NEW ENGLAND FLOODS AND THE SOCIETY'S FLOOD REPORTS

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THE New England flood history is interesting because in the last 35 years since 1927 (except in Maine) there were floods in excess of any preceding records which extend over many years. The latest flood in 1955 was in some ways the greatest of all. This period experienced four large floods—The Vermont flood of 1927, the great flood of 1936, the hurricane flood of 1938, and the recent 1955 flood.

This period is also interesting in that it was accompanied by great progress in the engineering of flood analysis which had started after the 1913 flood in Ohio. Since 1936 the period is also noted for the great flood control programs which have been undertaken by the federal government and various state and local communities.

We are fortunate here in having data from flood records, some of these going very far back, such as the gage heights of the Connecticut River at Hartford, which gives records of large floods for over 250 years. Other flood histories in Connecticut go back to 1634.

FLOODS PRIOR TO 1927

Prior to the great 1936 flood, the largest one of record on the Connecticut River was in 1854 with a flow at Hartford estimated at 184,000 cubic feet per second (c.f.s.). The 1927 flood was probably a record peak at Sunderland, Mass., but at Hartford it was not quite as great as the 1854 flood. As will be seen later, these floods in the large rivers were all very much less than the great flood of 1936. "Great" floods occurred in 1639 and 1642. A flood in central Connecticut around Waterbury occurred in 1691. It was probably higher than the recent 1938 flood in western Connecticut.

On the Merrimack River there was a large flood in 1785 which is referred to in some places as being the largest on record up to 1936.

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However, it cannot have been very different from the flood of 1852, which had a peak of 108,000 c.f.s. at Lawrence. This was very much less than the great flood of 1936 on the Merrimack. The 1927 flood was not a large one.

On the large rivers in Maine, the flood on the Penobscot in April 1923 is the largest flood of record. This was a major with a peak of 153,000 c.f.s. at Bangor (drainage area 6600 sq. mi.), which has not since been exceeded. Prior to 1936 this was the outstanding of any of the large New England floods. On the Kennebec River the 1901 flood was slightly larger than the 1936 flood. The recent large floods have not been excessive northeast of New Hampshire.

Here in the eastern part of New England there was a large flood in Waltham in a limited area in 1860. A flood that has been used a great deal as an example was the 1886 flood in Boston, the so-called "Stony Brook" flood, which caused a great deal of damage.

There are some incidents which are of interest in connection with these earlier floods which may be worth repeating. In 1850 James B. Francis, the engineer at Lowell, built at one of the critical spots at the head of the original navigation canal, a large drop gate 27 by 25 feet of 18 inch timber to provide a barrier to be used in a great floods. Figure 1. This was called by the inhabitants in Lowell "Francis's Folly" because no one could believe that water would be high enough to require lowering this gate. Francis really was pretty lucky because two years after the gate was installed it had to be lowered during the flood of 1852. It was not lowered again until 1936.

In March 1913, considering the duration, the rainfall intensity, and area covered, occurred what probably was one of the greatest storms ever experienced in the East. This caused the great flood on the Ohio with the disaster on the Miami River at Dayton. New England was outside the center of that flood, but it was a fairly large flood on the Connecticut River, the highest since 1869. The dam of the Connecticut River Power Company at Vernon had just been built. Construction of the redevelopment at Turners Falls, twenty miles below was under way. The eastern abutment of the Vernon dam was on a projection of land, not on ledge, against which the river washed as it curved around below the dam. This spit of land was considerably higher than the abutment of the dam. At Turners Falls it was rumored that the river was washing this land and that there was danger of a channel cutting through so that the river could bypass the dam on the

FIGURE 1.—PAWTUCKET CANAL HEADGATES AT LOWELL, MASS., 1956, SHOWING THE "FRANCES GATE" CLOSED AND ADDITIONAL FLASHBOARD PROTECTION.

east side. This was considered important enough so that men were sent up, who stayed continuously on the job for enough days to be sure that the place was stable. There was some washing. Later the area was protected with riprap. It was during this flood that a Springfield paper came out with the reassuring statement that the dam at Vernon was "bulging but still holding."

THE 1927 VERMONT FLOOD

Then came the 1927 Vermont flood. This was the first of our recent large New England floods. It was caused by a tropical storm from the South. The center of the storm moved up through Vermont in a northerly direction. It lasted from Nov. 2 to Nov. 5, but most of the rainfall came in the two days—the 3rd and 4th. The greatest recorded precipitation for this storm occurred in Vermont, with a maximum of 9.65 inches at Somerset. It is probable, however, that as much as 11 or 12 inches fell in the higher portions of the Green Mountains. A secondary storm area adjacent to Rhode Island also showed nearly as great a maximum—9.37 inches at Westerly, R.I. Over the whole State of Vermont (about 9600 square miles in area), the average rainfall was about 6.0 inches. The rainfall during October had been twice the normal so that the ground was saturated and the streams and ponds full.

The intensity of the storm and the steep slopes of the Vermont topography caused very rapid run-off. Entire river valleys were flooded. The rivers rose rapidly. The average rate of rise on the Winooski at Montpelier Junction was 2.07 feet per hour, on the Westfield the rate of maximum hourly rise was 2.60 feet. It was said that at Waterbury and Bolton, Vermont, a rise occurred of 3 to 4 feet per hour or about a foot every fifteen minutes. Some very high discharge records were noted on the smaller rivers; for example, the White River in Vermont reached a peak flow of 120,000 c.f.s., or 174 c.f.s. per square mile on a drainage area of 690 square miles, which compares with some of the high peak flows of the 1955 flood. There was a great deal of damage. A total of 84 lives were lost. There was no failure of any dam of importance on any of the main rivers, though six smaller dams failed and 68 were damaged. The total damages amounted to about $40,000,000, two thirds of which was in Vermont.

The bulk of this flood was on Vermont rivers. The floods in Massachusetts and Connecticut were not so great, but the flow down the Connecticut River from Vermont was of sufficient magnitude so that the flood at Sunderland probably exceeded the peak of the maximum record flood of 1854.

The Great Flood of 1936

The 1936 flood was different from the 1927 flood and the subsequent recent large floods of New England in that it was due to several storms that lasted several days, and included a good deal of melting snow. This affected the larger rivers generally, more than the smaller streams, though in a great many places these also established record flows. During the period March 9 to 22, 1936, four distinct storm centers passed over the northeastern part of the United States. The first disturbance, that of March 9 and 10, was accompanied by snow in northern New England. On March 10, a gulf disturbance from the Georgia coast moved northeastward with increasing intensity.

Another storm caused more precipitation of snow on March 11 and 12. On the 17th and 18th another storm pressure moved from the Gulf states, causing heavy precipitation over the whole area. Although this centered in the White Mountain area, it reached very considerable magnitude over most of central New England. On the 20th, 21st and 22nd, another small disturbance crossed the area, accompanied by minor rainfalls. Added to the heavy precipitation recorded for these storms, the first heavy rain fell on a snow cover that had a water content of 4 to 10 inches or more in most of Massachusetts, Vermont, New Hampshire and Maine. The total area covered was 66,000 square miles, with more than 6 inches of rain to which, of course, was added the melting snow.

Except in Maine this flood caused maximum flows on the bigger rivers. On the Merrimack it was necessary to protect with sand bags the abutments of the dams at Manchester and down stream. The Francis gate at Lowell was lowered and the judgment of the engineers who had raised the walls at this point by 2½ feet after the 1927 flood was justified as they were of sufficient height. It was necessary to block up the railroad entering Lowell. The direct and indirect damages amounted to $101,000,000 and 11 lives were lost.

