwater from Connecticut River, but this station controls the computation of flow from a very small area and therefore the errors involved have no great bearing on the accuracy of the computation of total inflow above Hartford.

(b) The accuracy of the determination of the volume of the reservoir above Hartford at various gage heights. It is possible that an accurate topographic map of this area might reveal errors in the surface area and volume of this reservoir used in the computations, but it is not believed that these errors were of sufficient magnitude to have any material effect on the computation of the mean daily discharge at Hartford.

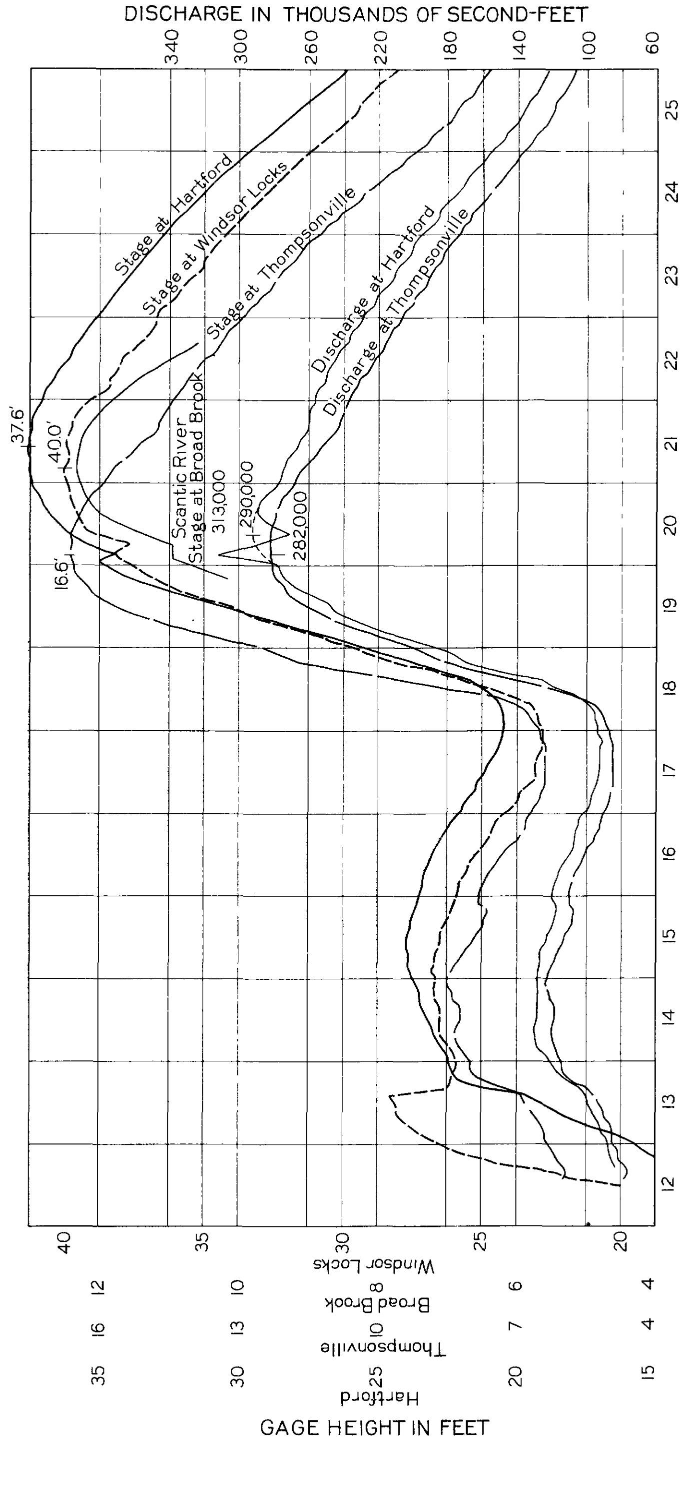


FIGURE 2.—Connecticut River hydrographs for the flood of March 1936.

