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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE PASSAIC FLOOD OF 1903

BY

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CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., December 4, 1903.

SIR: I have the honor to transmit herewith a manuscript entitled, "Passaic Flood of 1903," prepared by Marshall Ora Leighton, and to request that it be published as one of the series of Water-Supply and Irrigation Papers.

This paper is a continuation of Water-Supply and Irrigation Paper No. 88, by George B. Hollister and Mr. Leighton, and describes the flood of October, 1903, which was higher and far more disastrous than the flood of 1902. The occurrence of two great floods in the same basin during so short a period makes the subject worthy of attention, especially as the district is, from a manufacturing and commercial standpoint, one of the most important along the Atlantic coast.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE PASSAIC FLOOD OF 1903.

By Marshall O. Leighton.

INTRODUCTION.

In the following pages is given a brief history of the disastrous flood which occurred in the Passaic River Basin in October, 1903. In the report by George Buell Hollister and the writer, entitled "The Passaic Flood of 1902," and published by the United States Geological Survey as Water-Supply and Irrigation Paper No. 88, are discussed the principal physiographic features of the drainage basin and their general relations to the stream flow. This report will not repeat this information, and the discussion will be confined to the flood itself. References to local features will be made without explanation, the presumption being that this publication shall accompany the earlier one and be, as it is, a continuation of it. In the present report more attention is given to an estimate of damages than in the earlier work, and remedies by which devastation may be avoided are briefly considered.

Passaic River overflowed its banks on October 8, 1903, and remained in flood until October 19. Between these dates there occurred the greatest and most destructive flood ever known along this stream. Ordinarily the channel of the lower Passaic at full bank carries about 12,000 cubic feet of water per second, but at the height of this flood it carried about 35,700 cubic feet per second.

The flood period for the entire stream can not be exactly stated, as the overflow did not occur at the same time in different parts of the basin. For example, the gage-height records at Dundee dam show that the flood began to rise on October 8 at 6.30 a. m., and reached a maximum of 9½ inches over the dam crest at 9 p. m. on October 10. Similarly, on Beattie's dam at Little Falls the flood began to rise at midnight on October 7, and reached its maximum at 2 p. m. on October 10, or about thirty-eight hours after the initial rise, the height of the water being 1.29 inches over the crest of the dam.

The flood rose on the highland tributaries as follows: On Ramapo River the flood crest passed Hillborn at about 10 a. m. on October 9 and reached Pompton, at the mouth of the river, shortly after noon of the same day.

The highest reading recorded on the Geological Survey gage at the feeder of Morris Canal, in Pompton Plains, was 14.3 feet, at about 6 o'clock on the morning of October 10. As this gage is read only once daily it is probable that this reading does not represent the height of the flood crest. Evidence shows that it passed this point on the previous day. Records of the Newark water department show that the flood on Pequanac River began to rise at Macopin dam on October 8 at noon, and rose rapidly to the maximum of 6,000 cubic feet per second at 4 p. m. on October 10.

No records are available with reference to the rise of flood on Wanaque River.

Observations made on Pompton Plains on the morning of the 11th show that Pompton River was well within its banks at that time; therefore the Ramapo, Wanaque, and Pequanac must have discharged their flood waters some time previous to this hour. The fact is important when considered in connection with the height of water in the main stream at that period. This observation was made only eighteen hours after the maximum height over Beattie's dam at Little Falls, and twelve hours after the flood crest passed Dundee dam. The conditions here outlined illustrate the rapidity with which flood waters are discharged from the Pompton drainage area, and the deterring effect of Great Piece Meadows upon the flood.

The rise of the flood on Rockaway River at Old Boonton was almost coincident with that on Pequanac River at Macopin dam. The maximum flow occurred fourteen hours later than the maximum on the Ramapo at Pompton.

The flood crest did not reach Chatham on upper Passaic River until the morning of October 11, or about twenty-four hours later than the flood heights in Pompton and Rockaway rivers, and about twelve hours later than the maximum over Dundee dam.

Adequate reasons for these differences in flood periods between neighboring points are abundant. They are apparent after a review of the physiographic conditions described in Water-Supply Paper No. 88.

The flood of 1903 was the immediate result of an enormous rainfall, and not, as is often the case in north temperate latitudes, the combined effect of rainfall and the rapid melting of accumulated snows. The records of weather-observation stations in northern New Jersey and New York fail to show, throughout their entire observation periods, as great an amount of precipitation in so short a period. The storm which was the immediate cause of the flood occurred principally between October 8 and 11. During that interval rain fell to an average depth of 11.74 inches over the Passaic Basin.

The Passaic Basin is fairly well supplied with storage facilities, which, under ordinary circumstances, would temper the severity of floods by holding back a large amount of water. In this case no such effect was produced, as the reservoirs, lakes, and ponds on the drainage area were filled, or practically so, at the beginning of the storm, and there was consequently no available space in which to hold back even an appreciable part of the run-off water. Over some of the dams in the highland region a comparatively small amount of water was being discharged at the beginning of the storm. Therefore, while these storage basins may have had a certain deterring effect upon the rate of flood accumulation, they could not, in the end, assist materially in preventing damages in the lower part of the drainage area.

PRECIPITATION.

The precipitation records for June, July, August, and September are given below:

Precipitation, in inches, in Passaic Valley and vicinity, June to September, 1903.

	June.		July.		August.		September.	
	Normal.	Observed.	Normal.	Observed.	Normal.	Observed.	Normal.	Observed.
Highland region:								
Dover	3.29	15.02	5.54	5.47	5.08	9.04	4.02	3.39
Chester	3.48	12.80	6.42	7.59	5.16	9.35	4.60	......
Charlotteburg	3.52	9.45	5.54	3.97	4.98	7.78	4.80	3.29
Ringwood	......	10.13	......	3.08	......	6.17	......	3.06
Red Sandstone plain:								
Paterson	4.31	11.17	5.32	5.40	4.31	10.89	4.86	2.88
Hanover	3.32	......	5.23	5.40	5.20	9.40	4.52	......
River Vale	3.17	10.62	4.87	3.41	4.17	......	3.61	2.90
Essex Fells	3.08	......	7.03	......	5.95	......	3.67	1.80
Newark	3.60	11.51	4.48	4.27	4.75	14.54	3.83	4.56
South Orange	3.57	9.28	5.43	4.22	5.05	13.75	4.04	3.80
New York City	3.13	7.42	4.26	3.23	4.70	5.96	3.72	2.60
Plainfield	3.62	10.14	5.86	4.70	4.37	6.87	4.42	7.10
Elizabeth	3.68	8.76	5.74	4.31	4.26	7.15	4.14	4.38

