ENGINEERING ASPECTS OF FLOOD CONTROL IN NEW ENGLAND *

By Colonel T. F. Kern, District Engineer, U. S. Engineer Office, Providence, R. I.

1. INTRODUCTION

WE are gathered here this evening on the 10th anniversary of the greatest flood of record and probably the most disastrous event from the standpoint of economic loss in the history of the City of Hartford. The event would have been repeated with almost equal severity in September 1938 but for partially completed permanent flood protection improvements and the great emergency measures which effectively prevented the river from overflowing into the city.

Research into the historical documents of Connecticut reveals without a doubt that the 1936 flood was the greatest flood in a period extending back to 1639. The fact that such a flood could be approached only two years later shows that the flood control engineer cannot depend upon estimates of probabilities or average intervals of occurrence as a basis of selecting design floods for reservoirs and local protection works. Floods are unpredictable as to time and height, but we know that there will be floods in the future and there is a hazard in the flood plain.

The peak of the 1936 flood at Hartford was estimated at 313,000 second-feet, during the sudden surge following the breaching of the existing low dikes at Hartford, which caused a drop in the water surface at the lower end of the Hartford reach. This peak rate of discharge was of very short duration. The natural peak discharge would have been 290,000 c.f.s. The maximum daily discharge was 586,000 acre feet or approximately 25 billion cubic feet. Fifty percent of the flood runoff occurred during the four days of March 19 - 22. This four day discharge of the Connecticut River at Hartford, 90 billion cubic feet was 1.6 times the usable capacity of the Quabbin Reservoir which covers 24,700 acres.

Colossal discharge figures mean little to the average citizen who knows only that inundation from floods means property damage, loss of income, electric power failures, transportation tieups, depreciated property values, and hazards to life and health. In March 1936 large commercial and industrial sections of Hartford were flooded with a consequent direct damage to property of $7,660,000 and an equivalent amount in indirect losses consisting of loss of wages, interruption of business affecting a wide area, and emergency defense measures and cleanup.

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2. Federal Policy

Congress provides flood control, but flood control improvements of river basins are initiated by the people. Upon request of a member of Congress the Flood Control Committee of the House of Representatives or Senate directs the Chief of Engineers to report on the flood problem, method of protection, economic justification and desirability of improvement. Congress then takes under consideration the enactment of the authorization of the recommended improvements. Subsequent to the authorization Congress appropriates funds for the execution of the plan of improvement; first by appropriating funds for planning and later funds for construction. This procedure takes time but it permits deliberate consideration which avoids unwise expenditures and undesirable improvements. There exists a large backlog of desirable flood control improvements so that procedure is not delaying the completion of flood protection for the nation.

The great flood events of 1936 which covered almost the entire northeastern United States led the Congress to declare that flood protection was a national problem and "flood control on navigable waters or their tributaries is a proper activity of the Federal Government in cooperation with States, their political subdivisions, and localities thereof." Congress further declared that the Federal Government should participate in the cost of flood control improvements "if the benefits to whomsoever they may accrue are in excess of the estimated costs and if the lives and social security of people are otherwise adversely affected."

The extent of Federal participation in flood control projects varies. In general the United States pays the construction cost of local protective works which are turned over to the local interest for maintenance and operation. Lands and rights-of-way for local protective works are furnished to the United States free of cost by the local interest. The City of Hartford contributed to the cost of the construction of the local protective works to procure features beyond the scope of the authorized improvement. The cost of the additional height of the dikes above the U. S. grade was paid by the city. The United States, however, acquires the lands, relocates the roads and railroad and constructs the dams for flood control reservoirs, thus paying all the direct cost, and maintains and operates the reservoirs and dams after construction.

The plan as a whole for the Connecticut River Basin is economically justifiable. There is, however, no satisfactory method of allocating the benefits of a system of reservoirs to the individual units or to allocate the benefits between the system of reservoirs and the local protective works. The plan for the Connecticut River Basin was designed to provide complete security

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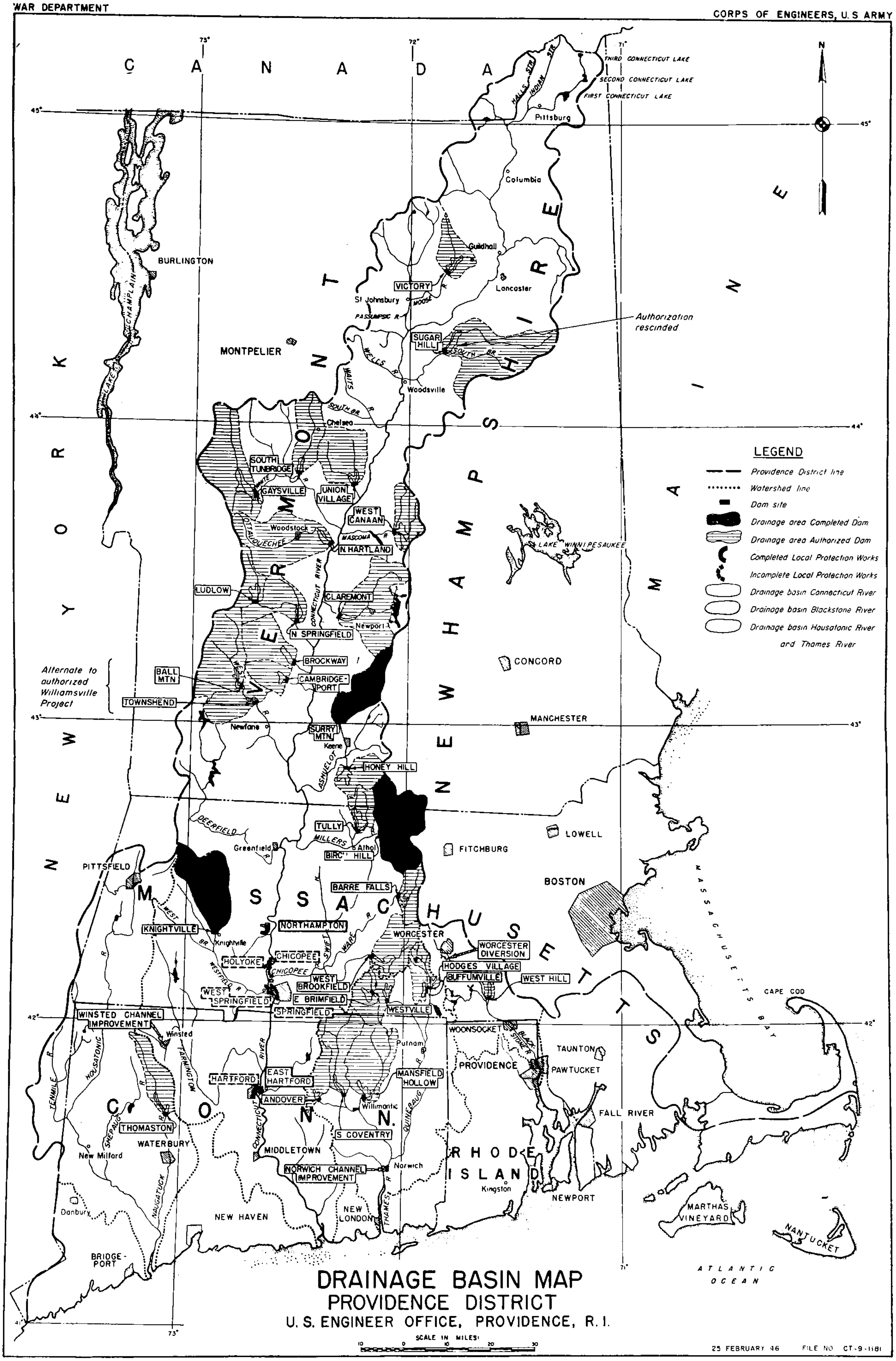

DRAINAGE BASIN MAP
PROVIDENCE DISTRICT
U. S. ENGINEER OFFICE, PROVIDENCE, R. I.

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PLATE 1

to the important commercial and industrial centers, and a high degree of relief to other affected communities and localities by reducing flood stage throughout the basin.

3. Flood Problem

The flood problem in New England is important because of the extensive development within the flood plain. The annual rainfall is usually fairly uniformly distributed throughout the year. Geographically the country is old and the rivers have cut adequate channels to carry the normal runoff between well defined banks even during the spring thaw. However, the rugged character of the topography produces a high concentration of storm runoff and New England is susceptible to intense storms over large areas. The early settlers depended upon the river for communication and power, and were not aware of the flood hazard and developed the flood plain. In fact it was not until 1936 that the seriousness of the flood problem in New England was recognized.