Since the 1927 flood there had been constructed three flood reservoirs on the Winooski in Vermont. The large Federal flood control program started with the flood control act of June 1936 and much other flood work was done after this flood. A repetition of the large flood of 1936 on our main rivers will not cause the disaster which occurred then on account of the large flood controlwork now done and proposed.

The Hurricane Flood September, 1938

This was caused by extremely heavy hurricane rainfall. A tropical hurricane moving northward from the Atlantic Coast veered inland from the ocean on the afternoon of September 21, crossed the coast into Connecticut and Massachusetts, and gradually diminishing, went over Green Mountains in central Vermont and passed into Canada. New England had been experiencing heavy rainfall on September 18, to 20th, when the rain just preceding the hurricane brought the total rainfall during the four-day period to an average of more than 11.5 inches over an area of 10,000 square miles. The major storm period essentially embraces the rain that fell on September 17 to 21st. In a very considerable part of Connecticut and central Massachusetts the total storm precipitation in this period exceeded 16 inches, and maxima of more than 17 inches were recorded in central Massachusetts and Connecticut. At Barre, Mass., 11.83 inches was recorded during one 24-hour period, at that time a maximum for record in New England.

This storm produced record floods on small rivers in Massachusetts and Connecticut, exceeding by 50% to 100% the highest flows previously recorded. On drainage areas of less than 50 sq. mi. flows of 500 c.f.s. per square mile were observed. On the Hockanum River in Connecticut the flood run-off was 9.9 inches. On the eastern tributaries of the Connecticut entire river valleys were devastated. Though the flows in the upper Connecticut were minor, the great inflow from the southern area caused the second highest flood at Hartford, 251,000 c.f.s., compared to 313,000 c.f.s. in 1936. This storm did a great deal of damage. Twelve lives were lost and the total direct and indirect flood losses were $69,400,000.

The 1955 Floods

This storm was caused by the Hurricane Diane of August 17-20. This had been preceded by Hurricane Connie from August 11-16 and was followed by another one on October 13 to 17. The first hurricane had saturated the ground so that when the big storm came the great floods were produced. Figure 2 shows the course of Hurricane Diane. It is interesting to note that it moved parallel to the southern shore of Long Island, and thus went from west to east, whereas most of our other storms have moved from south to north. The characteristic of the 1955 storm was the extreme intensity of the storm rainfall. Many of the stations in Massachusetts, Connecticut, registered 12″ or more in a two-day period, with a maximum of 19.75″ in Westfield, 18.15″ of which fell in 24 hours. Rainfall of 3.2″ in an hour was recorded in Mendon, Mass., and 5.2″ in two hours. Figure 3 shows some typical Connecticut rainfall charts. They show that most of the rainfall came in a period of a little over 24 hours.

Record floods on the smaller rivers in Massachusetts and Connecticut were thus caused. Of the two large rivers, the Merrimack had practically no flood at all. On the Connecticut, the peak flow at Hartford was the third highest on record, although the flood was all produced in the lower third of the drainage area. Figure 4 shows

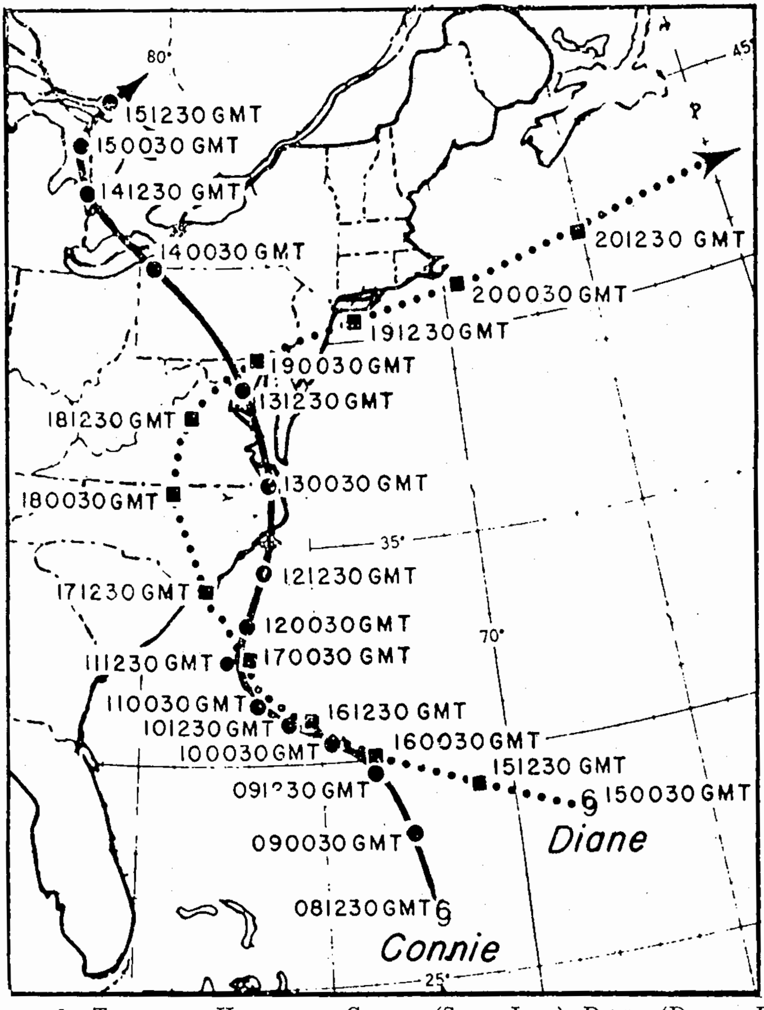

FIGURE 2.—TRACKS OF HURRICANES CONNIE (SOLID LINE) DIANE (DOTTED LINE) WITH 12-HOUR POSITIONS INDICATED, AUGUST 1955. (From W. T. Chapman and Y. T. Sloan, "The Paths of Hurricanes Connie and Diane." Monthly Weather Review, Vol. 83, No. 8, Aug. 1955, p. 171.)

hydrographs of the recent floods at Thompsonville, Conn. which shows clearly the effect of the small drainage area contributing in 1955. Very high flood peaks were reached on rivers with drainage areas less than 350 square miles. Maximum examples are as follows: On