An examination of the above table shows that throughout the summer of 1903 the precipitation was considerably above normal. The records for June and August indicate extremely wet months, and the July figures are slightly above while the September figures are somewhat below normal. The important fact shown by this table is that disastrous floods may occur after long periods of abundant rains. It has been observed that heavy precipitation may be expected after protracted periods of drought. Such a belief is not altogether fanciful. In the northeastern part of this country the total amount of precipitation is approximately uniform from year to year. The variations, comparatively speaking, are not very wide, and we are therefore led to expect that there are in operation influences which serve to compensate for excesses or deficiencies in our annual rainfall. Therefore after the abundant precipitation of the summer of 1903, an observer might have had some measure of justification in predicting a normally or abnormally dry fall. In view of the actual events the fact must be emphasized that in adopting measures to prevent floods the margin of safety must be extremely wide. The extraordinary rainfall of those three October days can not with assurance be accepted as the maximum.

Precipitation, in inches, in Passaic Valley and vicinity, October 7 to 11, 1903.

Station.	From—		To—		Amount.
	Day.	Hour.	Day.	Hour.	
Highland region:					
Dover	7		11	9 p. m	10.13
Little Falls	7	4 a. m	11	7 a. m	14.13
Charlotteburg	7		10		12.67
Ringwood	8	11 a. m	9	8 p. m	10.63
Red Sandstone plain:					
Paterson	7	5 a. m	9	3.45 p. m	15.04
River Vale	8	8 a. m	11	6 p. m	12.55
Essex Fells	8		9	4 p. m	10.66
Newark	8	8.30 a. m	11	5 a. m	12.09
South Orange	8	6 a. m	10	Night	10.48

The extremely rapid rate of precipitation during the crucial part of the storm is shown by the recording gages placed at observation stations in Newark and New York City.

Hourly records of precipitation at New York observation station, October 8 and 9, 1903.

	Inches.
Oct. 8, 9 to 10 a. m	0.08
10 to 11 a. m	.02
11 to 12 m	.32
12 m. to 1 p. m	.10
1 to 2 p. m	.05
2 to 3 p. m	.06
3 to 4 p. m	.34
4 to 5 p. m	.01
5 to 6 p. m	.10
6 to 7 p. m	.02
7 to 8 p. m	.93
8 to 9 p. m	.32
9 to 10 p. m	.24
10 to 11 p. m	.27
11 to 12 p. m	.26
9, 12 to 1 a. m	.30
Oct. 9, 1 to 2 a. m	0.25
2 to 3 a. m	.75
3 to 4 a. m	.34
4 to 5 a. m	.46
5 to 6 a. m	.41
6 to 7 a. m	.29
7 to 8 a. m	.51
8 to 9 a. m	1.38
9 to 10 a. m	1.04
10 to 11 a. m	.08
11 to 12 m	.23
12 m. to 1 p. m	.24
1 to 2 p. m	.31
2 to 3 p. m	.32
3 to 4 p. m	.01
Total	6.92

Hourly record of precipitation at Newark observation station, October 8–11, 1903.

	Inches.
Oct. 8, 8.25 to 9 a. m	0.05
9 to 10 a. m	.04
10 to 11 a. m	.00
11 to 12 m	.00
12 m. to 1 p. m	.14
1 to 2 p. m	.72
2 to 3 p. m	.49
3 to 4 p. m	.11
4 to 5 p. m	1.05
5 to 6 p. m	.45
6 to 7 p. m	1.20
7 to 8 p. m	.60
8 to 9 p. m	.24
9 to 10 p. m	.24
10 to 11 p. m	.13
11 to 12 p. m	.17
9, 12 to 1 a. m	.29
1 to 2 a. m	.33
2 to 3 a. m	.62
3 to 4 a. m	.29
4 to 5 a. m	.35
5 to 6 a. m	.26
6 to 7 a. m	.13
Oct. 9, 7 to 8 a. m	0.29
8 to 9 a. m	.69
9 to 10 a. m	.69
10 to 11 a. m	.39
11 to 12 m	.20
12 m. to 1 p. m	.39
1 to 2 p. m	.28
2 to 3 p. m	.34
3 to 3.25 p. m	.13
11.50 to 11.55 p. m	.01
10, 3 to 4 a. m	.02
7 to 8 p. m	.07
8 to 9 p. m	.09
9 to 10 p. m	.02
10 to 11 p. m	.04
11 to 12 p. m	.04
11, 12 to 1 a. m	.06
1 to 2 a. m	.09
2 to 3 a. m	.03
3 to 4 a. m	.05
4 to 5 a. m	.01
Total	11.83

From the above tables it may be seen that the maximum rate of precipitation per hour was 1.38 inches at New York and 1.2 inches at Newark. Comparison of the tables on pages 11 and 12 gives an excellent idea of the intensity of the storm. The amount of water falling in a single storm is nearly equal to the total for June, a month of unusual precipitation.

The average of the total amounts of precipitation recorded at the various stations in the Passaic area is 11.74 inches. These totals are fairly uniform, none of them varying widely from the average. Therefore the figure 11.74 represents a conservative mean for a calculation of total amount of water over the drainage area. Assuming this as the correct depth, the amount of water which fell on each square mile of the Passaic drainage area during the storm was 27,273,000 cubic feet, or for the whole Passaic drainage area over 27,000,000,000 cubic feet, weighing about 852,000,000 tons. This amount of water would, if properly stored, fill a lake with twenty times the capacity of Greenwood Lake, would cover Central Park in New York City, which has an area of about 1.5 square miles, to a height of 645 feet, and, at the present rate of water consumption in the city of Newark, N. J., would supply the city with water for twenty years.

DESCENT OF FLOOD.

HIGHLAND TRIBUTARIES AND CENTRAL BASIN.

A description of the descent of flood waters from the highland tributaries into the Central Basin has been given in Water-Supply Paper No. 88. It has been shown that the lands of the Central Basin are covered even in ordinary freshets, and that in the event of a great flood the waters merely rise higher, being, for the greater extent, almost quiescent, and beyond the flooding of houses and barns and the destruction of crops, little damage is done. In other words, the flood along this portion is not torrential in character.