Flood protection in New England is a form of insurance. It may never be needed in our lifetime, but every year there is a possibility of a flood. The next flood probably will not equal the 1927 flood stages; it is even less probable to equal the 1938 flood stages, but it might even exceed that flood. Floods in New England are unpredictable.

The potential flood damage to highly developed cities like Hartford and Springfield justify costly local protection works, but there are hundreds of miles of main river and tributary reaches occupied by small communities, isolated factories and farms and miles of important railways and highways where the potential flood damage, although substantial, does not justify costly local protective works. A survey of basin wide damages in the flood of 1927, 1936, and 1938 shows that 70 percent or $53,000,000 of the direct damages occurred outside of communities now receiving local protection. The only economic method of flood relief for most of the basin is regulation of flood runoff. The upstream reservoirs will reduce future flood destruction.

4. Physical Characteristics of the Connecticut River and Watershed

The basin is distinctly mountainous in its northern and western areas, the ruggedness decreasing southerly to the coastal regions, which are comparatively low and level. The Berkshire Hills in Massachusetts and Connecticut, the Green Mountains in Vermont, and the White Mountains in northern New Hampshire form sharply defined drainage boundaries and barriers which have a pronounced effect on the rainfall and runoff characteristics. The Green Mountain ridge has an average elevation of 2,000-3,000 feet above sea level with a few peaks extending up to 4,000 feet. The eastern rim of the basin in southern and central New Hampshire is generally lower, but in the White Mountains of northern New Hampshire it rises above 4,000 feet and reaches a maximum of 6,000 feet at Mt. Washington.

The total length of main river from First Connecticut Lake to the mouth is 392 miles and the total fall is about 1,640 feet. For about 25 miles the fall averages 25 feet per mile. Between miles 300 and 270 the fall is 400 feet, most of which is in the Fifteen Mile Falls. Below the latter point the fall averages slightly less than 2 feet per mile. When the river is in flood about one-third of the fall below mile 270 is concentrated at power developments at Wilder, Bellows Falls, Vernon, Turners Falls, Holyoke, and Thompsonville.

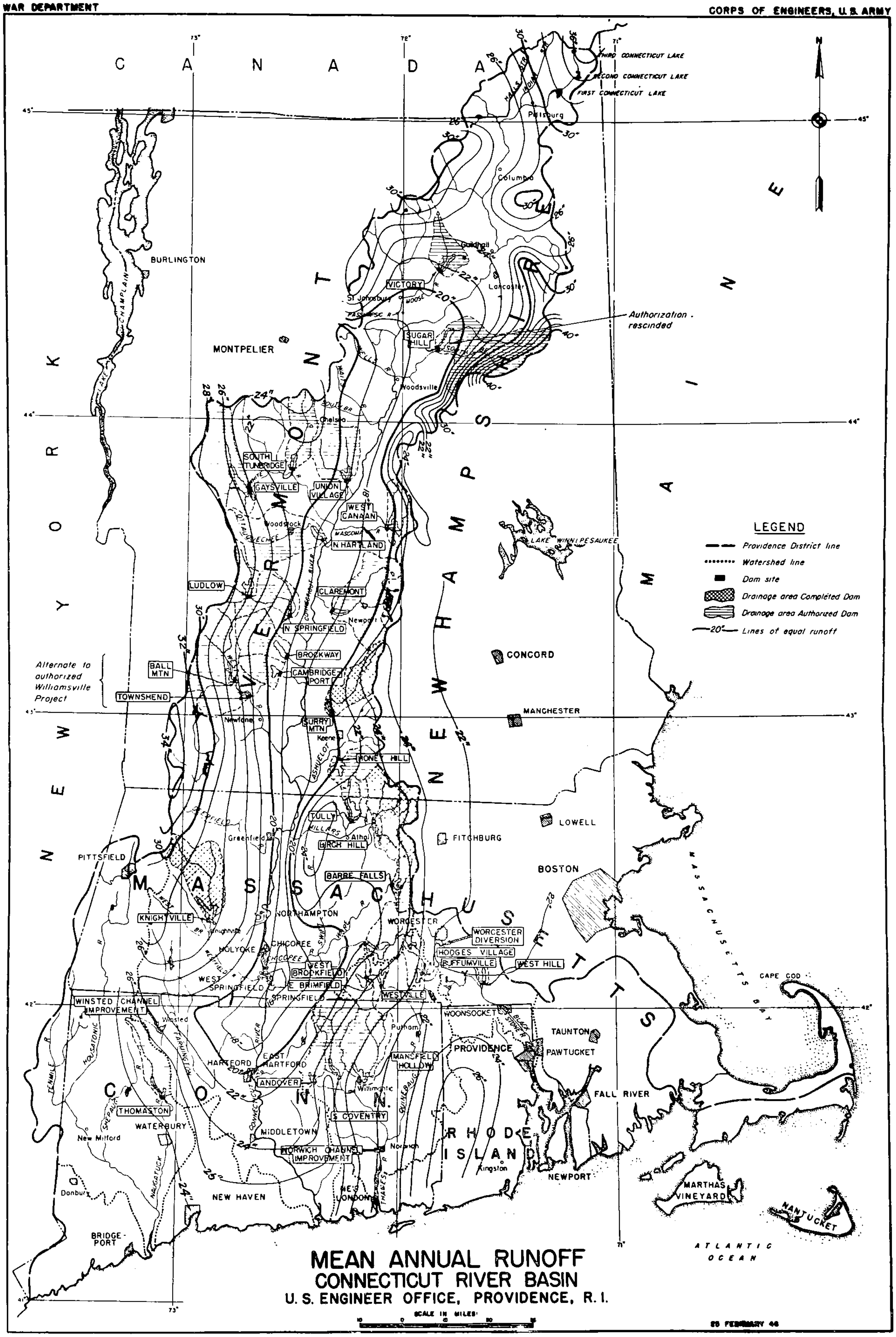
The tributaries are relatively short and steep and follow a general course which is at right angles to the main river. With the exception of the tributaries draining the White Mountains in New Hampshire, those entering from the west are the steepest and drain the most rugged areas.

5. CHARACTERISTIC HYDROLOGY OF WATERSHED

The basis of any flood control plan is an adequate appraisal of the rainfall and runoff characteristics or the hydrology of the basin.

The New England Region in general receives an extraordinary number of continental storms through the year. In fact the area eventually comes under the influence of the majority of disturbances which cross the continental United States and whose paths converge on the northeastern states. General storms are less prevalent in the summer months when precipitation is localized and caused by showers and thunderstorms. In spite of the variations in the causes of seasonal precipitation, the distribution is uniformly distributed throughout the year.

The great cyclonic storms draw in moisture from the Atlantic Ocean and cause it to be distributed over the basin in patterns which vary with each storm. Because it is nearer the sources of moisture, the average precipitation is high in the coastal regions and tends to decrease in an inland direction. This decrease is offset by the effect of increased elevation in the Berkshire Hills and in the Green and White Mountains still further north. The higher elevations cause the moist air masses to be lifted and cooled and as a



MEAN ANNUAL RUNOFF
CONNECTICUT RIVER BASIN
U. S. ENGINEER OFFICE, PROVIDENCE, R. I.

PLATE 2

result more moisture is deposited in the upland areas. The eastern slopes of the hills and mountains tend to receive more moisture than the western slopes which are subject to what is known as a "rain shadow". This latter effect is, of course, only present to a minor degree.

Average annual precipitation in Connecticut varies from 49 inches near the coast to 41 inches inland near the Massachusetts border. In Massachusetts the precipitation is rather uniform, varying between 40 and 45 inches with high centers of about 50 inches in the western part. Precipitation in Vermont varies from 34 inches along the Connecticut River Valley to 55 inches in the southwestern corner. A high of at least 50 inches is indicated for almost the entire Green Mountain ridge. In New Hampshire there is a high center of 70 inches around Mt. Washington but this decreases sharply to 35 inches in the river valley. Unfortunately these variations have not been defined in either magnitude or areal extent because official rainfall stations are located in populated areas or at convenient points in valleys. It has been necessary to estimate the rainfall on the mountains by known altitude-rainfall relations and from records of average runoff at stream gaging stations.