Discharge of the Connecticut River at Hartford, Conn.,
during the flood of March 1936

Location.- Lat. 41°46'10", long. 72°40'0", at Memorial Bridge in Hartford, Hartford County, three-quarters of a mile above Park River and 1½ miles above mouth of Hockanum River. Zero of gage is 0.55 foot below mean sea level.
Drainage area.- 10,480 square miles.
Gage-height record.- Water-stage recorder graph. Gage heights given to tenths.
Stage-discharge relation.- Determined from continuous records of discharge from 98.4 percent of the drainage area as measured at gaging stations on Connecticut River at Thompsonville, Farmington River at Tariffville, and Scantic River at Broad Brook plus computed flow from ungaged area and adjusted for gain or loss in valley storage between these points and Hartford gage.
Maxima.- 1936: Discharge, 313,000 second-feet 3 a.m. Mar. 20 (augmented by breaching of Hartford dikes); maximum gage height, 37.6 feet 8 to 9 a.m. Mar. 21.
1896-1935: Gage height, 29.0 feet Nov. 6, 1927 (discharge not determined).
1639-1935: Maximum known stage, 29.8 feet May 1, 1854 (discharge not determined).
Remarks.- Flood run-off affected by 20,500,000,000 cubic feet of artificial storage capacity above station. Gage-height record furnished by U. S. Weather Bureau.

Mean discharge, in second-feet, 1936

Day	Feb.	Mar.	Apr.	Day	Feb.	Mar.	Apr.	Day	Feb.	Mar.	Apr.
1		7,200	61,600	11		15,400	63,100	21		266,000	32,900
2		7,880	58,000	12		58,500	61,300	22		244,000	33,800
3		8,440	58,600	13		102,000	59,400	23		211,000	32,900
4		8,830	58,600	14		128,000	56,900	24		175,000	31,100
5		10,600	54,400	15		123,000	47,700	25		136,000	29,800
6		10,900	57,700	16		110,000	48,600	26		112,000	26,000
7		9,110	75,400	17		94,700	47,400	27		96,000	24,500
8		6,890	84,400	18		125,000	44,300	28		93,800	22,000
9		8,720	74,400	19		243,000	40,000	29		93,600	19,800
10		10,300	67,700	20		286,000	36,500	30		80,800	19,100
								31		68,500	
Mean monthly discharge, in second-feet										95,200	47,600
Run-off, in inches										10.47	5.06