During the flood of 1903 the water fell so quickly all over this basin, and was collected so rapidly by the small tributaries, that a lake was formed at once which served as a cushion against which the raging torrent of the highland tributaries spent itself without doing extraordinary damage in that immediate region. Bridges which might have been lost in a smaller flood like that of 1902 were actually standing in slack water by the time the mountain torrents appeared in force. These streams caused much destruction higher up in the mountains, but in the Central Basin their energy became potential—a gathering of forces to be loosed upon the lower valley. A discussion of the effects of this will be taken up under the heading "Damages."

In Water-Supply Paper No. 88 is given the proportion of flood waters contributed to the Central Basin by each of the tributaries. These figures were computed from the results of gagings maintained for a period sufficient to afford this information within a reasonable approximation. In the case of the storm which resulted in the flood of 1903 it is probable that data referred to can not be safely applied.

The flood of 1902 was the result of abundant rains following upon and melting a heavy snow. Weather Bureau records show that neither the depth of the snow nor the amount of subsequent rainfall was uniform, or even approximately so, over the Passaic drainage area. Indeed, so marked was the variation that it was believed that the mean rainfall for all the observation stations on the basin did not bear sufficient relation to observed run-off to allow of any reliable deductions. In the case of the October storm, however, the distribution of rainfall was more nearly uniform, and the run-off from the highland tributaries into the Central Basin must have been proportionately different in amount from that indicated in the upland tributary tables in the report of the previous flood. The data given for the 1902 flood can not, therefore, in the case of the highland tributaries, be applied to the conditions which obtained in the flood of 1903.

FLOOD AT MACOPIN DAM.

Mr. Morris R. Sherrerd, engineer of the Newark city water board, has furnished flow computations over Macopin intake dam, which is the head of the Newark pipe line. As about 73 per cent of the Pequanac drainage area lies above this intake, the table on page 16 shows roughly an equivalent percentage of the flow contributed by Pequanac River to the Central Basin of the Passaic. In consulting this table it should be borne in mind that the entire run-off of the drainage area above Macopin is about 25,000,000 gallons per day more than the amounts presented in this table. All reservoirs and ponds connected with the conservancy system of the Newark water supply were filled except that at Oakridge, which was about 1.5 feet below the crest of the spillway.

Flow of Pequanac River over Macopin dam, October 7–24, 1903.

[From Newark water department.]

	Cubic feet.		Cubic feet.
Oct. 8, 6 a. m. to 12 m	240,600	Oct. 14, 12 to 6 a. m	9,626,000
12 m. to 4 p. m	347,600	6 a. m. to 12 m	8,690,000
4 to 6 p. m	842,200	12 m. to 6 p. m	8,022,000
8–9, 6 p. m. to 6 a. m	40,110,000	6 to 12 p. m	7,353,000
9, 6 a. m. to 12 m	51,870,000	15, 12 to 6 a. m	6,952,000
12 m. to 1 p. m	15,100,000	6 a. m. to 6 p. m	12,700,000
1 to 5 p. m	62,430,000	15–16, 6 p. m. to 6 a. m	10,965,000
5 to 10 p. m	89,040,000	16, 6 a. m. to 6 p. m	10,025,000
10 to 11 p. m	19,520,000	16–17, 6 p. m. to 6 a. m	9,091,000
9–10, 10 p. m. to 8 a. m	201,350,000	17, 6 a. m. to 6 p. m	8,690,000
10, 8 a. m. to 12 m	75,670,000	17–18, 6 p. m. to 6 a. m	9,893,000
12 m. to 6 p. m	103,650,000	18, 6 a. m. to 6 p. m	10,565,000
6 to 12 p. m	73,530,000	18–19, 6 p. m. to 6 a. m	8,690,000
11, 12 to 6 a. m	56,820,000	19, 6 a. m. to 6 p. m	6,952,000
6 a. m. to 12 m	41,440,000	19–20, 6 p. m. to 6 a. m	6,150,000
12 m. to 6 p. m	32,755,000	20, 6 a. m. to 6 p. m	5,882,000
6 to 12 p. m	25,665,000	20–21, 6 p. m. to 6 a. m	5,749,000
12, 12 to 6 a. m	23,800,000	21, 6 a. m. to 6 p. m	5,481,000
6 a. m. to 12 m	20,725,000	21–22, 6 p. m. to 6 a. m	5,214,000
12 m. to 6 p. m	18,450,000	22, 6 a. m. to 6 p. m	4,144,000
6 to 12 p. m	15,105,000	22–23, 6 p. m. to 6 a. m	3,677,000
13, 12 to 6 a. m	13,370,000	23, 6 a. m. to 6 p. m	3,877,000
6 a. m. to 12 m	11,890,000	23–24, 6 p. m. to 6 a. m	5.749,000
12 m. to 6 p. m	11,230,000	24, 6 a. m. to 6 p. m	5,615,000
6 to 12 p. m	11,230,000		

FLOOD AT BEATTIE'S DAM, LITTLE FALLS.

The flow over Beattie's dam at Little Falls, has been calculated according to coefficients used for the same dam in Water-Supply Paper No. 88. Recorded gage heights show that over the main dam there was a maximum depth of 11.12 feet, which continued from 2 to 8 p. m., on October 10, representing a maximum flow of 31,675 cubic feet per second. (See Pl. I, *A*.) In the following table is set forth the flow of the river over Beattie's dam during the flood, and for purposes of comparison, the figures for the flood period of March, 1902. It should be borne in mind in consulting this table, that in the case of the flood of 1903 exact dates and hours are given, while the figures for the 1902 flood represent flow determinations at six-hour intervals, beginning with the initial rise of that flood.

A. BEATTIE'S DAM, LITTLE FALLS, N. J., IN FLOOD.

B. FLOOD-WATER LINES IN RESIDENCE DISTRICT, PATERSON, N. J.

Flood flow over Beattie's dam during floods of 1902 and 1903.