The average annual runoff in the Connecticut River Basin varies rather widely from 18 inches for short streams adjacent to the main river valley to 40 inches along the highest slopes of the White Mountains. The annual runoff is 50 to 65 percent of the annual rainfall and is subject to the same influences as the rainfall and to the additional influences of geologic structure, land slope, stream pattern, and storage in swamps, ponds, and artificial reservoirs. A map of the Connecticut River Basin showing generalized lines of mean annual runoff is presented in Plate 2. So far as is known a map of this type has never been presented before for the Connecticut River Basin, as only in the last 10 years have there been sufficient runoff records to give general coverage in the isolated portions of the basin. The shorter records have been adjusted statistically to conform to the 25-year period 1920-44, as indicated by the available long records. These runoff records have been used as a basis for estimating average precipitation in mountainous areas where no records have been kept, as it is known that the average difference between rainfall and runoff is a rather stable figure ranging with mean temperature from about 18 inches in the extreme north and at high altitudes to 24 inches in the southern coastal areas.

6. The Great Floods of the Last Two Decades

The flood history along the main Connecticut River prior to the establishment of continuous gage-height records has been revealed through research into historical documents. Descriptive references of flood occurrences dating back to the year 1639 have been found. Sufficient descriptive detail has been located to make actual flood-height estimates in terms of present gages as far back as 1683. A complete record of important flood heights at Hartford, Connecticut, extends back to 1838. A tabulation of the greatest known flood stages at Holyoke, Springfield and Hartford is given in order of magnitude in Table 1. The floods of March 1936 and September 1938 are obviously outstanding from Springfield to Hartford. At Springfield the six largest floods in the period 1801 to 1927 have almost equal stages, which must have given the impression that there was some influence limiting the magnitude of floods. To one well versed in flood history such a condition is a warning that a flood of greater magnitude is overdue as there is no reason in uncontrolled basins for such a similarity in magnitude. Upstream from Springfield the flood of November 1927 begins to achieve more importance until at White River Junction on the Connecticut River it is known to have exceeded all other floods, including that of March 1936.

The two great floods of the last decade, those of March 1936 and September 1938 have made a great impression on the people in the lower Connecticut River Valley and this has resulted in a belief that these two floods were the only great floods in the history of the basin, that their recurrence is quite improbable, and the 1936 flood can be considered as the greatest flood that will ever occur. The 1936 and 1938 floods were unprecedented on southern tributaries and on the lower reaches of the main river, but on the main river above the northern Massachusetts boundary and on many tributaries in New Hampshire and Vermont there is historic evidence of many other floods of equal or greater importance. The flood of November 1927 was the greatest natural disaster in the history of Vermont and broke all previous records in almost every river basin in the entire State, besides having high centers in the White Mountains of New Hampshire and in Massachusetts. A slightly different distribution of the storm center and somewhat longer duration as occurred in September 1938 would have made this storm and flood equal to the more publicized events of subsequent years. In spite of the severity of the 1927 flood, local histories indicate that in July 1830 the Otter Creek, White, Winooski, and Passumpsic River Basins in Vermont were visited by a flood of almost equal magnitude. In August 1826 a storm stretching from the lower Green Mountains to the vicinity of Mt. Washington had measured depths of 9 to 18 inches, which is considerably greater than the 1927 storm rainfall. The 1826 storm is the one that caused the famous Willey House disaster in the White Mountains. These two storms are examples of the known historic occurrences which point out what may be expected at any time in the future.

Table 1—Greatest Floods of Record on the Lower Connecticut River

Order of Magnitude	Holyoke, Mass.		Springfield, Mass.		Hartford, Conn.	
	Date	Stage in Feet	Date	Stage in Feet	Date	Stage in Feet
1	Mar. 19-20, 1936	16.8	Mar. 20, 1936	28.6	Mar. 21, 1936	37.6
2	Sept. 22, 1938	14.9	Sept. 22, 1938	25.8	Sept. 22-23, 1938	35.4
3	Nov. 5, 1927	14.8	Nov. 6, 1927	22.4	May 1, 1854	29.8
4	Oct. 5, 1869	12.7	May 1, 1854	22.3	Nov. 6, 1927	29.0
5	Apr. 20, 1862	12.5	Apr. 20, 1862	22.2	Apr. 21, 1862	28.7
6	Apr. 20, 1933	12.4	Mar. 20, 1801	21.7	Mar. 20, 1801	27.5
7	Mar. 29, 1913	12.0	Oct. 4, 1869	21.5	Mar. 29, 1843	27.2
8	Apr. 13, 1922	*11.4	Apr. 21, 1869	21.0	Oct. 6, 1869	26.3

* Same height equalled on April 8, 1901.

The outstanding feature of the 1936 flood was the fact that all parts of the basin were contributing at an unusually high and prolonged, but not always record-breaking, rate. The result was an enormous accumulation of runoff in the main river valleys which took up the valley storage which normally modifies more flashy floods. As will be discussed later, there is no reason why equivalent volumes of runoff from rain alone as well as rain plus melting snow could not occur and give equal or greater stages in the lower river.

A complete flood history of the tributaries would require a lengthy presentation as no one general storm and flood has broken the records on all the tributaries at once. Table 2 shows as far as can be determined the month and year of the greatest flood of record for each principal tributary. Historic data are inadequate in the sparsely settled regions and there is no doubt that isolated and little known storms and floods have exceeded contemporary records in the smaller headwater areas.

TABLE 2

DATE OF GREATEST KNOWN FLOOD ON PRINCIPAL TRIBUTARIES OF THE CONNECTICUT RIVER

Tributary	*Date*
Headwaters of Connecticut	June, 1943
Passumpsic	November, 1927
Ammonoosuc	November, 1927
White	November, 1927
Mascoma	March, 1936
Ottauquechee	November, 1927
Sugar	March, 1936
Black	November, 1927
West	September, 1938
Ashuelot	September, 1938
Millers	September, 1938
Deerfield	September, 1938
Chicopee	September, 1938
Westfield	September, 1938
Farmington	September, 1938

In view of the important part that runoff from melting snow has played in some past floods, brief mention of this factor is essential in evaluating the flood producing characteristics of the Connecticut River Basin. A large snow cover in the spring may contribute to floods or may go off in an orderly manner. For example, in March 1936 the heavy snow was melted in a short time by a combination of warm temperatures and heavy rains, but in March 1945 a greater snow cover disappeared without causing serious floods as a result of any extraordinarily dry and warm month of March. Extensive studies of maximum precipitation which have been made by the Hydrometeorological Section of the U. S. Weather Bureau working in cooperation with the War Department have shown that equally great floods will result in the Connecticut River Basin from either melting snow and rainfall in the winter or spring or from a great rainstorm occurring in the seasons in which snow is not present. The findings of the Weather Bureau are amply substantiated in that the great snow melt flood of record, that of March 1936, was closely approached by the September 1938 flood in the lower Connecticut River and exceeded in the tributaries in southern New Hampshire and Vermont and in Massachusetts and Connecticut. Furthermore, the flood of November 1927, a rain flood, equalled or exceeded all known spring floods in northern and western Vermont and in the White Mountain region of New Hampshire. Although the number and probability of snow melt floods is greater, rain floods must be given equal consideration in determining the flood producing potentialities of the basin.

7. Sources of Data on Rainfall and Runoff

In spite of the fact that the Connecticut River Basin has been settled for about 300 years, knowledge of the detailed variations of rainfall and stream flow in the headwater areas which contribute most to floods is far from satisfactory. The basin is not unique in this respect as widespread scientific observations of meteorologic phenomena have been taken in the country as a whole for a period of only about 50 years. Where official rainfall stations have been established they were usually located in populated areas or at convenient points in valleys where observers could be obtained. Many rainfall records have been kept by water supply organizations and power companies at remote locations and high elevations. Such records are of great value in supplementing official Weather Bureau stations.

As I have previously mentioned the coverage by runoff records is now quite complete and these records have been used to estimate average annual rainfall at remote places.