Gage-height, in feet, and discharge, in second-feet, at indicated time, 1936

Hour	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.	Feet	Sec.ft.
	March 8		March 9		March 10		March 11		March 12		March 13	
1			3.4		4.0		4.9		7.5	20,200	15.9	88,400
3			3.6		4.3		5.0		8.1	24,800	16.5	91,300
5			3.7		4.4		5.2		8.8	31,100	17.3	92,200
7			3.6		4.4		5.3		9.5	40,100	17.9	94,600
9			3.5		4.3		5.3		10.3	46,400	18.5	96,800
11		*6,890	3.4	*8,720	4.2	*10,300	5.2	*15,400	11.3	52,700	18.9	98,700
1			3.4		4.1		5.3		12.1	58,900	19.4	100,000
3			3.5		4.2		5.5		12.8	83,100	19.8	102,000
5			3.7		4.4		5.9		14.0	83,600	20.8	106,000
7			3.8		4.6		6.2		14.7	85,800	22.2	114,000
9			3.8		4.7		6.6		15.2	87,100	22.3	117,000
11	3.3		4.0		4.8		7.0		15.6	88,100	22.4	120,000
	March 14		March 15		March 16		March 17		March 18		March 19	
1	22.5	123,000	23.8	128,000	23.5	120,000	22.0	99,800	20.5	93,600	26.0	192,000
3	22.7	128,000	23.9	127,000	23.4	119,000	21.9	98,000	20.5	95,000	26.8	205,000
5	22.8	129,000	23.9	127,000	23.4	117,000	21.7	97,200	20.5	95,000	27.7	218,000
7	23.0	129,000	23.9	127,000	23.3	116,000	21.5	96,200	20.6	97,500	28.5	228,000
9	23.1	130,000	24.0	125,000	23.2	114,000	21.4	94,400	20.7	101,000	29.4	235,000
11	23.2	129,000	23.9	123,000	23.1	112,000	21.2	93,400	21.0	110,000	30.3	242,000
1	23.3	128,000	23.9	122,000	23.0	110,000	21.1	93,400	21.3	120,000	31.1	248,000
3	23.4	128,000	23.8	120,000	22.9	108,000	21.0	92,900	21.9	130,000	31.9	257,000
5	23.5	128,000	23.8	119,000	22.7	104,000	20.8	92,900	22.6	146,000	32.6	265,000
7	23.5	128,000	23.7	118,000	22.6	103,000	20.7	92,700	23.4	160,000	33.4	272,000
9	23.6	128,000	23.6	117,000	22.4	101,000	20.6	91,800	24.2	173,000	34.0	275,000
11	23.7	128,000	23.6	120,000	22.2	101,000	20.6	93,700	25.1	179,000	34.6	277,000
	March 20		March 21		March 22		March 23		March 24		March 25	
1	35.0	283,000	37.4	276,000	37.0	256,000	35.0	227,000	32.5	192,000	29.5	152,000
3	34.4	313,000	37.5	275,000	36.9	254,000	34.8	222,000	32.3	189,000	29.2	148,000
5	35.1	295,000	37.5	274,000	36.7	250,000	34.6	221,000	32.1	185,000	28.9	147,000
7	35.6	284,000	37.5	272,000	36.6	250,000	34.4	219,000	31.8	184,000	28.6	143,000
9	36.0	270,000	37.6	267,000	36.4	249,000	34.2	214,000	31.6	180,000	28.3	139,000
11	36.3	278,000	37.5	265,000	36.2	245,000	34.0	211,000	31.3	175,000	28.0	137,000
1	36.6	284,000	37.5	264,000	36.0	244,000	33.8	210,000	31.1	173,000	27.7	135,000
3	36.8	289,000	37.4	260,000	35.9	241,000	33.6	208,000	30.8	170,000	27.4	133,000
5	37.0	288,000	37.4	259,000	35.7	237,000	33.4	203,000	30.6	168,000	27.1	129,000
7	37.1	286,000	37.3	259,000	35.5	236,000	33.2	201,000	30.3	164,000	26.8	127,000
9	37.3	283,000	37.2	259,000	35.3	231,000	33.0	200,000	30.0	160,000	26.6	125,000
11	37.4	278,000	37.1	256,000	35.2	229,000	32.8	197,000	29.7	157,000	26.3	123,000

* Mean for the day.