Date and hour.	1903.	1902. *a*	Date and hour.	1903.	1902. *a*
	Sec.-feet.	*Sec.-feet.*		*Sec.-feet.*	*Sec.-feet.*
Oct. 8. 12 p. m.	1,645	490	Oct. 14. 12 m.	11,740	22,650
9. 6 a. m.	4,235	700	6 p. m.	10,975	22,350
12 m.	8,560	1,350	12 p. m.	9,820	22,100
6 p. m.	15,755	2,120	15. 6 a. m.	9,180	21,15[illegible]
12 p. m.	23,927	3,540	12 m.	8,330	19,9[illegible]
10. 6 a. m.	28,370	4,250	6 p. m.	7,700	18,9[illegible]
12 m.	31,305	4,600	12 p. m.	7,005	17,350
6 p. m.	31,675	5,000	16. 6 a. m.	6,695	15,750
12 p. m.	30,770	6,500	12 m.	5,920	13,900
11. 6 a. m.	29,840	7,600	6 p. m.	5,620	13,300
12 m.	28,950	8,250	12 p. m.	5,360	11,800
6 p. m.	26,960	9,000	17. 6 a. m.	4,855	10,650
12 p. m.	25,530	10,200	Below full bank		8,900
12. 6 a. m.	24,435	11,450	Do		8,500
12 m.	22,625	14,700	Do		8,100
6 p. m.	20,810	18,150	Do		8,200
12 p. m.	18,655	20,650	Do		7,000
13. 6 a. m.	17,930	22,200	Do		6,250
12 m.	16,190	22,700	Do		5,900
6 p. m.	14,900	23,400	Do		5,300
12 p. m.	13,615	23,300	Do		5,200
14. 6 a. m.	12,340	22,950	Do		4,900

a At six-hour intervals.

FLOOD FLOW OVER DUNDEE DAM.

The flood, as indicated by gage heights at Dundee dam, lasted from about 6.30 p. m. October 8 to about midnight October 18. Although the maximum recorded gage height was 19 inches higher than during the flood of 1902, the actual time during which the river was out of its banks was forty-five hours less than at the earlier flood. Examination of fig. 1 shows that the flood of 1903 was decidedly more intense than that of 1902, the maximum height being reached in 1903 in about sixty hours, while in 1902 the maximum was not reached until the expiration of about one hundred and twenty hours.

At Dundee dam the familiar break in the progress of the flood took place about thirty-five hours after the initial rise. It occurred before the time of the maximum gage height at the mouth of Pompton River, and there is nothing to indicate that it was caused, as has been claimed, by slack water from the Pompton flood being forced back into Great Piece Meadows. There is no doubt that a part of the Pompton flood was so diverted, but there was maintained throughout at Little Falls a steady pressure, which constantly increased to maximum. This flood check at Dundee dam was observed in 1902, but it could not be shown to arise from the frequently mentioned phenomena at the mouth of Pompton River. It is important to prove or disprove this hypothesis.

If it were found to be true, it could be advantageously taken into consideration in connection with measures for the prevention of flood damages. As the Pompton had no such effect upon the flood flow at Dundee dam in two consecutive historic floods, the writer is inclined to believe that the idea is entirely erroneous.

Since the flow curves in fig. 1 were drawn it has been found by careful observation that the depressions which occur in the rise of every flood over Dundee dam are probably due to the carrying away of the flashboards which are placed upon the dam crest in times of low water. A review of the gage heights recorded by floods for several years past shows that the break occurs when the height of water over the dam crest reaches from 40 to 60 inches. The flashboards used upon this

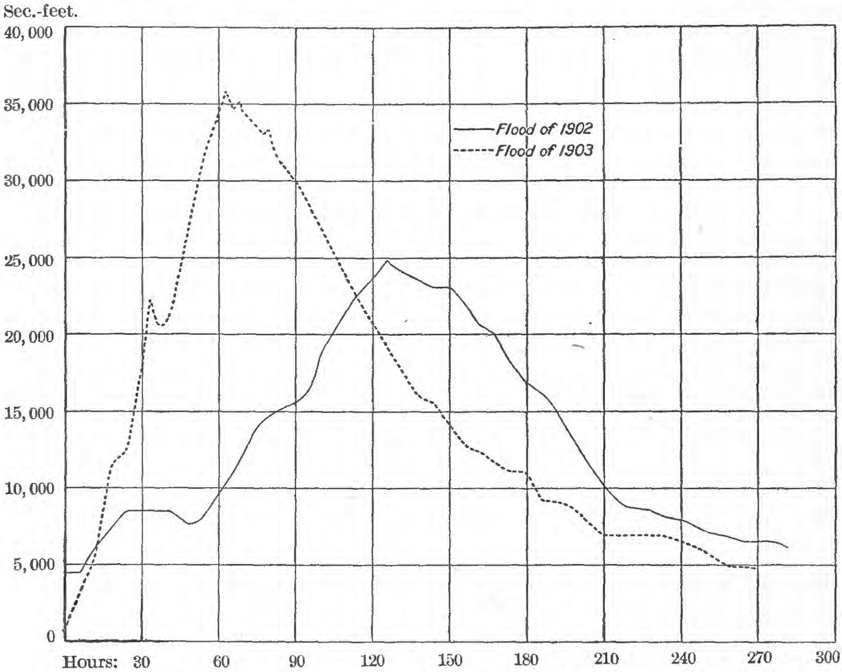


FIG. 1.—Comparative flood run-off at Dundee dam, March, 1902, and October, 1903.

dam are usually 18 inches wide, and as they are supported by iron rods, which are of approximately the same strength and are placed upon the dam by one crew of workmen, it may be safely assumed that they are of approximately equal stability and might be expected to fail almost simultaneously along the length of the dam crest. So sudden a decrease in the effectual height of the dam must lower the water on the dam crest markedly, and as every other probable cause has been eliminated in the case of the recent flood, the explanation of the check in the progress of floods over this dam may be safely accepted as due to carrying away of flashboards. This effect should be apparent in the gage-height records only.

In the flow diagrams (figs. 1 and 2) the effect would not be the same, but the curve would rise more sharply. Similarly, the measurements at the beginning are not correct, as they are calculated according to gage heights measured from the stone crest of the dam. Therefore, a true flood curve at this point would be much flatter at the beginning and rise sharply at a period coincident with the carrying away of the flashboards.