The question then arises, if the annual rainfall is difficult to determine in critical headwater areas, then the storm rainfall cannot be known with any great degree of certainty. This is true to some extent, but fortunately a method has been discovered and widely applied in the mountainous western regions which helps to estimate storm rainfalls at high altitudes and remote localities. This method consists of expressing storm rainfall at known points in terms of the annual rainfall. It has been found with some exceptions that in many mountainous areas that the rainfall in limited localities tends to be an equal percentage of the annual rainfall regardless of altitude

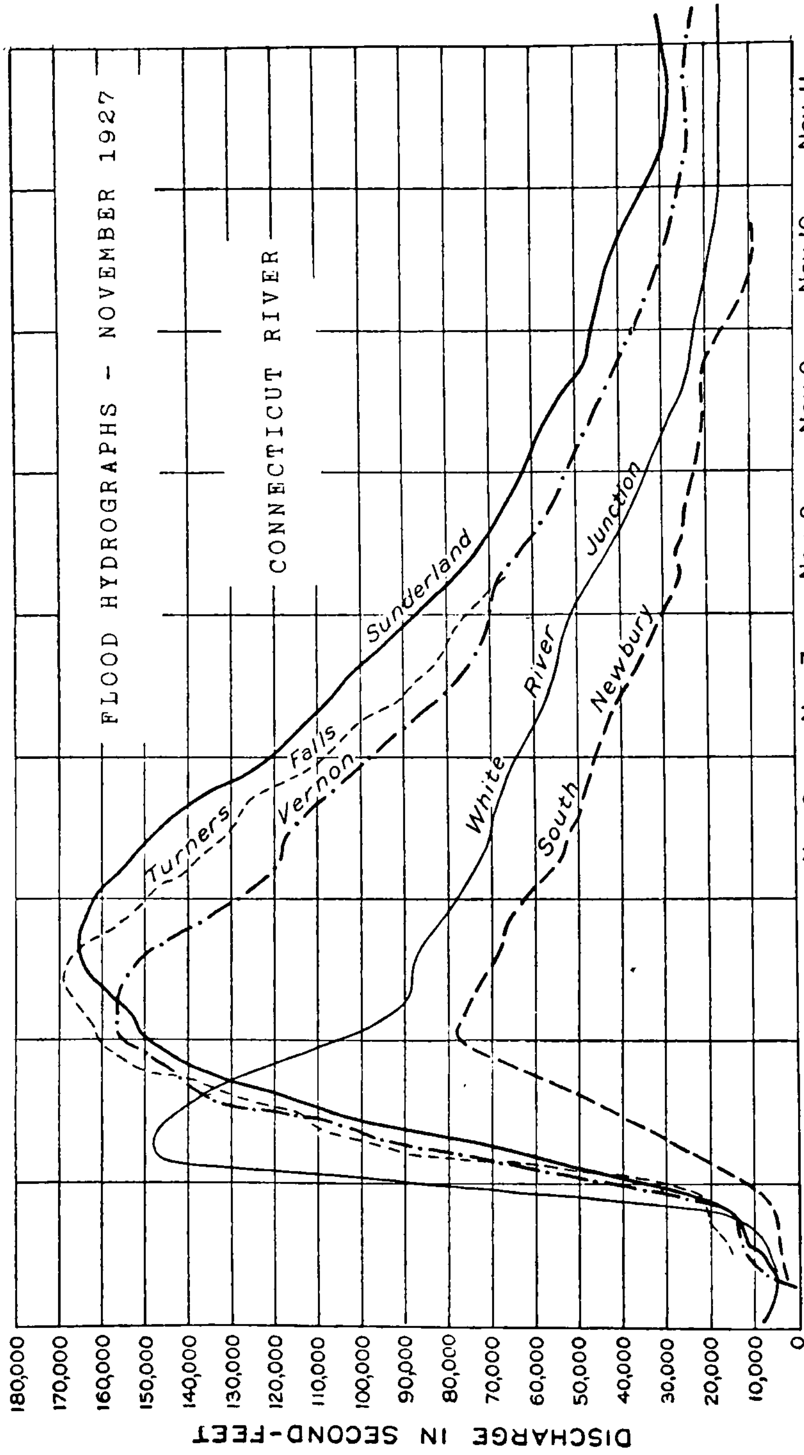

FLOOD HYDROGRAPHS - NOVEMBER 1927
CONNECTICUT RIVER
Sunderland
Turners Falls
Vernon
White River Junction
South Newbury
DISCHARGE IN SECOND-FEET
180,000
170,000
160,000
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Nov. 3
Nov. 4
Nov. 5
Nov. 6
Nov. 7
Nov. 8
Nov. 9
Nov 10
Nov. 11

Plate 3

and exposure, hence the procedure has been termed "the isopercential method". Storm rainfalls, such as those of November 1927 in Vermont, can be estimated with a fair degree of reliability and in turn runoff hydrographs can be computed using the unit-hydrograph theory. The unit hydrographs can be derived from stream flow records obtained subsequent to the occurrence of past storms.

8. BASIS OF DESIGN FOR COMPLETE PROTECTION

Studies of the distribution and depth of rainfall and runoff in the great floods of recent years do not indicate that any of these floods approach limiting conditions for any of the tributaries or for the basin as a whole. The severity of the storms and the runoff has varied from one general locality to another but the degree of severity expressed in some terms such as the percentage of the annual rainfall has occurred in equal amounts over most of central New England. It is entirely logical that the positions of the centers of past storms might have moved either east or west or north or south to produce substantially greater floods in the Connecticut River Basin. The conclusion, therefore, is that any comprehensive flood control plan which is to give security to the people of New England must provide protection against greater flood discharges than have occurred in the past, particularly along the main Connecticut River. The degree of protection over past occurrences must, of course, be a matter of judgment considering all possible scientific facts and studies. Studies have been in progress in the Providence District, although interrupted by the war years, which are taking into account the more recent data obtained from the 1938 flood.

9. CHARACTERISTICS OF GREAT STORMS AND THE DERIVATION OF A MAJOR DESIGN STORM

The War Department has developed a procedure for analyzing great storms over the United States which is more advanced than the former methods. The only previous research program of similar magnitude was that conducted by Miami Conservancy District, Dayton, Ohio, in connection with the design of the monumental system of flood control works constructed about 25 years ago. The War Department program proposes the analysis of some 1,400 storms of which 400 of the greatest have already been analyzed, including the three great storms in New England. In developing an isohyetal map of storms, all official and unofficial measurements are considered. The time distribution of rainfall is determined from mass curves