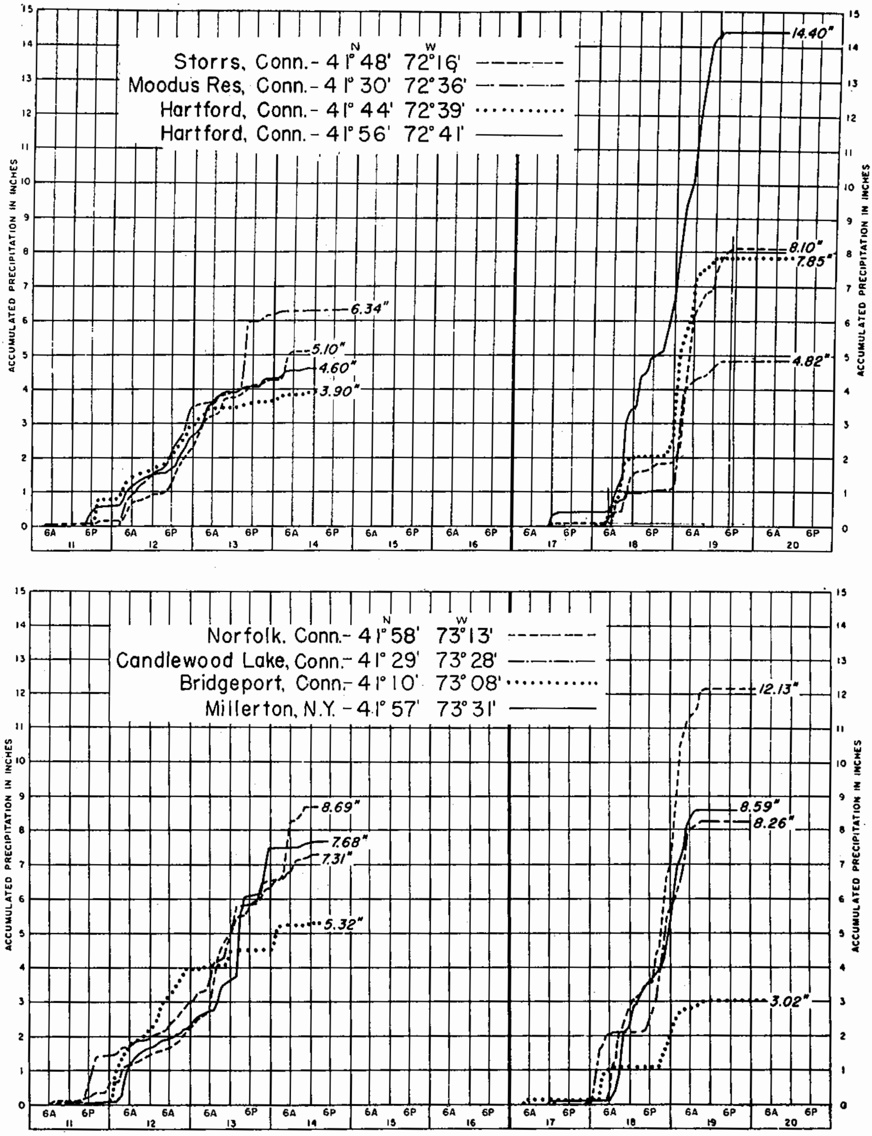

FIGURE 3.—MASS. RAINFALL CURVES AUGUST 11-16 AND 17-20, 1961. (From Weather Bureau Technical Paper No. 26, Hurricane Rains and Floods of August 1955, Carolinas to New England.)

the Naugatuck River in Connecticut, 71.9 square miles, 579 c.f.s. per sq. mi., and 246 sq. mi., 431 c.f.s. per sq. mi. Still River, Connecticut, 84.4 sq. mi., 521 c.f.s. per sq. mi. It is interesting to note what some of the higher peak flows mean in terms of the flood formulas now in use. In Massachusetts, where it is customary to rate floods by the Kinnison-Colby formula, some peak flows reached 84-88% of the "rare" flood, rated as having a frequency of 1,000 years. In Connecticut, the Bigwood-Thomas average curve shows seven times the mean annual flood as having a recurrence interval of about 323 years. Some of the largest records gave peak flows of over 12-15 times the mean annual flood.

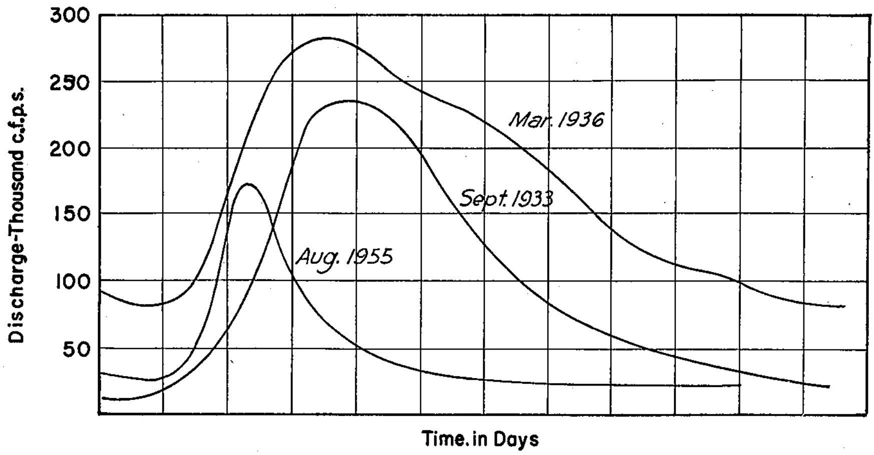

FIGURE 4.—HYDROGRAPHS OF FLOODS AT THOMPSONVILLE, CONN.

Some of the flood run-off figures were also very large: the Quinebaug River at Westville, Mass. 10 in., the Naugatuck River near Naugatuck 11.1 in., and the West Branch of the Farmington River 11.5 in.

No major dams were injured but there were a great many smaller dams which were damaged by various washouts and failures, mostly due to inadequate spillway capacity. The Corps of Engineers' figures are listed showing six dams damaged in Rhode Island, 35 in Connecticut and 165 in Massachusetts. The total damage in the August flood is listed as $531,000,000.

The August 1955 flood was followed by another flood in Connecticut in October which covered part of the previous flooded area and did $50,000,000 worth of damage. The August flood caused the loss of 90 lives and the October flood 17 lives.

The Corps of Engineers' initial reports, published in 1957, the preliminary reports of the Weather Bureau and the U. S. Geological Survey, and the Geological Survey's final report cover the history and data of this flood in great detail.

Since the 1955 floods there has been, of course, much work done so that another 1955 flood will not cause nearly the amount of damage.

Flood Summary

The recent flood history of New England is summarized in Figure 5 which shows the large flood heights of the Connecticut River at

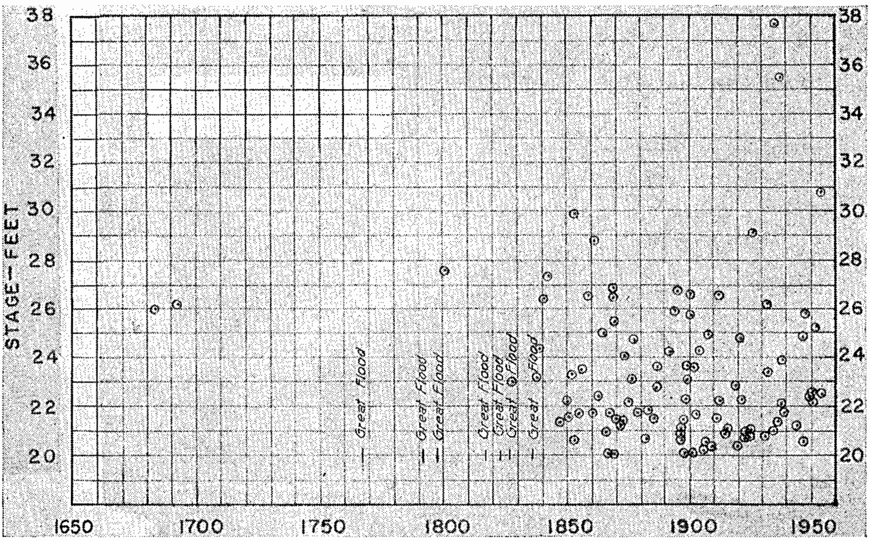

FIGURE 5.—FLOOD CREST STAGES—CONNECTICUT RIVER AT HARTFORD, CONN.

Hartford back to 1680. The comparative size of the floods since 1927 is clear. Figure 6 shows the areas covered by the 1927, 1938 and 1955 storms in New England. 1936 is not included because of its long duration. It shows that Maine has not been subject to the great floods experienced in the rest of the area. Figure 7 shows the comparative rainfall area depth data of large New England storms. This is taken from the Society's 1942 report with the August 1955 storm added.

FIGURE 6.—MAP SHOWING AREAS HAVING MORE THAN 7 INCHES OF RAIN FOR STORMS OF 1927, 1938, AND 1955.