An important difference between the two floods is that the earlier continued longer, but the later one was much higher. The flood of 1902 was caused by the turning of an equivalent of approximately 6 inches of precipitation into the main channel during a period of six days. In the deluge of 1903 there fell 11.74 inches of rain, the greater part of which was precipitated in 36 hours. Thus it is seen that there was in the flood of 1903 a larger rainfall during a much shorter period than in the flood of 1902. Computation shows that the total run-off from the drainage area above Dundee dam during the earlier flood was 13,379,000,000 cubic feet, and that on account of the frozen condition of the ground at that time this amount of water represented practically all of the precipitation. During the flood of 1903 there was a total run-off for the same area of 14,772,000,000 cubic feet, which represents about 66 per cent of the observed precipitation. According to these figures the total amount of run-off in the 1903 flood was only 10 per cent greater than that in 1902, while the actual flood height during the 1903 flood was 27 per cent higher than during the flood of 1902. The above comparison shows, in a striking manner, the effect of the condition of the surface. In the case of the later flood we had, as has been stated in previous pages, an area which had been well watered during the previous summer, and the observed ground-water levels were fairly high. There was, however, sufficient storage capacity in the basin to retain about 34 per cent of the precipitation occurring between October 7 and 11. This water must have been largely absorbed by the earth. The general relations of the floods of 1903 and 1902 can therefore be briefly stated as follows:

General relations of floods of 1903 and 1902.

	Average precipitation.	Duration of precipitation.	Maximum flood flow.	Total run-off.	Run-off.	Duration of flood at Dundee dam.
	Inches.	*Days.*	*Sec.-feet.*	*Cubic feet.*	*Per cent.*	*Hours.*
1902	6	6	24,800	13,379,000,000	[a] 100	270
1903	11.74	3	35,700	14,772,000,000	66	225

[a] Approximately.

In the following table and fig. 2 are recorded gage heights taken at hourly intervals during the crucial part of the flood and the amount of water expressed in cubic feet per second flowing over the crest of the dam at each gage height.

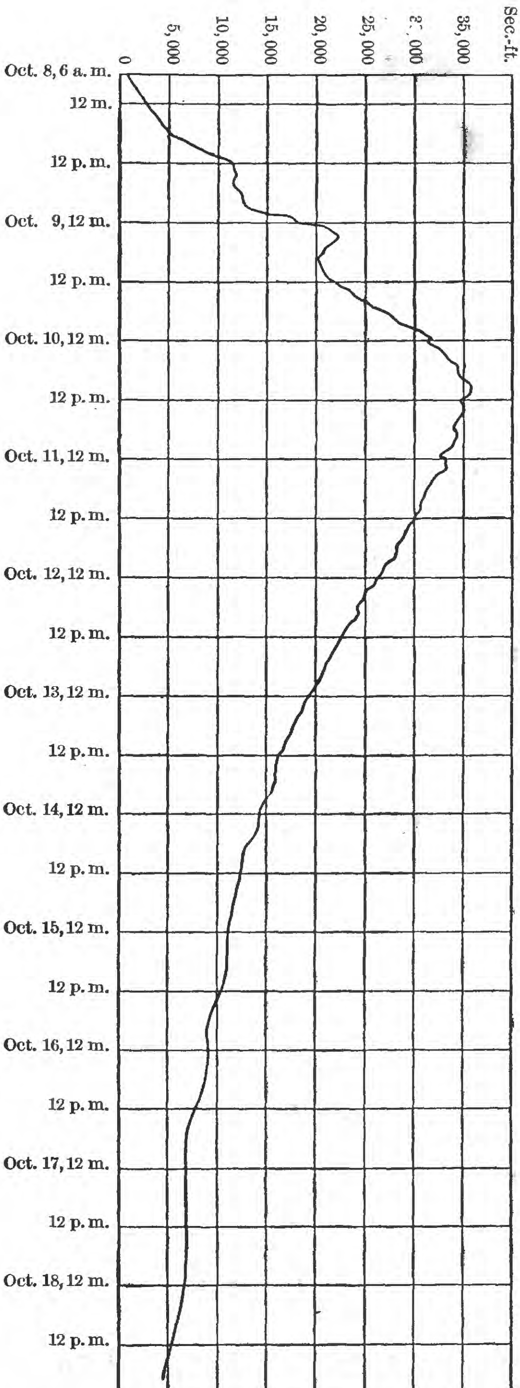


FIG. 2.—Diagram of flood flow at Dundee dam, flood of 1903.

Flow of Passaic River at Dundee dam, 1903.

Date and hour.	Gage.	Flow.	Date and hour.	Gage.	Flow.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
Oct. 8. 6.30 a. m	0.66	780	Oct. 10. 12 m	6.93	31,450
1 p. m	1.50	3,175	1 p. m	6.95	31,650
6.30 p. m	2.17	5,500	2 p. m	7.13	32,800
8 p. m	2.59	7,300	3 p. m	7.19	33,150
10 p. m	3.00	9,125	4 p. m	7.25	33,500
11 p. m	3.33	10,700	5 p. m	7.39	34,450
12 p. m	3.50	11,525	6 p. m	7.39	34,450
9. 1 a. m	3.50	11,550	7 p. m	7.40	34,500
2.30 a. m	3.59	11,950	8 p. m	7.54	35,350
4 a. m	3.50	11,525	9 p. m	7.62	35,800
6 a. m	3.66	12,300	10 p. m	7.60	35,700
8.30 a. m	3.75	12,775	11 p. m	7.57	35,500
9.40 a. m	4.00	14,075	12 p. m	7.43	34,650
10.55 a. m	4.66	17,650	11. 1 p. m	7.47	34,950
12 m	4.75	18,200	2 a. m	7.5	35,100
1 p. m	5.25	21,050	3 a. m	7.42	34,700
2 p. m	5.37	21,750	4 a. m	7.3	34,450
3 p. m	5.45	22,250	5 a. m	7.3	34,150
3.45 p. m	5.37	21,750	6 a. m	7.3	34,150
4.25 p. m	5.29	21,300	7 a. m	7.37	34,300
5 p. m	5.23	20,950	8 a. m	7.33	34,100
5.45 p. m	5.19	20,700	9 a. m	7.31	33,900
6.30 p. m	5.17	20,600	10 a. m	7.23	33,450
7 p. m	5.11	20,250	11 a. m	7.25	32,525
8 p. m	5.13	20,350	12 m	7.18	33,100
9 p. m	5.17	20,600	1 p. m	7.18	33,100
10 p. m	5.21	20,750	2 p. m	7.17	33,300
11 p. m	5.27	21,150	3 p. m	7.08	32,450
12 p. m	5.4	21,950	4 p. m	7.00	31,950
10. 1 a. m	5.5	22,500	5 p. m	6.96	31,700
2 a. m	5.66	23,500	6 p. m	6.89	31,250
3 a. m	5.73	23,900	7 p. m	6.86	31,050
4 a. m	5.91	25,050	8 p. m	6.83	30,850
5 a. m	6.00	25,650	9 p. m	6.79	30,600
6 a. m	6.2	26,900	10 p. m	6.81	30,700
7 a. m	6.33	27,700	11 p. m	6.73	30,200
8 a. m	6.4	28,150	12 p. m	6.71	30,100
9 a. m	6.6	29,400	12. 1 a. m	6.63	29,600
10 a. m	6.83	30,750	2 a. m	6.59	29,350
11 a. m	6.89	31,250	3 a. m	6.55	29,100
11.35 a. m	6.97	31,750	4 a. m	6.51	28,800