Effect of the overtopping of the Hartford dikes

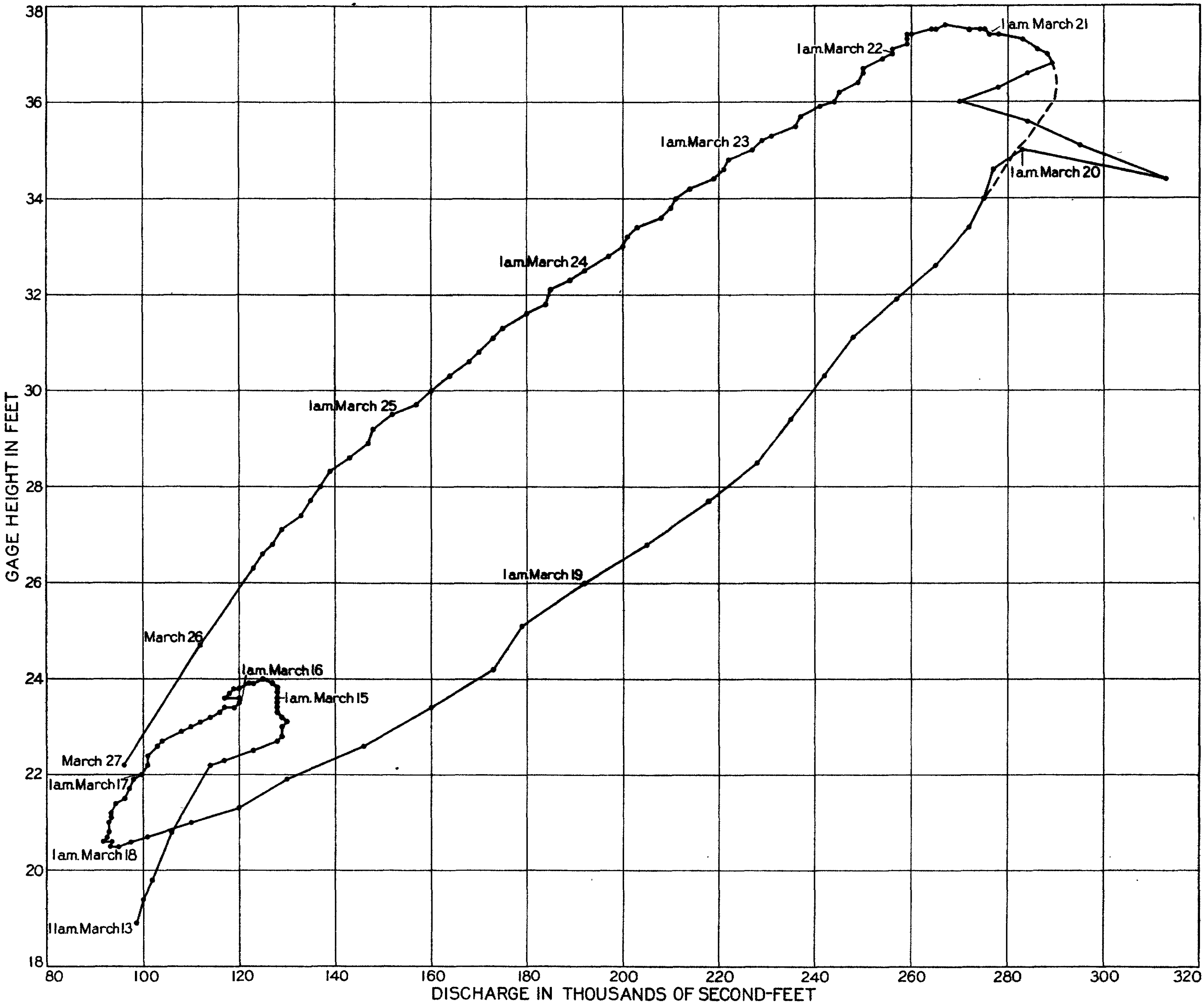
As the flood waters continued to rise at Hartford, an attempt was made to prevent overtopping of the protecting dikes by raising them from altitudes of 32.5 feet at the Colt Dike and 33.5 feet at the Clark Dike to an altitude of 35.0 feet. This attempt proved unsuccessful, and the water started spilling over the Colt Dike about 10 p.m. March 19. By 1 a.m. on March 20 the flow over the top of both dikes had become so great that the material used in raising them was swept away. This allowed an outlet for so enormous an amount of water that the rise of the river was temporarily checked, and the stage fell rapidly for a period of about 2½ hours while the area back of the dikes was filling. This fall took place even though the rate of inflow was continually increasing during the period, and as shown in figure 2, it was reflected at the Broad Brook gage about 2 hours later and at the Windsor Locks gage about 3 hours later. In a reservoir of standing water the time lag would be very short, but in the reservoir above Hartford the upstream travel of the wavelike action was apparently retarded by the opposing downstream current.