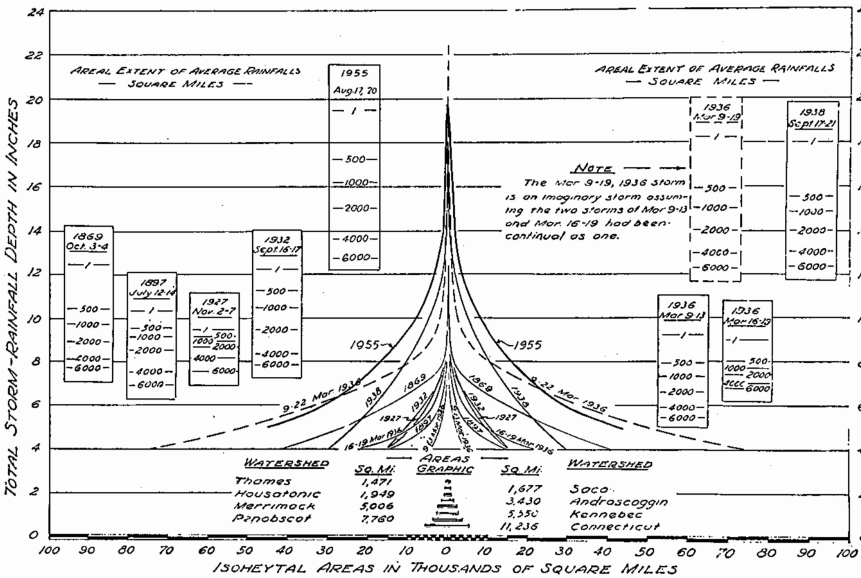

FIGURE 7.—DISTRIBUTION OF STORM RAINFALLS.

It is interesting to show the 1932 storm rainfall which produced no large floods at all as the ground was dry. Figure 8 shows various peak discharges during these floods.

FLOOD ENGINEERING

Before taking up the Society's flood reports, it is interesting to go back briefly over the history of flood analysis. Prior to the 1913 flood, there was little of flood analysis as it is now known. There were formulas used for storm sewers and culverts and some for rivers but not much real river analysis. On the larger rivers, like the Connecticut and the Merrimack, records showing past floods were used. The 1854 flood on the Connecticut, and the 1852 flood on the Merrimack, were taken as the measure of the flood capacity required for dam spillways with, of course, large freeboards which gave factors of safety.

The great 1913 flood gave a great impetus to flood study, particularly the Miami River Conservance work. It is interesting to review the state of the art when these reports were made. Some of the conclusions are now interesting in view of our modern analyses. Considering flood frequency which modern analysis has covered in

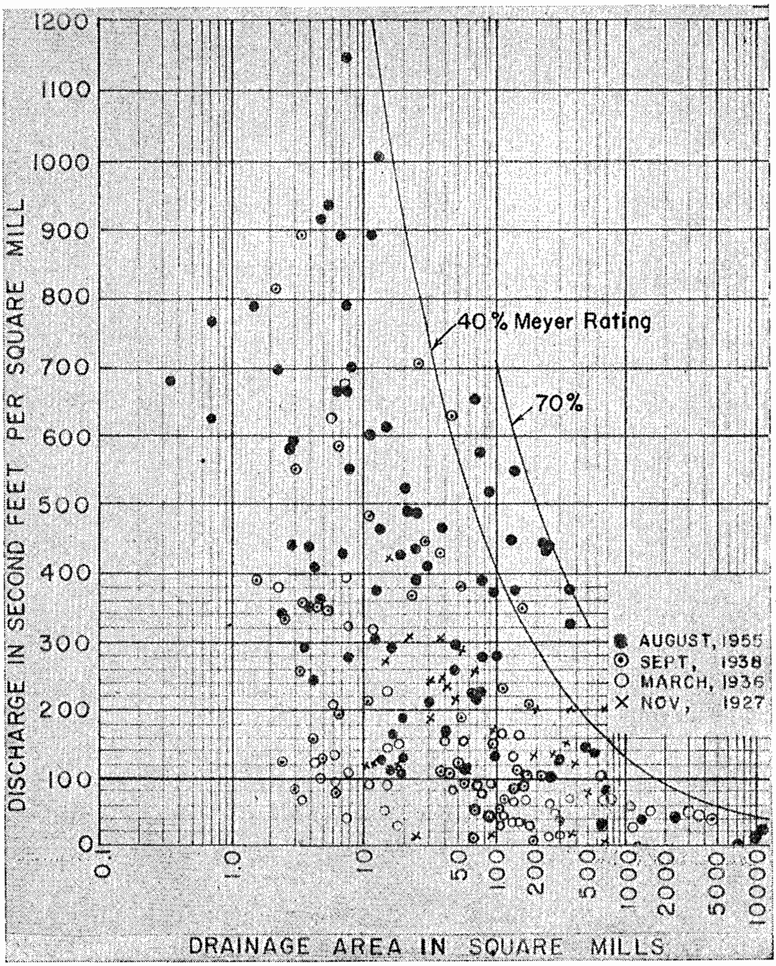

FIGURE 8.—PEAK FLOWS OF NEW ENGLAND STREAMS.

such detail, the Miami study used two plotting analyses, one method giving a frequency of 318 years to the 1913 storm and the other 3000 years. These they discarded. They made studies of various long-time records in Europe, and found that "there is no evidence that would lead to the conclusion that the greatest possible flood discharge could be appreciably more than 20% in excess of the 1913 flood." For their maximum flood they used nearly 40% larger for the design of their flood works. Present conclusions regarding flood frequency and even more so of our present ideas regarding maximum possible floods are much larger.

Two important papers followed,—Weston E. Fuller's "Flood Flows," in the A.S.C.E. transactions of 1914. His formula took into account elements now used,—the drainage area, A, the stream characteristic expressed as a coefficient, C, determined by past floods for each station, and the recurrence interval, T, i.e., the frequency. It is interesting to note that he considered frequencies up to 1000 years. In the discussion of this paper, Maj. C. E. Pillsbury applied the normal law of error, i.e., the probability, to flood flows, and Fuller pointed that the curve would not be the normal probability but a skew curve. Allen Hazen in his discussion refers to his studies and his development of probability paper described in his later paper of the same year on "Storage to be Provided in Impounding Reservoirs." After this date there is a great deal more flood engineering as shown by the steadily increasing flood literature.

The 1930 Flood Report

The Geological Survey published Water Supply Paper No. 636c describing the floods of November 1927, giving rainfall figures, both daily and hourly where available, descriptions and pictures of the flood and data as to the peak flows on the various rivers.

The Society's 1930 Flood Committee Report gave certain data not included in the U. S. Geological Survey report. These included, among other things, the total runoff of certain streams and tables of flood profiles of the various rivers. Flood damage figures were given of various river basins and sub-divided among various items.

The chief contribution which this report made was in its study of the floods for the development of a flood formula for New England. This formula was based on the study of the flood hydrograph and in this chapter the Committee showed: "that a flood hydrograph once determined for a given river even for an ordinary flood will serve as a basis of the estimates of greater flood runoff due to the fact that the base of the flood hydrograph (or time of flood period) appears to be approximately constant for different floods." Figure 9. This use of the flood hydrograph served as the basis for the whole modern analysis of flood flows through the unit hydrograph.