Flow of Passaic River at Dundee dam, 1903—Continued.

Date and hour.	Gage.	Flow.	Date and hour.	Gage.	Flow.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
Oct. 12. 5 a. m	6.42	28,250	Oct. 13. 9 p. m	4.54	17,000
6 a. m	6.42	28,250	10 p. m	4.51	16,750
7 a. m	6.39	28,100	11 p. m	4.49	16,700
8 a. m	6.39	28,100	12 p. m	4.37	16,000
9 a. m	6.25	27,200	14. 1 a. m	4.37	16,000
10 a. m	6.21	26,950	2 a. m	4.35	15,925
11 a. m	6.17	26,700	3 a. m	4.35	15,925
12 m	6.05	26,100	4 a. m	4.33	15,800
1 p. m	6.06	26,050	5 a. m	4.34	15,850
2 p. m	5.93	25,200	6 a. m	4.31	15,700
3 p. m	5.89	24,950	7 a. m	4.27	15,500
4 p. m	5.87	24,800	8 a. m	4.25	15,300
5 p. m	5.79	24,300	9 a. m	4.17	14,900
6 p. m	5.77	24,150	10 a. m	4.08	14,500
7 p. m	5.75	24,250	11 a. m	4.05	14,325
8 p. m	5.73	23,950	12 m	4.02	14,150
9 p. m	5.63	23,300	1 p. m	4.02	14,150
10 p. m	5.59	23,100	2 p. m	4.01	14,100
11 p. m	5.54	22,750	3 p. m	3.97	13,900
12 p. m	5.49	22,450	4 p. m	3.94	13,750
13. 1 a. m	5.44	22,200	5 p. m	3.85	13,300
2 a. m	5.39	21,000	6 p. m	3.75	12,775
3 a. m	5.35	21,650	7 p. m	3.75	12,775
4 a. m	5.30	21,350	9 p. m	3.71	12,550
5 a. m	5.24	21,000	12 p. m	3.66	12,300
6 a. m	5.21	20,850	15. 6.30 a. m	3.50	11,525
7 a. m	5.16	20,525	1 p. m	3.41	11,050
8 a. m	5.13	20,350	6.30 p. m	3.41	11,050
9 a. m	5.08	20,100	16. 6.30 a. m	3.00	9,125
10 a. m	5.04	19,800	1 p. m	3.00	9,125
11 a. m	5.00	19,560	6.30 p. m	2.91	8,700
12 m	4.94	19,200	17. 6.30 a. m	2.5	6,900
1 p. m	4.89	18,900	1 p. m	2.5	6,900
2 p. m	4.85	18,700	6.30 p. m	2.5	6,900
3 p. m	4.84	18,650	18. 6.30 a. m	2.5	6,900
4 p. m	4.75	18,200	1 p. m	2.41	6,500
5 p. m	4.71	17,900	6.30 p. m	2.33	6,200
6 p. m	4.66	17,650	19. 6.30 a. m	2	4,900
7 p. m	4.64	17,550	1 p. m	2	4,900
8 p. m	4.59	17,250	6.30 p. m	2	4,900

DAMAGES.

GENERAL STATEMENTS.

Estimates of flood damages are always approximations only. It is possible to determine with a fair degree of assurance the cost of replacing structures which have been carried away, to estimate the value of goods destroyed—especially if they be commodities stored in shops or warehouses—to calculate the amount of operatives' wages lost, and in the case of general mercantile business to estimate the damages incurred through consequent reduction of trade. Destruction by flood, however vast, is incomplete. It differs materially from destruction by fire, for often destructible property is of value after floods have passed. Buildings which are inundated still retain value, and many kinds of merchandise are not totally destroyed. Therefore when the amount of damages is calculated there is always to be taken into consideration the fact that a part of the material which has been flooded can be reclaimed, and retains some proportion, at least, of the value which it had previously possessed. Furthermore, damages by flood enter into practically every detail of social and business affairs. There are losses which are severe to one or more persons, and which can not be appreciated except by those whom the floods have actually overtaken. Therefore estimations of flood damages can be only approximate, and while a measure of accuracy may be reached with respect to a part of the losses, there remains a necessity for approximation which can not be classed with carefully computed damages along other lines.

HIGHLAND TRIBUTARIES.

Along the three northern tributaries, the Ramapo, Wanaque, and Pequanac, and at their confluence with the Pompton, the destruction by flood waters was far greater than along the Rockaway, Whippany, and upper Passaic, or in that area described as the Central Basin. In the drainage areas of the three tributaries last mentioned the waters were higher than in the flood of 1902, but the general effects were of the same nature, and consisted principally of flooded lands, houses, and washouts. There were few radical cases of complete destruction like those which marked the course of the flood in the northern tributaries. The principal interest is therefore confined to the Pompton and the three highland tributaries which discharge into it.

Ramapo River.—The greatest destruction was along the Ramapo. It is the largest of the upland branches, and was therefore the heaviest contributor to the main stream. Throughout the flood period the stream was especially violent, causing great apprehension in the lower valley.

The destruction along several stretches of the valley was almost complete. Nearly all the dams failed, and every bridge across the river, with one exception, was carried away. Some small villages were swept bare, and the damages to realty value and personal property were excessive.

It was only by strenuous measures that the dam impounding the waters of Tuxedo Lake was saved. If this had failed the destruction along the entire course of the river, even to the cities in the lower valley, would have been enormously increased.