When the stage fell as a result of the overtopping of the dikes, water was removed from storage in the reservoir above the gage at a rapid rate. This rate was added to the inflow, which was nearing its maximum, to produce the maximum rate of discharge of 313,000 cubic feet a second past the Hartford gage at a stage of 34.4 feet. Had this break not occurred, the natural peak discharge past the Hartford gage would have been about 290,000 cubic feet a second at about 9 a.m. March 20. (See fig. 2.)

As soon as the available storage back of the dikes had been filled, the stage in the river again started to rise, and water was again being stored in the reservoir above the gage. Plate 1 shows the sudden rise and fall in discharge caused by the overtopping of the dikes and also the loop discharge curves for the flood period.

Effect of the Middletown gorge on stages at Hartford

The relatively narrow section of the river in the vicinity of Middletown, about 18 miles below Hartford, forms the principal high-water control for the Hartford gage. At that place the channel capacity is not as adequate to pass the flood flows as the much wider flood channel upstream. Wide overflow areas adjacent to the river channel immediately upstream



STAGES OF CONNECTICUT RIVER AT HARTFORD AND CORRESPONDING DISCHARGE AT 2-HOUR INTERVALS, MARCH 13 TO MARCH 27, 1936.

from the Middletown gorge gave storage to a large volume of water during the flood.

These natural conditions combined to cause the stage at Hartford to continue to rise for a period of 24 hours after the maximum natural flow had passed Hartford. During the greater part of this period of increasing stage the discharge at Hartford was decreasing. This action is peculiar to rivers having the conditions mentioned above and may be explained as follows:

(a) The stage of the water in the storage reservoir in and adjacent to the river channel above the control, including the stage at Hartford, continued to rise until the discharge from the reservoir became equal to the inflow.

(b) The stage of the reservoir remained stationary only so long as the inflow and the outflow were practically equal. As at Hartford the inflow was rapidly decreasing at the time when the outflow became equal to the inflow, it follows that the reservoir remained at peak stage for a short time only.

(c) The reservoir began to fall as soon as the inflow became less than the outflow.

(d) During the time when the stage of the reservoir was increasing the inflow was greater than the outflow, and the difference in these rates of flow was the rate at which water was going into storage.

(e) During the time when the stage of the reservoir was constant no water was going into or being removed from storage, and the flow into, out of, and past each cross section within the reservoir was assumed to be the same. Under natural conditions this stage of equal flow throughout the reservoir may not be reached, as a time interval is required for the conditions at the upper end of the reservoir to be reflected throughout its length. At Hartford the peak stage was reached at 9 a.m. March 21, at which time the inflow was 267,000 cubic feet a second. This flow was approximately the maximum discharge past the control section at Middletown.

(f) During the time when the reservoir was falling the outflow was greater than the inflow, and the difference in these rates of flow was the rate at which water was being removed from storage.

RECORDS OF FLOOD CRESTS

The following revised list of crest stages at Holyoke and Springfield, Mass., and Hartford, Conn., is included in this report for use in connection with flood studies of the lower Connecticut River:

Crest stages of floods of Connecticut River at Holyoke and Springfield, Mass., and at Hartford, Conn.