Based on this, the report gave flood characteristic curves developed for stations on various rivers. These curves put the flood hydrographs on a unit basis for one inch of run-off and one square mile of drainage area. This, in a way, anticipated the unit hydrograph now extensively used, except that it used a unit drainage area basis. The

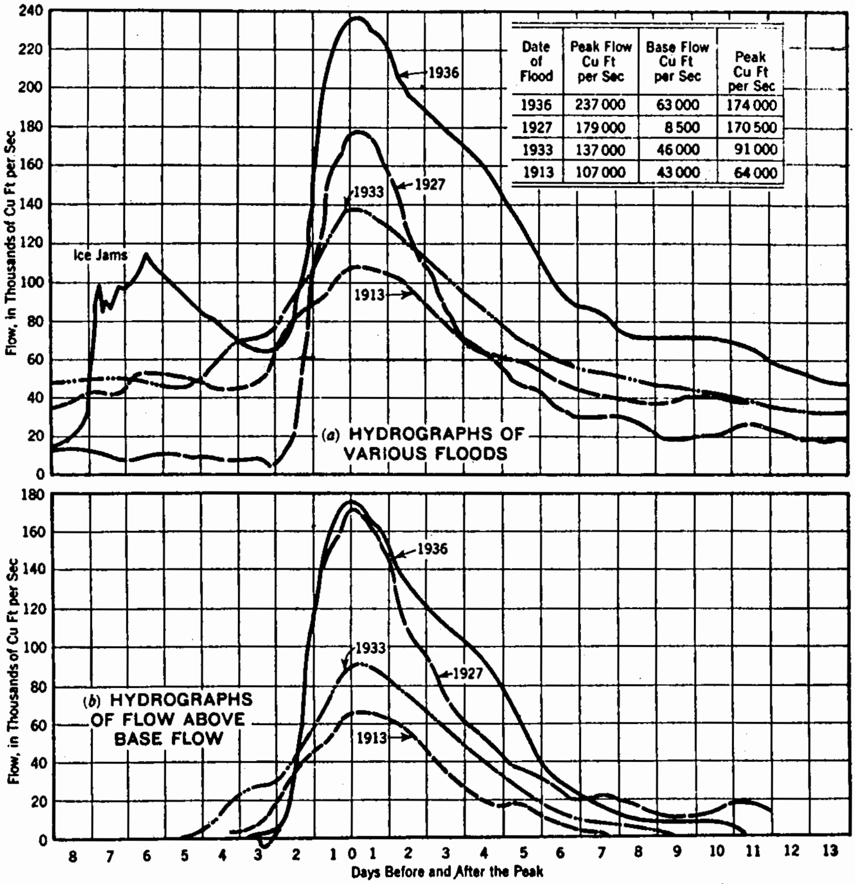

FIGURE 9.—FLOOD HYDROGRAPHS, CONNECTICUT AT SUNDERLAND, MASS. (1936, Montague City).

Committee recommended that floods should be classified in inches of total run-off. The peak discharge for any flood run-off would be then determined by means of the flood characteristic curve.

The report reached some conclusions regarding flood frequency though not by any plotting or computation of the probabily from existing flood records. The conclusion for New England rivers with drainage areas of 10 to 1000 sq. mi. was summarized as follows:

1. "An occasional flood run-off, R, of three inches within the concentration period is to be expected. . . . Information is too limited to definitely state the frequency but in general it appears that such a flood should be looked for with a frequency of between 25 and 75 years, or, say, once in 50 years.

2. "A rare flood run-off, R, of six inches within the concentration period is to be expected. . . . The frequency of such floods is probably somewhere between 50 and 200 years.

3. "The maximum flood run-off, R, is probably not over 8 inches.

4. "From the flood history of New England it appears that storms producing heavy run-off are likely to occur with greater frequency in those regions having a high annual rainfall than in those territories with a low annual rainfall. However, the information available is not sufficient to determine whether there is any direct relation which can be formulated."

It is interesting to compare these with some recent studies. The Kinnison-Colby formula, for example, gives the following averages: a "minor" flood, once in 15 years, 3.6 inches, instead of the 1930 report's, 3″ in 50 years; a "major" flood, once in 100 years, 6.1 inches which compares to the 1930 report run-off of 6 in. with a frequency of between 50 and 200 years; a "rare" flood, 1000 years, 8.9 inches compared to the 1930 report of a maximum "probably not over 8 in." The Kinnison-Colby formulas did not give any maximum run-off figures but their maximum possible peak flows are given as over three times the rare flood.

These figures, as were most all of the figures prior to the latest floods, were thus lower than modern results, particularly if it is assumed that the maximum possible flood should be used in any flood computations.

The 1930 report gave a description of the flood characteristics of various New England streams. This included a very vivid, brief description of the geology of New England written by the late Professor J. W. Goldthwaite of Dartmouth College.

1942 Flood Report

The United States Geological Survey Water-Supply papers covered in detail the data of the 1936 and 1938 floods. The Society's

1942 Report covered these two floods: the Great Flood of March, 1936 and the later Hurricane Flood of September, 1938. The former, which included melting snow, affected generally the large rivers more than the smaller areas. The intensity of the latter, however, affected the smaller rivers. The report covered general descriptions of the floods, storm, rainfall data and maps and flood run-off data, flood run-off analysis, a chapter on flood losses and economics, and a description of the flood control program.

In the study of storm rainfall there was considerable space given to the maximum possible precipitation which had been treated in a Weather Bureau publication, the first of its kind, published in 1940, in the "Maximum Possible Precipitation Over the Ompompanoosuc Basin" in Vermont. The conclusion is given that total precipitation rates could have been from "15% to 30% larger than in the large floods which have been recently experienced." This chapter also covered a considerable discussion of snow melt which added to the 1936 flood. In the section of flood run-off, there was a study such as has been recently made of the effect of storage reservoirs on the flood run-off.

There had been a great deal of work done on flood run-off analysis since the Society's 1930 Flood Report which developed the B.S.C.E. flood formula. In 1932, the unit graph method had been described by L. K. Sherman and the unit hydrograph derived for a given point on a stream became the standard hydrograph used in flood control analyses.

The section on spillway design floods is interesting as it gave a discussion of the use of maximum possible storms as a measure for spillway designs. "With the use of maximum possible storm rainfall, assuming a high percentage of run-off and also melting snow, it is possible to estimate very high peak discharges for spillway design floods. If there are added freeboard for wave action and frost on earth abutments, there is perhaps a tendency to reach a size of spillway that may be prohibitive in cost for any but the very largest structures paid for by public funds. While it is certainly advisable to know the absolute limit which nature may reach, there may be a question in many structures whether such safety is necessary or advisable. Some of the maximum peak floods, reached by this type of analysis, are of such a quantity that there would be a few structures left in the whole river valley were they ever attained, and the failure of a river dam would add but little to the total destruction which would be caused. Like many other engineering problems, the exact figure to use for the design of a given struction will depend on its importance and cost and on the effect of its failure. Important structures for storage reservoirs, impounding very large bodies of water, require a high degree of safety, whereas other structures perhaps on the same river, impounding smaller amounts of water, may not justify anywhere near such extreme values."

The report devoted considerable space to flood frequency study which had been developed since the 1930 Report. It also gave various plottings to determine the frequency of the 1936 flood but was unable to reach any satisfactory result in plotting the extended frequency curves, as for example one case, the Connecticut River before and after the 1936 flood, this conclusion was reached: "Any method of figuring, where a 98-year record shows that a given flood would have had a frequency of very many thousands of years or even would never have occurred, and a record of three years later, 101 years, shows a frequency of once in two hundred and sixty-five years, hardly seems worth the effort involved in the computation." Since the 1930 flood report there had been much work done on the frequency analysis of hydrological data. The frequency of the Connecticut River and the Merrimack River floods were also studied by this method with very varying results. The final conclusion was: "It seems to this Committee that the ordinary river has a normal flood regime, reaching normal maximum of a flood which may be expected perhaps once or twice a century, and that then due to very exceptional conditions there may come a very large flood that has a frequency of several hundred to a thousand or more years. While the frequency figures of the flood regime of a river with a 100-year record may be assembled and plotted for the ordinary floods, up to say that flood expected to be equalled or exceeded once or twice in a century, the attempt to put a frequency beyond that on these very rare floods gives such varying results that it is hardly worth the attempt.