The dam at Cranberry Pond, in Arden, failed in the early part of the storm, the flood waters disabling the Tuxedo electric-light plant and inundating the Italian settlements along the river below. The failure of the dam conserving the waters of Nigger Pond, which lies at the head of a small tributary emptying into the Ramapo below Tuxedo, resulted in the inundation of Ramapo village. The village of Sloatsburg was practically obliterated.

The damage at Pompton Lakes was especially severe. During the early part of the flood the timber dam of the Ludlum Steel and Iron Company, which raised the water to a height of 27 feet, and afforded 7.04 horsepower per foot fall, was carried away with a part of the headrace. (See Pl. II, *A*.) This sudden emptying of Pompton Lake, an expanse of 196 acres (see Pl. II, *B*), was extremely destructive to Pompton Plains, and the destruction of the dams above on Ramapo River, which followed some time after the bursting of the lower dam, refilled Pompton Lake above its former level, and caused greater damage than that which resulted from the failure of Pompton dam itself. The large iron bridge just below the dam was carried away, with the stores of the Ludlum Steel and Iron Company. The river front along this company's property was destroyed, along with coal docks at the head of Morris Canal feeder. The channel of the river below the dam is filled with débris, which will raise the height of the water in the tailrace, and unless it is cleared will diminish the available power at the iron works. It has been authoritatively announced, however, that the power facilities will not be restored, as the Ludlum Steel and Iron Company is preparing to use steam power exclusively.

Pequanac and Wanaque rivers.—Along Pequanac River the principal damage consisted of washed-out roads and destroyed bridges. The large ponded area in this basin was practically full at the time of the flood, and, as measurements at Macopin dam show, the run-off per square mile was extremely large. In the Wanaque drainage area the storage facilities afforded at Greenwood Lake were probably useful in holding back a part of the water for a brief period, but the damages along the stream are comparable to those of the Pequanac.

The effect of the flow from these two streams, added to that of the Ramapo, was particularly disastrous over the Pompton Plains. Three

A. POMPTON LAKES DAM AND WATER FRONT OF LUDLUM STEEL AND IRON COMPANY.

B. DRY BED OF POMPTON LAKE.

FLOOD DISTRICT OF PATERSON, N. J.

bridges at Pompton station, over Wanaque and Pequanac rivers, were carried away, and in the end one bridge only remained over Pompton River, that at Pequanac station. In all about 100 houses were inundated on Pompton Plains, and the damage to roads and culverts was particularly severe.

The total loss in the drainage area of Pompton River was $350,000.

CENTRAL BASIN.

Over the Central Basin there was the usual impounding of flood waters, but the effects were not materially different from those described in the report on the flood of 1902. The damage along this basin from floods of this character is accumulative by reason of the fact that the presence of water over the land for so long a period kills the desirable feed grasses and fosters in their place the coarse meadow grass. This effect has been observed for some years, particularly since the flood of 1896. It is estimated that over the Central Basin the damage to crops and arable land alone arising from the floods of 1902 and 1903 amounts to $300,000. A statement of the damage arising from the later flood can not separately be made, as its effect upon the fertility of the meadow lands can not be determined without the experience of a planting season.

LOWER VALLEY.

The flow of the stream through the constricted channel at Little Falls and on to Great Falls at Paterson is given in the weir measurements on page 17. It was attended by comparatively large damages, the features of which were not materially different from those described in the previous report. The pumping station of the East Jersey Water Company, situated just below Little Falls dam, did not suffer as severely as during the previous flood, by reason of the fact that extensive and effective barricades were placed so as to keep a large part of the water away from the pumps. This was not accomplished in the flood of 1902. The total damage in this district amounted to nearly $200,000.

The channel contours were changed somewhat in this portion of the stream. In the river at the pumping station of the East Jersey Water Company there was completed a somewhat interesting cycle of changes, described in the following extract of a letter from Mr. G. Waldo Smith, chief engineer for the New York aqueduct commissioners, and formerly engineer and superintendent of the East Jersey Water Company:

"No better illustration of the old adage, 'The river claims its own,' could be given than that offered by the action of Passaic River at Little Falls, New Jersey, at the point where the works of the East Jersey Water Company have been constructed. These works were built between 1897 and 1900. In the course of the work the river channel for a distance of several thousand feet down stream from the power house was drained and improved, so that the head on the wheels at the ordinary stage of the river was increased about 6 feet. From the time this improvement was completed to March, 1902, through the action of the ordinary flow of water and moderate floods, this head had been reduced about one-third. The great freshet of March, 1902, cut off about another third, and the recent flood has completed the cycle and entirely wiped out the benefit due to the river improvement, and the water at the pumping station stands now at almost precisely the same level that it stood before any improvements were undertaken. New bars were formed in approximately the same location as they existed before, and, so far as possible, except for the changed conditions brought about by the building of the power station, the condition of the river is not dissimilar to that existing when the work was commenced.

"In this connection it might be well to state that a New Jersey drainage commission, in blasting out a channel below the Little Falls dam some years ago, dumped a considerable portion of the excavation in the deep water under the Morris Canal viaduct.

"The action of the two great floods, March, 1902, and October, 1903, has washed a large part of this material out of this deep hole and piled it up in the river about 300 feet below where the river widens, and reduces the force of the current.

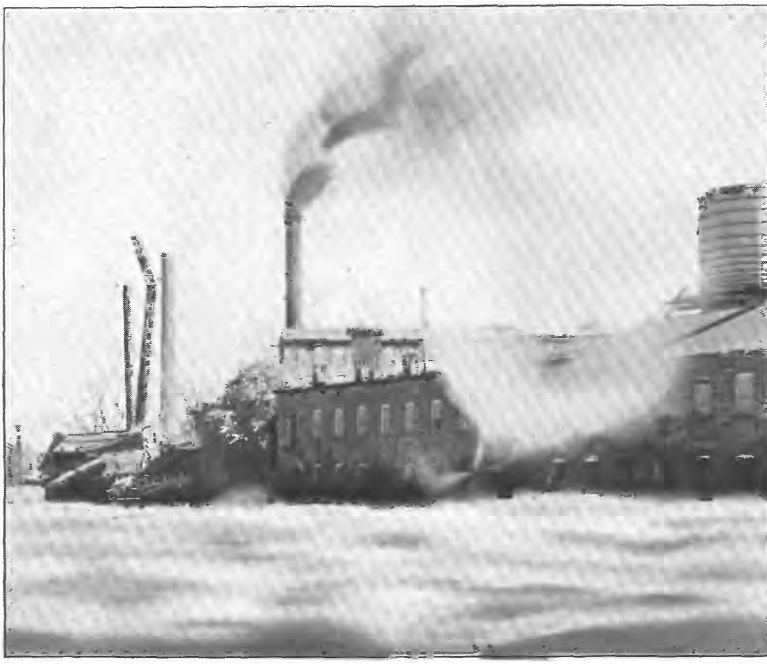
"I have made no estimate of the amount of material deposited in the river, but offhand should say that it would be at least 100,000 yards."