Year	Holyoke, Mass.		Springfield, Mass.		Hartford, Conn.	
	Date	Stage (feet)a	Date	Stage (feet)b	Date	Stage (feet)c
1639	-	-	-	-	March 18	(d)
1642	-	-	-	-	May-June	(d)
1683	-	-	-	-	July-August	26.0
1692	-	-	-	-	February-March	26.2
1767	-	-	-	-	January 12	(d)
1793	-	-	-	-	February 21	(d)
1798	-	-	-	-	March 25	(d)
1801	-	-	March 20	21.7	March 20	27.5
1807	-	-	-	-	February 1	(d)
1818	-	-	-	-	March 3	(d)
1818	-	-	-	-	May 6	(de)
1824	-	-	-	-	February 12	(df)
1824	-	-	-	-	December 30	(dg)
1827	-	-	-	-	March 30	(dh)
1828	-	-	-	-	February 11	22.8
1836	-	-	-	-	April 4	(di)
1838	-	-	-	-	January 28	23.0
1839	-	-	-	-	January 29	j24.2
1841	-	-	-	-	January 9	26.3
1843	-	-	January 8 (9)	20.3	-	-
1843	-	-	-	-	March 29	27.2
1843	-	-	April 18	20.7	-	-
1844	-	-	-	-	December 25	19.5
1845	-	-	-	-	February 25	19.0
1845	-	-	-	-	April	19.0
1846	-	-	-	-	March 16	18.8
1847	-	-	-	-	April 25	21.2
1847	-	-	-	-	December 14	17.0
1848	-	-	-	-	January 17	16.0
1849	-	-	-	-	November 11	17.5
1850	May 1	9.5	-	-	May 1	21.3
1850	May 8	(k)	-	-	May 8	22.0
1851	-	-	-	-	January 1	14.5
1852	-	-	April 24	19.5	April 24	23.1
1853	-	-	-	-	May 29	16.0
1853	-	-	-	-	November 15	20.5
1854	May 1	10.5	May 1	2[illegible].3	May 1	29.8
1855	-	-	-	-	April 22	21.5
1856	-	-	-	-	April 12	18.0
1856	-	-	-	-	August 9	18.1
1856	-	-	August 21	18.8	August 22	23.3
1857	-	-	February 21	13.5	February 21	19.5
1857	-	-	-	-	October 28	18.2
1858	-	-	-	-	March	12.2
1859	-	-	March 20	20.5	March 20	26.4
1860	-	-	-	-	March 3	16.0
1861	-	-	April 15	16.0	April 17	21.5
1862	April 20	12.5	April 20	22.2	April 21	28.7
1863	-	-	-	-	April 20	22.2
1864	-	-	April 29	10.3	April 29	17.2
1865	-	-	March 18	18.8	March 20	24.8
1865	-	-	-	-	May 14	18.0
1866	-	-	-	-	February 26	20.8
1867	-	-	February 17	13.0	February 17	17.2
1867	-	-	April 17	13.4	April 18	20.0
1867	-	-	-	-	August 18	16.2

a Zero of gage at altitude 97.98 feet above mean sea level.
b Zero of gage at altitude 37.76 feet above mean sea level.
c Zero of gage at altitude 0.55 foot below mean sea level.
d Great flood.
e As high as on March 3, 1818.
f Highest since 1818.
g 17 to 19 feet above summer level.
h Highest since 1807; 20 feet above ordinary low water.
i Nearly 20 feet.
j Highest since 1801.
k Several inches higher than on May 1, 1850.

Crest stages of floods of Connecticut River at Holyoke and Springfield, Mass., and at Hartford, Conn.--Continued.