"The use of flood frequency figures also appears to be limited in scope. There seems to be no reason whatever why the frequency should be used in determining the size of flood for which the spillway of a dam should be designed. The capacity of a dam spillway is much better determined by many other factors."

"The use of frequency figures comes down chiefly to the single question of economics on flood control projects as, for example, how much money it is advisable to spend compared to the corresponding benefits." The report stated that actually the 1936 flood on the Connecticut was believed to be the largest in 300 years and that it was satisfied to say that it was a major flood with a frequency of several hundred up to perhaps a thousand years. All this does not greatly differ from the conclusion of the 1961 report.

A chapter on flood control programs summarized the work done on the flood control reservoirs on the Merrimack and Connecticut River basins both by the federal and state governments. Perhaps one of the most interesting of these was the local work done on the Nashua River in Fitchburg as described below: The flood control project on the North Branch of the Nashua River in Fitchburg, Massachusetts, was built after the 1936 flood and finished before the 1938 flood. The former flood had a magnitude of about 11,500 c.f.s. through the city. It caused damages estimated at $2,700,000. Extensive channel improvements were undertaken with Emergency Relief funds, and completed in January, 1938. The September, 1938 flood had a maximum peak of 8,500 c.f.s. at Fitchburg. No flood damages occurred in the city. It is estimated that the channel improvements prevented over $1,500,000 flood damages in the 1938 flood.

As to the desirability of the flood control program as a whole the Committee reached this conclusion:

"As to whether the actual savings which may be experienced are sufficient to justify the large cost of the program, there is a divided opinion among the Committee. There is no division of opinion about the improvement attained whether the cost can be justified or not. The work was begun at a time when large expenditures on public works programs were undertaken for employment purposes. The benefit from this work is certainly as great as or greater than that from many other projects of the public works programs."

The report closed with a description of various flood forecasting systems in use. It reached the conclusion that there was no need of a new organization for gathering flood data and disseminating warnings in New England, and did not favor the elaborate and expensive set-ups sponsored by state and federal bureaus such as were then operating in Pennsylvania. This was summed up as follows:

"The facilities now existing, though varying considerably in different states, are adequate if properly handled and extended to take care of some of the outlying areas on the smaller streams. Every effort should be made to keep the existing organizations on the alert and ready to function at all times."

The 1961 Flood Report

The recent report covering the 1955 flood gives very little factual data. This was given in various publications by the U.S. Corps of Engineers, the Weather Bureau and the Geological Survey. The Society's report is rather a summary and review of the floods and discussion of the latest flood engineering and its application to the 1955 floods and to local conditions. Various chapters have been selected for comment.

Chapter III of the report is devoted to the effect of reservoirs and flood protection works. When it is considered that there was a great deal of flood control works, reservoirs and channel improvements in existence during the time of this flood, it is interesting to speculate on how much worse it would have been if these works had not existed. On six Federal flood control reservoirs in the flooded area the total of the in-flow peak in the August flood was 38,800 c.f.s. and the total of the maximum out-flow peaks was 10,250 c.f.s.—a reduction of 18,550 c.f.s. The effective reduction was much greater than this as the out-flow peaks were several days later than other flood peaks, and thus came at a time when the main flood peaks on other streams had passed. Figure 10 shows a graph of the operation of the Knightsville Reservoir on the Westfield River. This shows the great reduction and also the delay in the out-flow, which was entirely shut off until over two and a half days after the flood in-flow peak.

In addition to the government flood control works the effect of the many private reservoirs also served to reduce the flood peaks. For example, Shepaug Reservoir on the Housatonic reduced the estimated out-flow peak of 95,000 c.f.s. to 65,000 c.f.s. In addition to this, the many local protection works saved a great deal of damage. The report lists a total benefit in the saving of damages on the Connecticut River basin of $6,480,000 by reservoirs and $21,780,000 by protection works, or a total of over $28,000,000 in the August flood and a total of $5,040,000 in the October flood; on the Thames River a total of $4,300,000 in the August flood and $250,000 in the October flood. Practically none of these works were effective in the floods covered by the previous reports.

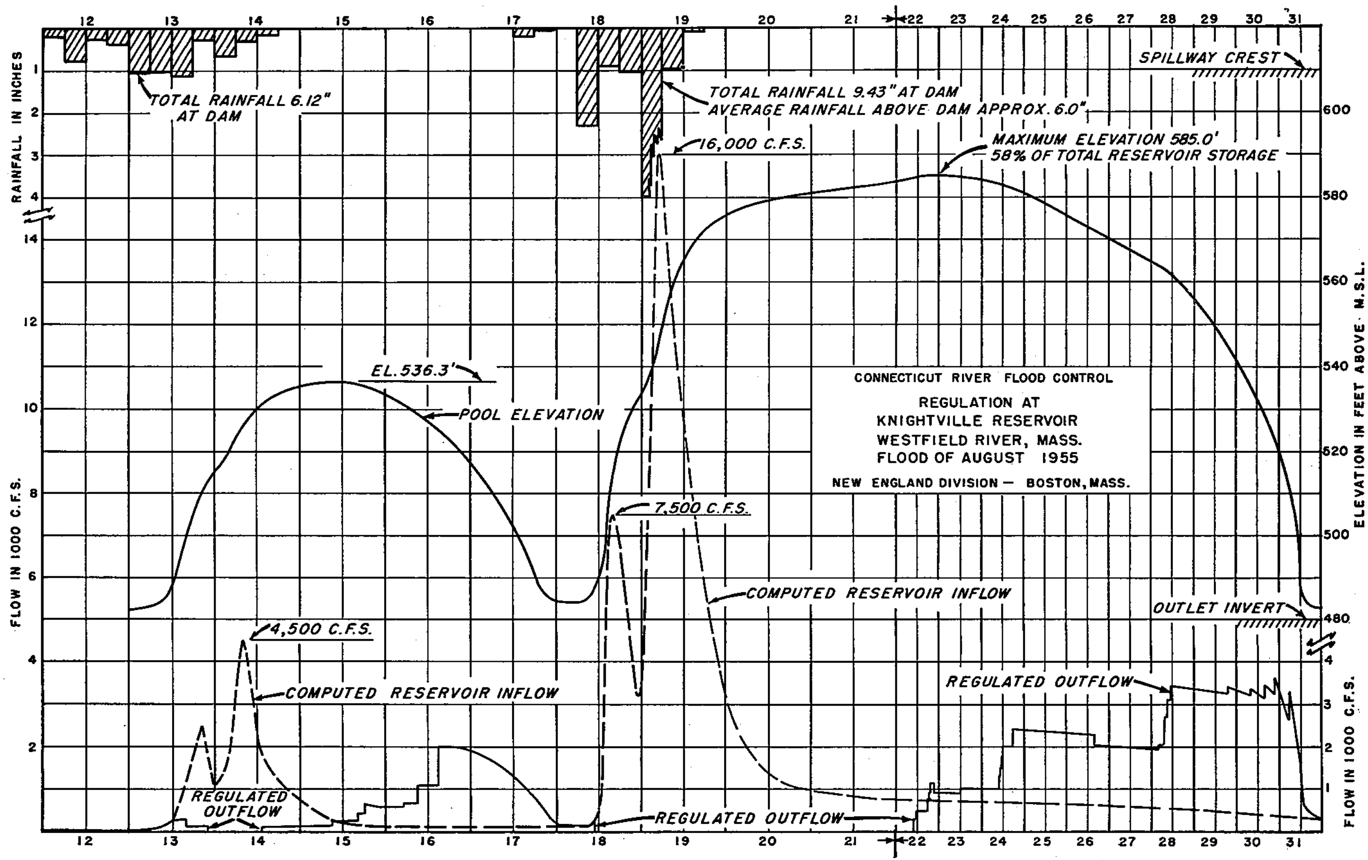

FIGURE 10.—REGULATION AT KNIGHTVILLE RESERVOIR DURING FLOOD OF AUGUST 1955. (From New England Floods of 1955, Part 5, Corps of Engineers, U.S. Army, New England Division, Waltham, Mass.)