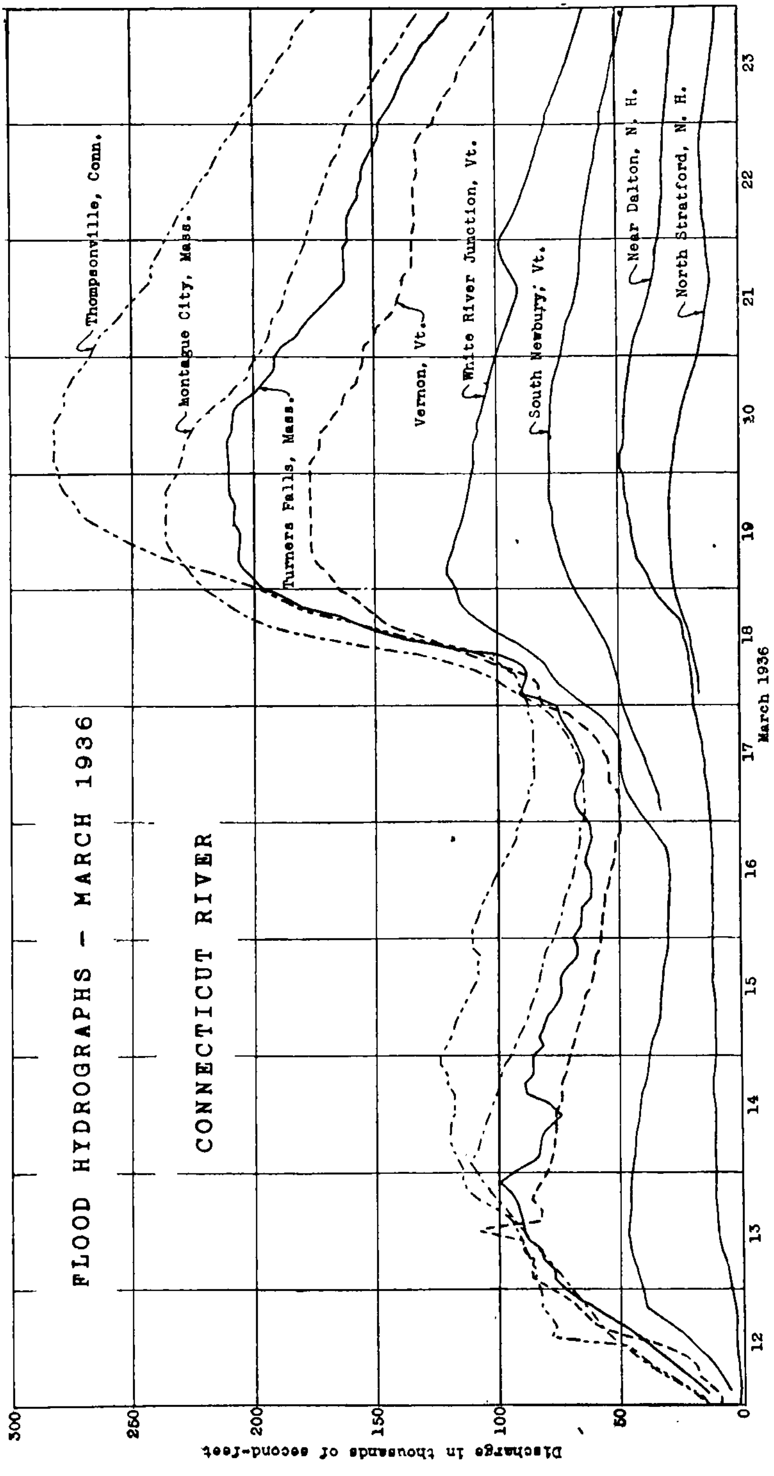

FLOOD HYDROGRAPHS - MARCH 1936
CONNECTICUT RIVER
Thompsonville, Conn.
Montague City, Mass.
Turners Falls, Mass.
Vernon, Vt.
White River Junction, Vt.
South Newbury, Vt.
Near Dalton, N. H.
North Stratford, N. H.
300
250
200
150
100
50
0
Discharge in thousands of second-feet
12
13
14
15
16
17
18
19
20
21
22
23
March 1936

PLATE 4

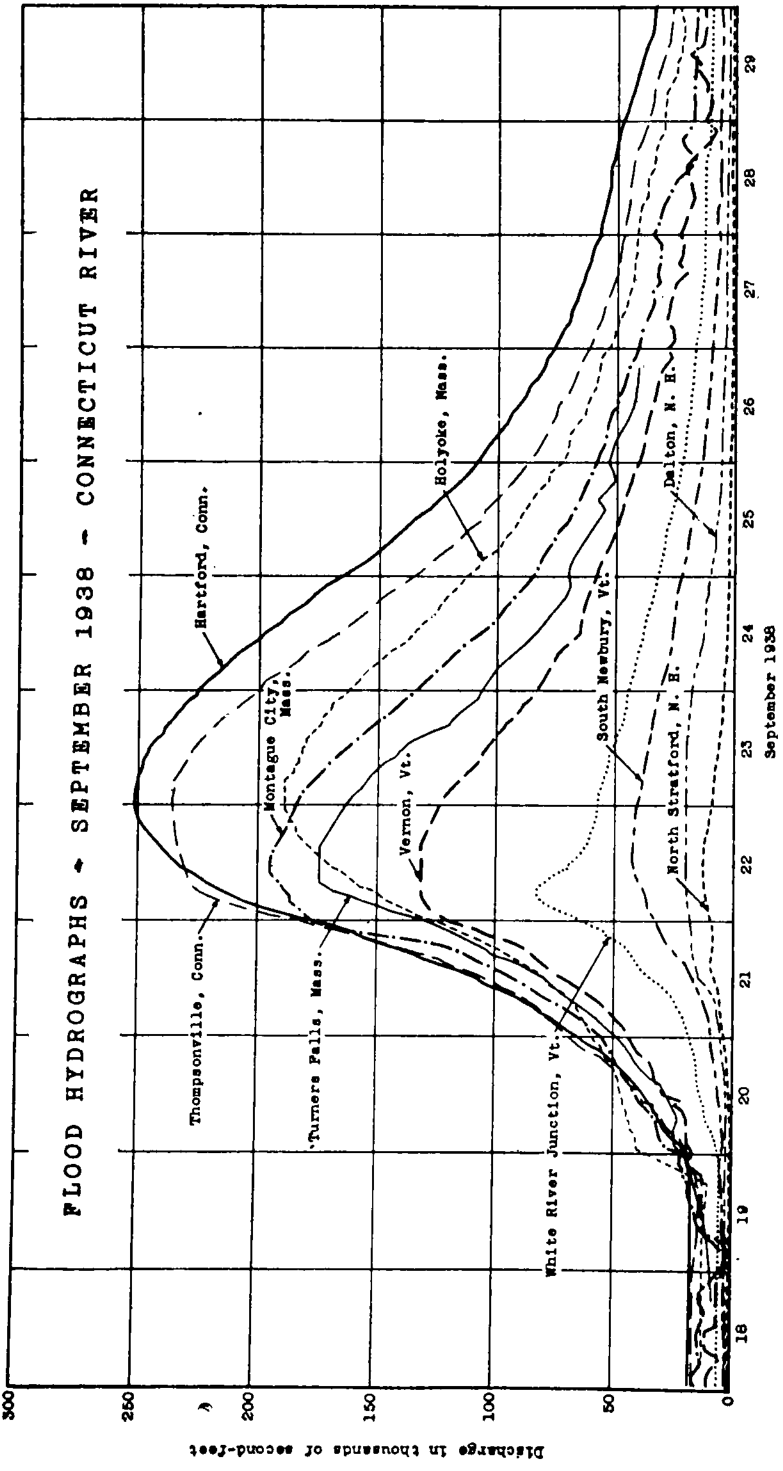

FLOOD HYDROGRAPHS - SEPTEMBER 1938 - CONNECTICUT RIVER
Hartford, Conn.
Holyoke, Mass.
Thompsonville, Conn.
Montague City, Mass.
Turners Falls, Mass.
Vernon, Vt.
White River Junction, Vt.
South Newbury, Vt.
Dalton, N. H.
North Stratford, N. H.
Discharge in thousands of second-feet
300
250
200
150
100
50
0
18
19
20
21
22
23
24
25
26
27
28
29
September 1938

PLATE 5

of the records at recording stations and estimated mass curves are then constructed for non-recording stations. Such a procedure gives a much different picture of the true distribution of rainfall than is gained by examination of the published records for calendar-day rainfall only.

Plates 6 to 8 show the isohyetal patterns for the total storm rainfall in the storms of 1927, 1936, and 1938. Certain generalizations can be made from these patterns and comparisons with the pattern of the mean annual rainfall. In Connecticut the position of high rainfall centers is rather unpredictable and dependent on where the storm center passes and the frontal action of the air masses. Going north into Massachusetts the isohyetal patterns show a pronounced gradient upwards from the coast to the Connecticut River divide west of Worcester. The storm rainfall in the Connecticut River valley is usually less intense but increases westward to the Berkshires. These variations in Massachusetts conform in general to the gradations in annual precipitation and to changes in altitude. Northward into New Hampshire and Vermont the storm patterns parallel in a more pronounced manner the topography and mean annual precipitation. None of the recent great storms have shown even a secondary center along the valley of the main river. The greatest depths of rainfall north of Massachusetts have occurred in either or all of the following places:

(a) Along the Green Mountain ridge beginning in the headwaters of the Deerfield River.