Year	Holyoke, Mass.		Springfield, Mass.		Hartford, Conn.	
	Date	Stage (feet)a	Date	Stage (feet)b	Date	Stage (feet)c
1868	-	-	-	-	March 19	21.5
1868	-	-	-	-	May 23	20.0
1869	April 22	11.2	April 21	21.0	April 23	26.7
1869	October 5	12.7	October 4	21.5	October 6	26.3
1870	January 4	7.5	-	-	January 4	19.2
1870	February 20	8.3	-	-	February 20	21.3
1870	April 20	9.5	April 20	19.0	April 21	25.3
1871	-	-	-	-	March 15	16.5
1871	-	-	May 6	13.0	May 7	18.7
1872	-	-	April 12	14.2	April 13	21.0
1873	-	-	April 12	15.0	April 13	21.2
1873	October 22	5.2	-	-	October 22	15.6
1874	January 9	8.0	January 9	17.5	January 9	23.9
1874	May 23	4.8	-	-	May 23	16.3
1875	April 5	4.5	April 5	15.0	April 6	18.7
1875	April 18	6.0	-	-	April 18	18.4
1876	April 16	9.2	April 16	17.0	April 16	22.0
1877	March 29	8.8	March 29	16.5	March 29	22.9
1878	April 14	7.0	-	-	-	-
1878	April 30	6.5	-	-	April 30	18.5
1878	December 11	9.2	December 11	18.5	December 13	24.5
1879	May 1	8.5	May 1	15.8	May 1	21.5
1880	April 6	5.7	April 6	10.8	April 7	15.4
1881	-	-	April 26	11.5	April 26	16.5
1881	December 31	7.3	-	-		-
1882	-	-	March 3	10.8	-	-
1882	May 30	5.2	-	-	May 31	14.8
1882	September 24	8.1	-	-	-	-
1883	April 15	7.6	April 14	14.6	April 15	20.5
1884	March 28	7.6	March 28	16.0	March 28	21.6
1884	April 20	7.1	-	-	April 20	19.9
1885	April 24	6.5	April 24	13.3	April 24	18.0
1885	November 10	7.3	-	-	November 8	16.8
1886	January 6	6.4	-	-	January 7	18.4
1886	April 2	8.4	April 2	16.0	-	-
1886	May 4	2.2	-	-	May 4	21.8
1887	April 12	8.7	April 12	17.0	April 13	22.5
1888	-	-	-	-	April 8	19.4
1888	May 1	9.6	May 1	17.5	-	-
1888	December 18	7.0	-	-	-	-
1889	April 21	4.8	-	-	April 21	11.8
1889	November 29	5.1	November 29	11.3	November 30	15.6
1890	May 3	5.3	-	-	May 9	15.2
1890	September 18	6.1	-	-	-	-
1890	-	-	October 21	11.7	-	-
1890	-	-	-	-	October 26	16.0
1891	January 25	4.2	-	-	January 24	17.5
1891	April 19	7.1	April 17	14.2	April 17	19.8
1892	January 15	6.9	January 16	13.8	January 16	18.3
1892	April 5	5.7	-	-	April 4	16.0
1893	May 5	8.4	May 5	18.2	May 6	24.0
1894	April 25	5.0	April 26	10.4	April 25	13.8
1895	April 16	9.6	April 17	20.2	April 16	25.7
1896	March 2	9.5	March 3	20.2	March 3	26.5
1897	April 10	5.0	-	-	April 10	17.4
1897	June 11	7.5	June 12	15.2	June 12	20.6
1897	July 16	6.0	-	-	July 16	20.8
1897	December 16	7.3	-	-	December 17	20.4
1898	-	-	March 15	15.5	March 16	20.0
1898	March 21	7.5	-	-	March 22	21.2
1899	April 26	7.8	April 27	16.2	April 27	22.0
1900	February 13	9.4	February 14	17.0	February 15	23.4
1900	April 21	10.8	April 21	17.1	April 22	22.8

a Zero of gage at altitude 97.98 feet above mean sea level.
b Zero of gage at altitude 37.76 feet above mean sea level.
c Zero of gage at altitude 0.55 foot below mean sea level.

Crest stages of floods of Connecticut River at Holyoke and Springfield, Mass., and at Hartford, Conn.--Continued.