Chapter V deals with flood protection measures, including flood control, flood forecasting and warning, and flood insurance. It discusses the topography and points out that the vegetation probably has small effect on large floods.

The report contains a discussion of flood control, pointing out that New England is somewhat behind other sections of the country in the flood control works done. A list is given of the present and proposed U.S. Government flood control reservoirs showing ten that were not in existence at time of the 1955 flood, and four more that are now under construction. In the same way, it lists seven local protection works which were not available in 1955, and five more are under construction. The report also lists flood control projects by the U. S. Department of Agriculture, and the various States which have been completed since 1955.

There follows a discussion of flood forecasting which is now pretty well established. It sums up this question as follows: "The preparation of a flood forecast and the related public warning statement is done by an agency of the Federal government and this is proper and necessary since rainfall patterns and river drainage areas are for the most part interstate." The Chapter closes with a discussion of flood insurance concluding that a self-sustaining program of flood insurance is impossible due to the type of peril involved.

Chapter VI is a review of the various work that has been done on flood analyses in the twenty years since the 1942 report. The first subject considered is flood frequency. The conclusion of the 1942 report is repeated as follows: "that the graphical method of making use of some form of probability plotting may be used for drawing a curve through the actual points plotted from such a record, but there is grave doubt as to whether any extension beyond the length of the record by any method gives a result at all reliable." It is noted that the Joint Division Committee on Floods of the American Society of Civil Engineers, 1951, was equally emphatic in pointing out the errors that can result from the extrapolation of computed frequency curves. The report continues "The difficulty becomes obvious when the flood peak discharge of certain streams in New England are plotted on some form of probability paper. Most of the points follow a general trend, but the discharges from the large floods of 1927, 1936, 1938 and 1955 may depart radically from any orderly pattern."

The report further states "The above general conclusions regarding the inadvisability of extending frequency curves need not be a reason for disregarding the many contributions to the subject of flood frequency, particularly as they enter into the development of the flood formulas now in use." The report then considers the question raised as to whether there may be, as has been suggested, two or more frequency curves for a given station with the greatest floods forming a steeper part than the frequent floods. The Committee reaches the following conclusion: "Benson points out that 'There is in general no particular flood magnitude below which all floods are caused by one factor and above which they are caused by another.' This is particularly true in New England. On this basis, these extremely large floods should be carefully analyzed to determine any unusual conditions contributing to their magnitude." The report further states that "It is believed that in New England, for the purpose of an economic analysis, the accuracy of predicting the frequency-magnitude relationship by the statistical methods now available will be at least of the same order as the accuracy of the cost and value estimates for a period of about 300 years in the future. Where public safety is involved methods which utilize all meteorological and hydrological factors known should be employed in the design of hydraulic structures."

The next subject discussed is Flood Formulae for New England, starting with the B.S.C.E. flood formula first given in the 1930 Flood Report. It is pointed out that this formula, in a general way, proposed to follow the methods proposed earlier by Weston E. Fuller in that the flood flows are based on basin characteristics reflected in the actual floods at each point.

This is followed by a discussion of the Kinnison-Colby formula first proposed in 1945 and widely used in Massachusetts. This was the first flood formula which was based on stream characteristics determined from the topography of the watershed itself and not purely from the hydrograph of the stream. In other words, the formula enabled one to predict floods on rivers where there were no past records but where the flood characteristics could be determined from a topographical map. This formula took care of the frequency by classifying floods as "minor," 15 years; "major," 100 years; "rare," 1,000 years and maximum. This is the first formula that actually put an estimated figure on the maximum possible flood.

The Bigwood-Thomas formula for Connecticut, based on an analysis of various floods in Connecticut, was expressed in a frequency magnitude curve extending to a frequency of 300 years. The coefficient used was based upon general factors of watershed characteristics. The area and the slope were important factors. The report gives comparisons of this formula of the Kinnison-Colby formulas expressed in terms of ratios to the mean annual flood.

One of the latest studies of New England flood streams was developed by Manuel A. Benson, of the U. S. Geologic Survey, from an analysis of vast amounts of flood data using graphical multiple correlation and digital computers. A great number of various steam characteristics were studied and it was found that the drainage area and slope of the stream were the two most significant characteristics of an area for producing floods.

The report analyzed the recent U. S. Bureau of Public Roads charts of "Peak Rates of Runoff, New England, New York and New Jersey" for providing a uniform basis for design in connection with the interstate highway construction program. These were analyzed in terms of ratios to the mean annual floods for various streams in all the New England states and with a comparison of the maximum floods of record. The B.P.R. curves were stated to cover 50-year flood peak.

Chapter VI next discussed drainage basin characteristics and reached the following: "A recent U. S. Geological Survey Water Supply Paper (986C) gives the characteristics of 340 drainage basins in the Northeast. Of the basin characteristics, all studies for New England flood formulas have found the drainage area to be of first importance in correlating flood peaks. Second in importance is some measure of slope. These two factors alone were the bases of the Kinnison-Colby (except for minor floods) and the Bigwood-Thomas formulas; other characteristics were found less significant and were omitted. Benson's conclusions were the same as to importance of these characteristics, but additional factors were included to obtain even better correlation. The report states:

"Although the magnitude of the flood peaks of the 1955 flood may have raised questions as to the validity of the frequency-magnitude relations expressed by the various formulas, no studies have as yet indicated that any specific changes should be made in the selection or use of the basin characteristics."

The report gives a comparison of the 1955 floods with the U. S. Corps of Engineers' project floods, and of the storm with the U. S.

Weather Bureau maximum probable precipitation noting that for six and twelve-hour depth of rainfall the maximum precipitation estimates greatly exceed the actual storm by nearly two times. For 24-48 hours' duration, however, the 1955 maximum storm rainfall ran from 70 to 83 per cent of the maximum possible.

The chapter closes with an analysis of the unit hydrographs, a subject that was much discussed in the two previous flood reports. This discussion refers to the 1930 report where it was noted that the length of the base of the hydrograph at a given point for floods of all sizes due to storms with the concentration period of the storm was practically constant, and finds that:

"The basic assumption that the length of the base of the flood hydrograph is approximately constant for all floods (excluding, of course, those due to storms of longer duration than the normal concentration period of the stream at the measuring station) still holds generally true within the range of accuracy required and obtained in studies based on hydrologic data though there may be more variation in the smaller streams. This is the basis of the unit hydrograph, Figure 11.

When the unit hydrograph was first used it was assumed that it would be approximately similar for all sizes of floods. Hathaway and Kinnison and Colby's paper showed that this was not true, particularly on smaller drainage areas, that the peaks of the unit hydrographs derived from large floods are generally higher than those derived from small floods. Figure 12. The reasons for this variation in the peak of the unit hydrograph for large floods over that for small floods have not been found. The report points out that this variation is greater in the case of hydrographs for short periods: that is, for a 6-hour unit graph rather than for a 24-hour unit graph. It concludes:

"A great part of the value and usefulness of the unit graph is to enable a large flood at a given point on a river to be predicted from a small flood at that point. This advantage is lost if the unit graph of a small flood cannot be used without great error for this purpose.