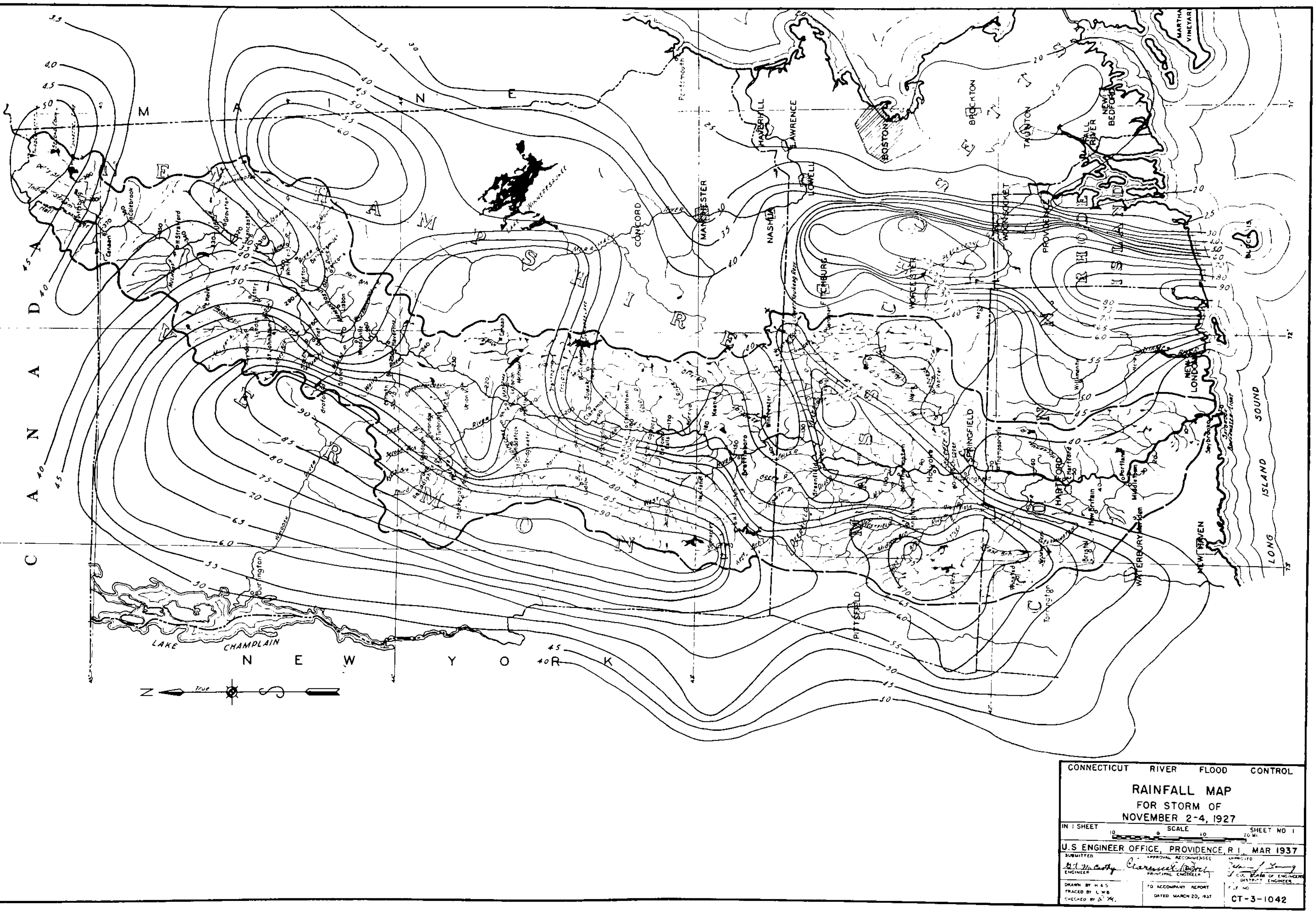
(b) Around Mt. Monadnock and Peterboro, N. H., and extending south along the eastern divide of the Connecticut River.

(c) In the White Mountains extending north and southwest from Mt. Washington.

These generalizations point out that flood control by headwater reservoirs in New England is logical and that the expected reductions in flood discharges will in general be in excess of the percentage of area controlled. Of course, the control of some headwater areas is more effective than others due to differences in the natural timing of tributaries as they contribute to the flood peak of the main river.

10. Characteristics of Flood Hydrograph on the Connecticut River.

Plates 3 to 5 which have been taken from the special flood reports of the U. S. Geological Survey show for the three major floods under discussion the main river discharge hydrographs. Close examination of these plates



CONNECTICUT RIVER FLOOD CONTROL

RAINFALL MAP
FOR STORM OF
NOVEMBER 2-4, 1927

IN 1 SHEET
SCALE
10 0 10 20 MI
SHEET NO 1

U.S ENGINEER OFFICE, PROVIDENCE, R I, MAR 1937

SUBMITTED
G. A. McCarthy
ENGINEER

APPROVAL RECOMMENDED
Clarence E.
PRINCIPAL ENGINEER

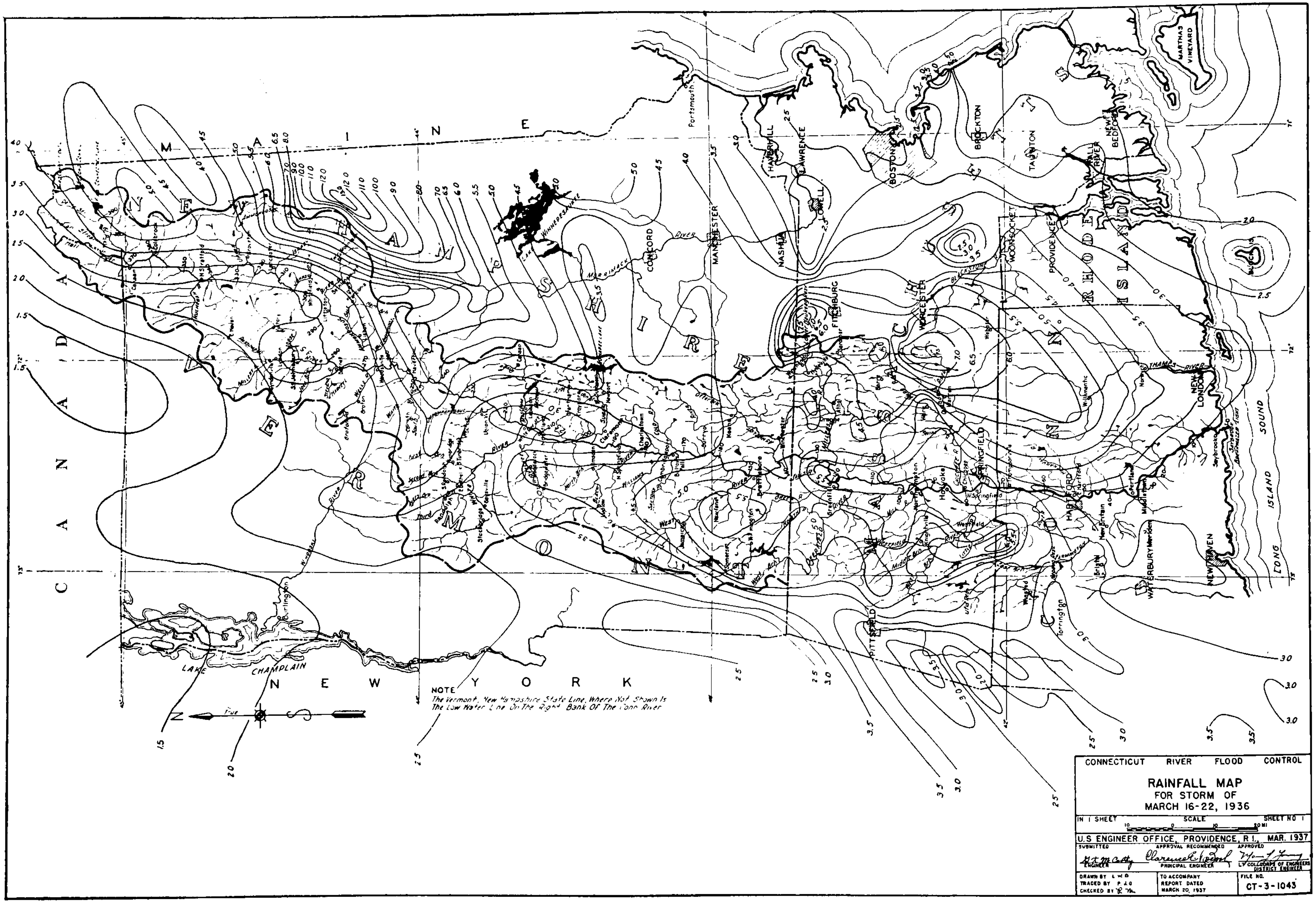
APPROVED
Young
COL. CORPS OF ENGINEERS
DISTRICT ENGINEER

DRAWN BY H A S
TRACED BY L W B
CHECKED BY

TO ACCOMPANY REPORT
DATED MARCH 20, 1937

FILE NO
CT-3-1042

PLATE 6



NOTE
The Vermont, New Hampshire State Line, Where Not Shown Is The Low Water Line On The Right Bank Of The Conn River

CONNECTICUT RIVER FLOOD CONTROL

RAINFALL MAP
FOR STORM OF
MARCH 16-22, 1936

IN 1 SHEET — SCALE 10 0 10 20 MI — SHEET NO 1

U.S ENGINEER OFFICE, PROVIDENCE, R.I., MAR. 1937

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
G. F. McCarthy ENGINEER	Clarence E. Boesel PRINCIPAL ENGINEER	LT COL CORPS OF ENGINEERS DISTRICT ENGINEER