Year	Holyoke, Mass.		Springfield, Mass.		Hartford, Conn.	
	Date	Stage (feet)a	Date	Stage (feet)b	Date	Stage (feet)c
1901	April 8	11.4	April 9	19.8	April 9	26.4
1901	December 16	8.5	-	-	December 17	20.0
1902	March 4	10.8	March 4	19.3	March 4	25.5
1902	October 30	7.3	-	-	-	-
1903	March 24	10.6	March 25	17.4	March 25	23.3
1903	June 22	7.6	-	-	-	-
1904	March 27	10.0	March 28	15.3	March 28	19.5
1904	-	-	-	-	April 30	21.4
1905	April 1	10.6	April 1	18.4	April 2	24.0
1906	April 17	9.3	April 17	15.1	April 18	20.1
1906	May 29	8.0	-	-	May 30	18.5
1907	March 31	7.5	-	-	April 1	16.0
1907	April 28	7.7	-	-	April 29	15.7
1907	November 8	9.0	November 8	15.5	November 9	20.3
1908	February 17	7.5	-	-	February 18	18.5
1908	March 30	7.6	March 30	13.1	March 31	18.2
1908	May 2	7.3	-	-	May 3	17.5
1909	April 16	10.6	April 16	18.7	April 17	24.7
1910	January 23	7.5	January 23	15.0	January 23	20.2
1910	March 2	7.5	-	-	March 3	18.6
1910	March 27	7.5	-	-	March 28	18.6
1911	April 16	7.2	April 17	11.9	April 17	15.5
1911	-	-	-	-	October 20	16.0
1912	April 9	9.3	April 9	16.1	April 10	21.2
1913	March 29	12.0	March 29	20.2	March 29	26.3
1914	April 22	9.9	April 22	17.0	April 23	21.9
1915	February 26	8.8	February 26	15.6	February 27	20.6
1915	April 13	7.2	-	-	April 14	15.8
1915	July 9	7.5	-	-	July 10	16.4
1915	August 5	7.0	-	-	August 6	16.5
1916	February 27	6.0	-	-	February 28	17.7
1916	April 3	8.9	April 3	15.6	April 3	20.8
1917	March 30	7.4	March 29	13.5	March 30	18.3
1918	April 4	7.9	April 4	14.0	April 4	18.8
1919	March 29	9.2	March 30	15.0	March 30	19.8
1919	May 23	7.9	-	-	May 24	19.1
1920	March 28	9.8	March 29	17.3	March 30	22.5
1920	April 25	8.6	-	-	April 25	20.2
1920	December 16	8.1	-	-	December 17	18.8
1921	March 11	8.9	March 11	15.5	March 12	19.9
1921	May 2	7.6	-	-	May 2	16.8
1922	April 13	11.4	April 13	19.4	April 14	24.5
1923	April 7	9.4	April 7	16.8	April 8	22.0
1923	May 1	8.4	-	-	May 2	20.4
1923	December 2	7.1	-	-	December 8	15.9
1924	April 8	7.8	April 8	14.5	April 8	20.7
1925	February 14	6.4	-	-	February 14	16.2
1925	March 31	9.5	March 31	16.0	March 31	20.5
1926	April 27	9.1	April 27	16.0	April 27	20.8
1927	March 20	8.0	March 21	13.3	March 20	19.0
1927	November 5	14.8	November 6	22.4	November 6	29.0
1927	December 10	8.2	-	-	December 10	17.9
1928	April 9	8.7	April 9	13.5	April 10	18.6
1929	March 25	8.2	March 25	14.0	March 25	18.9
1929	April 28	7.0	April 30	12.7	May 1	17.7
1930	April 9	5.8	April 10	10.4	April 10	14.2
1931	April 12	8.5	April 12	13.1	April 13	17.9
1931	June 11	7.4	June 11	12.8	June 11	17.6
1932	April 14	9.5	April 14	15.3	April 14	20.5
1932	November 21	7.9	November 21	13.2	November 21	18.0
1933	April 20	12.4	April 20	19.9	April 21	26.0
1934	April 14	10.3	April 14	17.7	April 14	23.1
1935	January 11	9.0	January 11	15.5	January 12	20.7
1936	March 19-20	16.8	March 20	28.6	March 21	37.6

a Zero of gage at altitude 97.98 feet above mean sea level.
b Zero of gage at altitude 37.76 feet above mean sea level.
c Zero of gage at altitude 0.55 foot below mean sea level.

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DEPARTMENT OF THE INTERIOR
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