"When due consideration is given to the smaller variation of unit graph peaks for longer storms and a certain general usable uniformity in the increase in unit graph peaks with a given increase in flood peaks, it should be possible to use the small flood unit graph to predict the flood peak of a large flood of normal duration without

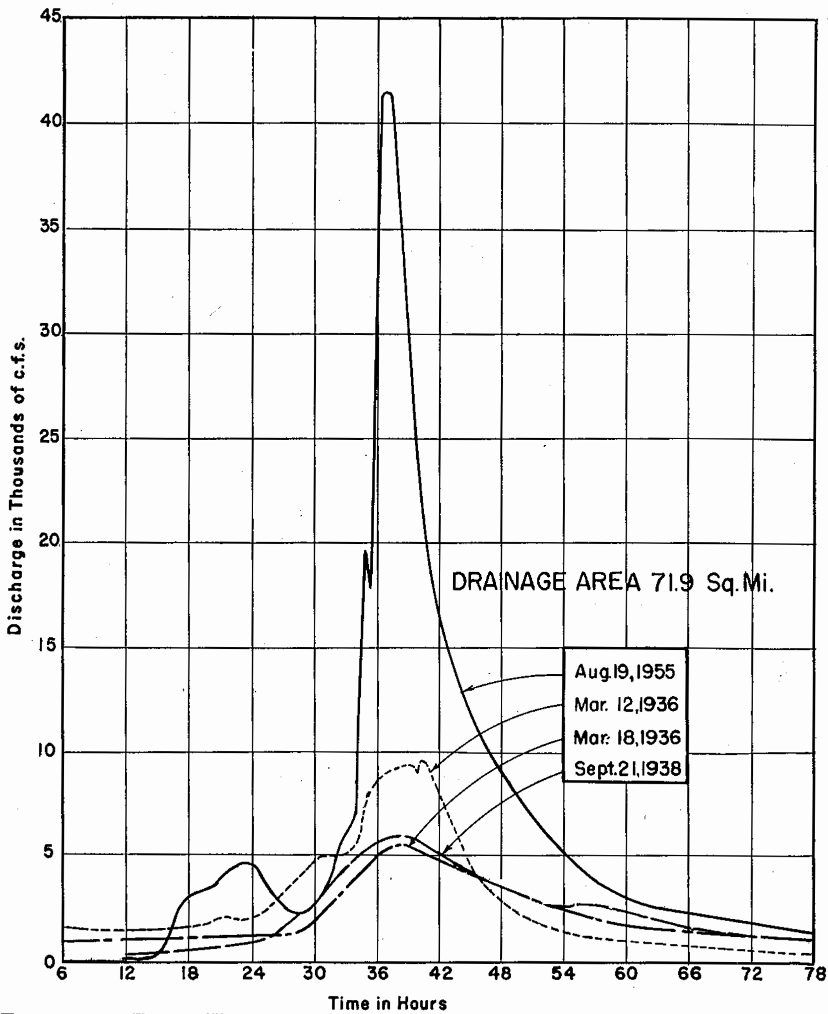

FIGURE 11.—FLOOD HYDROGRAPHS OF NAUGATUCK RIVER NEAR THOMASTON, CONNECTICUT.

more error than may be expected in such computations based on hydrologic data and valid assumptions."

Chapter VII deals with the design criteria for dams and channels. Referring to the former, it notes that the Corps of Engineers base their spillway design floods for critical structures on the maximum possible storm which may give results several times the August 1955 flood. As contrasted to this is the smaller spillway design of the dams for small watersheds used by the Soil Conservation Service of the U. S. Department of Agriculture. There follows a discussion of the economics of spillway designs, where it is pointed out that 1955

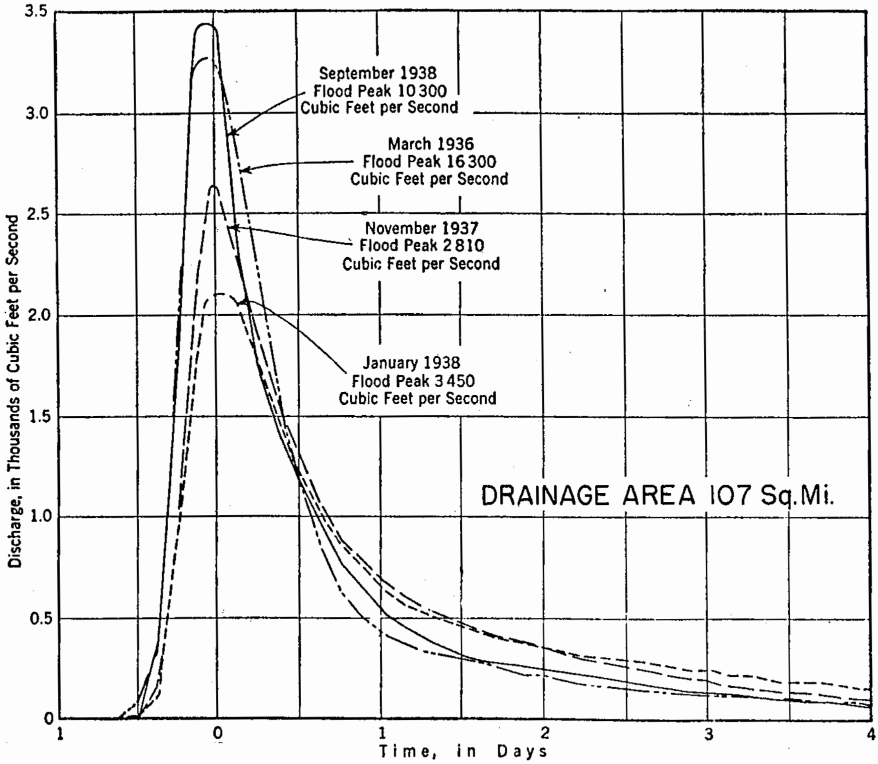

FIGURE 12.—SIX-HOUR HYDROGRAPHS COMPUTED FROM INDICATED FLOODS, NORTH NASHUA RIVER, NEAR LEOMINSTER, MASS.

is now a certain important measure of spillway capacity. The report concludes:

"The 1955 floods, in the areas of their greatest severity, exceeded all records. The rainfall intensity exceeded all records for the area, and it is believed was the greatest during the more than 300 years that the area has been settled. But we can establish no figure for their probability of recurrence upon which we have any confidence.

The interval might be 100 years or it might be 1,000 years. This would mean that for most major works the probability should be considered that a storm of equal or greater intensity than those of 1955 will visit the general area some time within the life of the project." It is pointed out: "No one formula nor method can be recommended as best suited for all cases, nor, for that matter, for any particular case."

There is a further discussion of the criteria for flood channels, covering municipal storm drainage systems and small brooks and channels. The section on culverts and bridges lists the requirements of the various New England states for culverts. Various examples of recent flood channel construction are given, including the present practice of the U. S. Corps of Engineers in determining their standard project flood which it is noted is larger than the maximum flood of record, with an exceedance of 10 to 60 per cent. The channel improvements on the larger rivers of New England are also described. The 1955 flood has become a measure of required capacity of many flood channel works.

The last chapter discusses the regulations by public authorities and is valuable in giving a history of the Flood Control Acts of New England, and of the Federal Power Commission and the Department of Health, Education and Welfare of the Federal Government. It then discusses the various laws in the different New England States regarding the regulations of all river construction particularly, generally, dams, water supply and sewerage. It is interesting to note that in Massachusetts there is a flood zoning law which is an ordinance or by-law which provides that lands deemed subject to seasonal or periodic flooding shall not be used for resident or other purposes in such a manner as to endanger the health or safety of the occupants thereof. The chapter then describes the flood control compacts on interstate rivers, on the Merrimack, Connecticut and Thames Rivers.

In conclusion, one is tempted to conclude that from an engineering standpoint Nature has recently co-operated with the Engineer in giving flood data which has added to our confidence in our flood engineering.