DRAWN BY L.W.D. TRACED BY P.J.O. CHECKED BY R. M.	TO ACCOMPANY REPORT DATED MARCH 20, 1937	FILE NO. CT-3-1043

PLATE 7

reveals more than words can describe the characteristic formation of a main river flood. For example, Plate 6 for the November 1927 flood shows by the graph for White River Junction that the White River in Vermont controls the timing of the main river peak below its mouth. The peak above the White River as represented by the station at South Newbury, Vermont, has always come later than the peak at White River Junction. However, that does not mean that flood control above White River Junction is not effective, because considerable benefit can be obtained by controlling the initial rise at White River Junction through control of the lower flashy tributaries such as the Passumpsic, Ompompanoosuc, and Ammonoosuc Rivers. The peaks of the hydrographs below White River Junction as shown by those for Vernon, Vermont, and Turners Falls, Massachusetts, are increased by the other large tributaries such as the Ottauquechee, Black, and West Rivers, and the Mascoma, Sugar, and Ashuelot Rivers in New Hampshire. Differences in timing of the tributaries plus a moderate amount of valley storage cause a broadening of the peak. The inflow of the long but rugged Deerfield River and the Millers River causes the peak to jump up sharply at Montague City, Massachusetts, as shown by the hydrographs for 1936 and 1938. The extensive valley storage between Montague City and Holyoke causes a retardation of the peak and, in the case of the 1938 flood, an actual reduction in the peak discharge at Holyoke. There are no important tributaries in this reach. Below Holyoke, the Chicopee River with a drainage area of 724 square miles enters from the east, and below Springfield the Westfield River with a drainage area of 520 square miles enters from the west. These two tributaries usually cause a substantial increase in the peak discharge as reflected by the hydrograph at Thompsonville, Connecticut. The increase in drainage area between Holyoke and Thompsonville is 16.3 percent, yet in the 1936 flood the peak discharge was increased 24.3 percent. To produce severe flooding at Hartford it is usually necessary for a great storm or storm plus snow melt to cover the Chicopee-Westfield River Basins, supplemented, of course, by severe conditions upstream in the Deerfield, Millers, West, and Ashuelot River Basins.

11. PLAN FOR FLOOD CONTROL IN THE CONNECTICUT RIVER BASIN

Many methods of flood control have been advocated including the plan once presented to the Mississippi River Commission for constructing steam plants along the Ohio River to evaporate the flood waters. Numerous methods of flood control are being applied throughout the United States on the many basins. Every flood control plan is a custom job for the particular river basin or tributary river basin. Cutoffs and floodways applicable to meandering rivers in alluvial valleys are not applicable in this section. New England is well-covered with vegetation and soil is not subject to erosion, so that I need not commit myself on that controversial plan for flood control.

In each of the New England Basins reported upon by the Engineer Department all methods of flood control were considered. Methods applicable for the protection were thoroughly investigated. Almost without exception where flood control was found justifiable, reservoir regulation proved to be the best plan for general basin benefit. The topography and development of this section, however, limits the extent to which the flood runoff can be regulated. In several New England river basins sufficient regulation can be developed to reduce experienced flows to non-destructive discharges. The Connecticut and Thames River Basin plans illustrate the use of supplementary improvements. In the Connecticut River less than half of the flood flow can be regulated by tributary control, and the experienced flow has been three and four times the bank full discharge at important damage centers. Thus for protection of the principal damage centers on the Connecticut River, dikes are needed to augment the system of reservoirs. In the Thames basin the rock ledge across the mouth of the Shetucket River forms a bottleneck which would cause flooding of Norwich, Connecticut, even with controlled runoff. The channel enlargement at Norwich will be both an effective and permanent improvement in the Thames River Basin.

Flood control naturally involves the investigation of artificial obstructions, and there are many artificial obstructions to flood flows which increase flood stages varying distances upstream in New England. Bridges without adequate flood openings, and structures within the flood channel of the river in some cases have increased the flood damage to some extent. Many of the bridges have been replaced with properly designed openings and some of the buildings and dams have been removed. New England is improving the flood channels.

Contrary to general belief dam failures because of the relative small storage have not materially contributed to flood damages in New England and in the last twenty years there have been many dam failures in this section. In numerous instances the dams have failed before the crest of the flood and did not increase the subsequent flood crest downstream. When many of the run-of-the-river dams failed the tail water was high so that the failure did not result in a disastrous surge in the flow. Damage directly contributed to the failure of the dams on the New England rivers has been localized at the nearby downstream communities. In very few instances would damages at these localities have been substantially less if the dam had withstood. However, in construction within the flood channel a reasonable pre-

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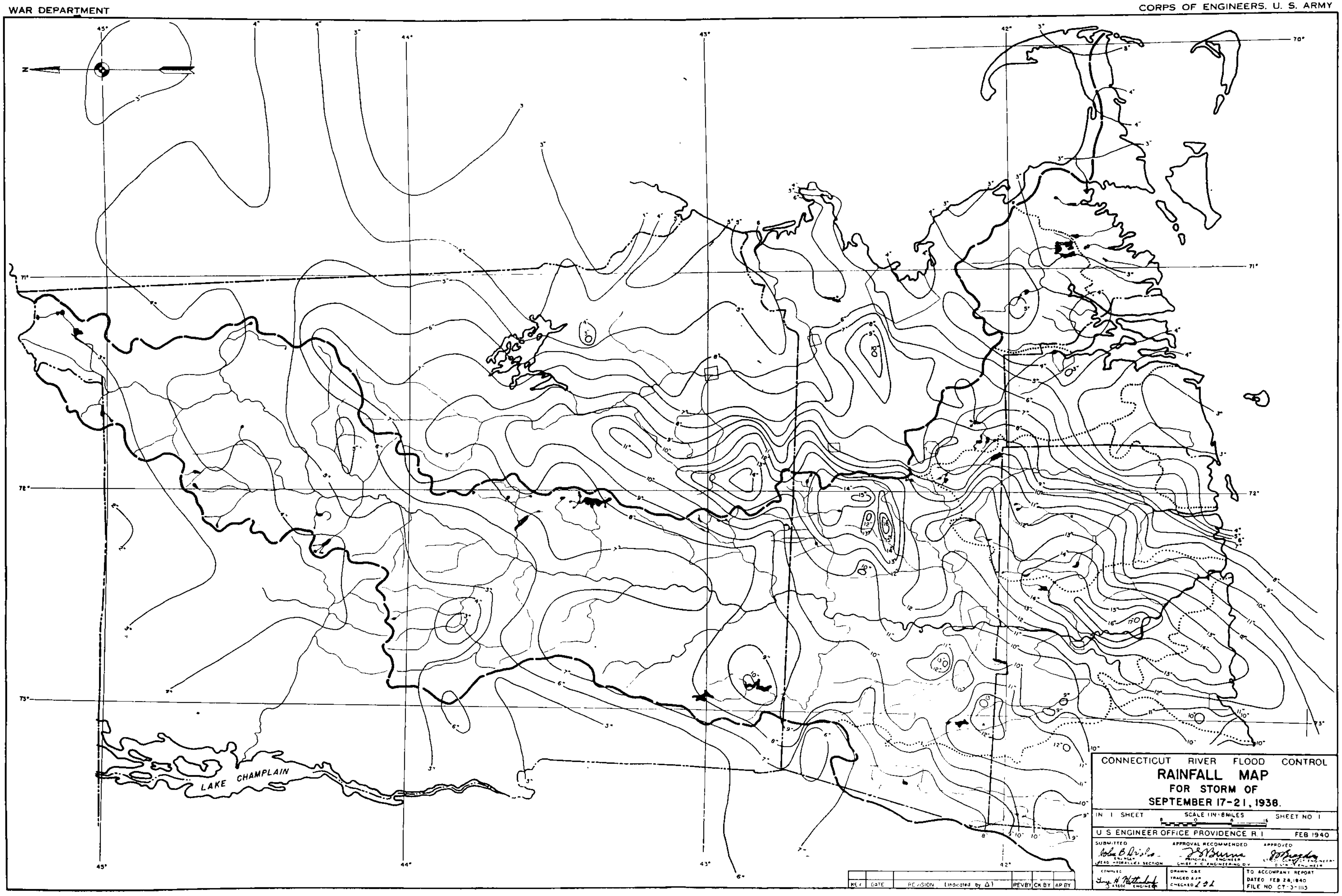

CONNECTICUT RIVER FLOOD CONTROL

RAINFALL MAP

FOR STORM OF

SEPTEMBER 17-21, 1938.

IN 1 SHEET

SCALE 1 IN = 8 MILES

SHEET NO 1

U S ENGINEER OFFICE PROVIDENCE R. I

FEB 1940

SUBMITTED
John B Drisko
ENGINEER
HEAD HYDRAULICS SECTION

APPROVAL RECOMMENDED
J S Burns
PRINCIPAL ENGINEER
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LT. COL. CORPS OF ENGINEERS
DISTRICT ENGINEER

COMPILED
ASSOC ENGINEER

DRAWN C&E
TRACED A J R
CHECKED L J L

TO ACCOMPANY REPORT
DATED FEB 28, 1940
FILE NO CT-3-1115

KEY	DATE	REVISION (indicated by Δ)	REV BY	CK BY	AP BY

PLATE 8

caution must be taken to protect the interest of others. The dam should be designed and constructed for the extraordinary high waters as well as the ordinary high waters. Spillways must be adequately designed. The Engineer Department spillway design criteria for flood control dams is a maximum possible inflow into the reservoir under the most unfavorable conditions.

Levees are a requirement for complete protection of damage centers at most places on the Connecticut River. Although the levees at the seven cities on the Connecticut River in Massachusetts and Connecticut were designed to augment the twenty reservoirs on the tributaries, it so happened that the project flood reduced by the reservoirs approximated the 1936 flood stage at these communities. As the Engineer Department foresaw that the construction of the reservoirs would be extended over a long period of years, the levee grade was established to give these damage centers a high degree of protection against floods equalling the magnitude of the flood of March 1936. The Hartford levee alone has additional height above the U. S. grade. Local protective works are less desirable than runoff regulation. Levees reduce valley storage and many constrict the flood channel. The dikes and pumping stations for internal drainage require a considerable amount of maintenance and operation. Protection against floods by levees inconveniences communities by the closing of openings for roads and railroads. Flood walls and levees must be protected against flood currents and drift. While reservoirs in reducing flood stages reduce the damage from all floods, levees are only effective against floods in which they are not overtopped. The overtopping of a levee results in greater damage to the locality than the gradual flooding with a rising stage of the river.

In planning flood control by reservoirs it is desirable from both cost and operation to minimize the number of units. Disregarding relative value of land or the improvements on the land and the relocation cost of roads and railroads, a natural basin upstream of a gorge is the most favorable location for a reservoir. Such a basin acts as a natural retarding basin so that the effective flood control capacity of the reservoir is less than the total capacity in reducing stream discharge. The incremental unit cost of storage decreases with the reservoir size of all projects which underdevelop the site. The land requirements per unit of storage also decrease with reservoir size. Multiple reservoirs on upstream tributaries control less drainage area and less runoff than a main river reservoir. Flood runoff is not uniform over a basin and varies with the storm pattern. Six inches of storage in individual tributary reservoirs is not the equivalent of six inches of storage for both watershed in a single main river reservoir. The nearer the reservoirs on the tributaries of the Connecticut River are to the main river the more effective the reservoirs can be operated for main stem flood reductions. Some degree of regulation can be economically developed on fifteen of the tributary rivers in the Connecticut Basin.

12. FLOOD CONTROL RESERVOIR

A flood control reservoir is a dry reservoir in which excessive flood runoff is temporarily impounded. In a dual purpose reservoir the storage capacity above a fixed elevation is similarly utilized exclusively for flood control purposes. The establishment of a recreation pool at a flood control dam using some capacity for permanent water storage converts the improvement to a dual purpose project. The reduction of flood control capacity one or two percent at many dams is advisable because of the desirability of promoting recreational facilities for the public on federal properties.

Large gated conduits are constructed through all flood control dams in New England. The conduits will pass the usual spring runoff without impounding water back of the dam. Very little head on the outlet gates will discharge a flow in excess of the bank full capacity of the stream below at dam. Full gate opening at the maximum pool stage would produce a destructive flood at downstream damage centers of the stream. The gates of a flood control dam are normally opened. The gates are partially or completely closed to reduce flows or flood heights at damage centers to non-destructive stages. The release of impounded water is regulated to safe downstream channel capacity and runoff from unregulated drainage areas. Flood control storage capacity is used exclusively for the regulation of the runoff to protect life and property. The capacity of the stream at damage centers governs the rate of emptying a reservoir not the size of gates or conduit.

The capacity of most of the reservoirs proposed in the Providence District equals approximately or slightly exceeds experienced flood runoff of the stream. All have sufficient capacity to retain all runoff prior to the cresting at damage centers or runoff from uncontrolled areas. For all experienced flood volumes it will not be necessary to pass the inflow through a full reservoir until the uncontrolled flood has passed the damage centers. The subsequent combined discharge of continuing runoff from unregulated areas and dam release will be very materially less than the peak discharge from the uncontrolled areas.

13. CONCLUSIONS.

I have purposely made no reference to flood frequency or probability. Determinations have been made for calculating the ratio of benefits of protection to cost of improvement and for design criteria. The periods between floods have been too irregular to predict the year of the next flood. The performance of the Connecticut River in the last twenty years was far different than its prior three hundred year record would have caused one to anticipate in 1926. I am not predicting when the next flood will be, nor the number of floods that will occur in the next twenty years. Neither am I predicting that the 1936 flood will be exceeded, but I do state that it can happen.

There is a serious flood problem in New England. More serious because of the infrequency and irregularity of destructive floods. New England cannot now afford to evacuate the flood plains which are only infrequently inundated, but any development on these flood plains requires security. The floods for the last twenty years have made people aware of the danger of floods. The Engineers, however, recognize these floods as a natural consequence of the common paths of the continental storms and the occasional path of the tropical hurricanes across New England, and the favorable topography for heavy storm precipitation and flashy runoff. There will be more floods in New England.

New England can have flood protection. Even at this late date in the development of these oldest states of the nation, a large part of the watershed of the main rivers can be controlled by reservoirs at an economically justifiable cost and the Federal Government will foot the bill. But the program will call for some sacrifice on the part of some New Englanders for the general good. There are people living in these reservoirs, most of them have lived there all their lives, some on the lands that have been in the family for generations. The acquisition of these reservoirs and utilization for flood control purposes will be a financial hardship on the towns wherein they are located. I feel that there is equity in their request for reimbursement of tax losses. The problem of flood control in New England is an understanding of the people in the upstream sections and the downstream damage centers of one another's problems and a compromise solution for the benefit of all. General Sanford H. Wadhams, Chairman of the Flood Control and Water Policy Commission of the State of Connecticut, Mr. William H. Putnam, of the Hartford Flood Control Committee, and the Honorable William L. Hadden, the Attorney General, are the Connecticut members of the New England Flood Control Committee which is considering this feature of flood control. They are well informed of the flood problem in Connecticut and the need for interstate accord for a successful flood control plan. Mr. Richard Martin, Director of the Flood Control and Water Policy Commission of Connecticut has made a very thorough study of the Connecticut flood problems and has been most helpful in assisting the Providence Office in matters pertaining to the State.

DISCUSSION

MR. WISE: You mention in your paper use of unit hydrographs for flood control work. A great deal has been written about the use of them. I would like to ask if, in the design of flood control reservoirs in New England, the unit hydrograph method is used, and to what extent they influence the design of flood control reservoirs.

COLONEL KERN: The unit hydrograph method is used exclusively for the design of spillway capacity. It is based on a hydrograph that is determined from runoffs of observed and recorded floods of the stream. Does that answer your question?

MR. WISE: Are they used to any great extent in the studies leading up to the design of the flood control reservoirs in New England?

COLONEL KERN: The capacity of the flood control reservoirs is based on observed or experienced runoffs, and the unit hydrograph studies for the establishment of spillway design criteria.

MR. ROBERT ROSE: I would like to ask the Colonel what part the denudation of forests have had in the effect of the storms and the floods in the Connecticut River Valley.

COLONEL KERN: The question of the effect of vegetation, I think, varies a great deal on the type of the soil. I do not think that reforestation in the Connecticut River basin will effect the Flood runoff. This is not a denuded area.

CHAIRMAN HENDERSON: Any further questions?

MR. ROSS: I would like to ask the Colonel if he is as modest in the statement of the likelihood of floods as was the speaker who we had here from one of the Federal agencies from Washington, and even though he was from Washington, a great deal of weight was put upon what he said. (Laughter) The question was asked in a lecture which he gave following the 1936 flood: When are we likely to have a flood equal to this one again? And he said, "From the best that I can figure, I would say about a thousand years."

The fact is that following the 1936 flood in Hartford, the Flood Commission was appointed and they got going, but, as I say, this statement was made and used as an argument against it to some extent. I think if we had not had the 1938 flood when we did, we might not have the fine protection against floods that we have here today, because having had that one within two years of the other, the Doubting Thomases were squelched and the protection was provided. I think the 1938 flood was a blessing in disguise as far as Hartford goes.