Paterson.—The flood district in the city of Paterson (see Pl. III) comprised 196 acres and involved the temporary obstruction of 10.3 miles of streets. Along the streets close to the river banks the height of water was 12 feet, sufficient to inundate the first floors of all the buildings (see Pl. I, *B*), and in some cases to reach to the second floor. During this flood period householders who remained at their homes were compelled to use boats, while in the more exposed places the danger was too great to admit of remaining, and at one time 1,200 persons were housed and fed in the National Guard armory at Paterson.

The bridges crossing Passaic River in Passaic, Essex, and Bergen counties were almost completely destroyed, and the damage amounted to $654,811. Within the limits of Paterson, below Great Falls, all of the highway bridges except two were either severely damaged or completely carried away. West street bridge, the first below the falls, was a Melan concrete, steel-arch structure, built in 1897, and costing $65,000. It was composed of three spans, each about 90 feet long. The flood practically split two spans longitudinally, the upstream side of each, equal to about one-third of the width of the bridge, being carried

A. WASHOUT AT SPRUCE STREET, PATERSON, N. J.

B. RIVER STREET, PATERSON, N. J., AFTER FLOOD.



A. EFFECTS OF FLOOD IN MILL DISTRICT, PATERSON, N. J.

B. THE WRECK OF A HOTEL IN PATERSON, N. J.

away. This structure was built to conform to the established grades of streets on both sides of the river and was completely inundated, forming a barrier for floating débris and practically making a dam in the river. Main street bridge is a 3-span, steel-arch structure, which was completely covered during the flood, but was only slightly injured. Arch street bridge, built in 1902 to take the place of a structure carried away by the March flood, was a concrete-arch bridge of three spans. It was undermined at the north pier and collapsed, being practically destroyed. The original cost of this bridge was $34,000. Its piers presented a serious obstruction to the flow of the stream, especially as the channel is very narrow at this point. In addition to this, the bridge was of low grade and admirably adapted for deterring flood flow. Below Arch street bridge all the other structures crossing the Passaic were of iron and were carried away, with the exception of Sixth avenue and Wesel bridges. Those destroyed were designated as follows: Straight street, Hillman street, Moffat, Wagaraw, Fifth avenue, East Thirty-third street, and Broadway bridges. All these structures were built too low, and were inundated during the early stages of the flood.

The damage to real property, stock, and household goods in the city of Paterson amounted, according to certified returns, to about $2,700,000. It is impossible to secure correct figures, because merchants and manufacturers refuse to give details of losses, fearing that the publication thereof would affect their credit. General ideas concerning the destruction by the flood can be gathered from Pls. I, *B*, III, IV, V, and VI.

Passaic and vicinity.—Below the city of Paterson destruction was as complete as in Paterson, although the damage was not as great because the improvements were not as valuable. Damage to property, exclusive of public works, in this region, amounted to about $1,250,000. This estimate does not take into consideration losses by manufacturers arising from destruction of raw materials or finished products. The flood was about 4½ feet higher than that of 1902. (See Pl. VII, *A*.)

On the right bank of Passaic River, in the city of Passaic, the damage was severe, especially to manufacturing plants. In addition to the flood in the Passaic itself, the bursting of Morris Canal, a few miles east of Passaic, flooded Wesel Brook, which in Passaic is used as the tail-race of the Dundee Power Company. The capacity of Wesel Brook channel is limited, and the extraordinary amount of water which was turned into it carried away all culverts and bridges from Richfield to Passaic.

Below Passaic, along the river front of Essex County, the damages to bridges amounted to $50,000. (See Pl. VII, *B*.) The loss due to washouts in roads throughout the county amounted to $15,000. The effects of the flood were apparent along the entire length of the river and into Newark Bay. The damage from inundation in Newark and vicinity amounted to $753,199.

The figures above given with reference to damage along Passaic River are uncommonly accurate, being for the most part the result of a house-to-house canvass by the northern New Jersey flood commission. As has been stated above, tradesmen are reluctant to give full details with reference to their losses through fear of injured credit. Roughly estimating the damage as a whole, and taking into consideration factors which were given to the writer confidentially, the damage throughout the drainage area from this flood will amount to not less than $7,000,000.

PREVENTIVE MEASURES.

GENERAL DISCUSSION.

In the consideration of means of preventing damages by floods every plan proposed falls under one of two general heads—the storage of flood waters or an increase in the capacity of the streams.

The first plan involves the construction at selected localities of reservoirs of sufficient size to hold all or a greater part of the waters which run over the surface during and after storms. This plan is not practicable except where valleys or plains are inclosed by high ridges and these ridges approach sufficiently near each other to admit of the economical construction of a bank or dam across the gorge or bed of the stream which flows through, so that the inclosure will be complete and form a water-tight basin. Where such a reservoir exists the water can be held back and gradually let down through properly provided gates so that the channel will not be flooded.

For flood purposes alone it would be necessary to provide reservoirs of sufficient capacity to contain the run-off waters resulting from the largest storms. With such provisions it would be necessary to entirely empty the reservoir as soon as possible after a storm had passed and leave its full capacity available for the next storm. It is therefore better, wherever possible, to provide a reservoir capacity considerably larger than that represented by the run-off from the heaviest storms, so that water may be stored for use as power or domestic supply. With such provision it is necessary merely to draw from the reservoir water to a depth equivalent to the stream run-off in the drainage area above.

The second plan for prevention of flood damages involves provisions for letting the flood water out rapidly by removing obstructions to its flow by straightening and deepening the channels and providing long embankments, dikes, or levees which rise above the ordinary river level to a height exceeding that of the stream during its highest floods. This plan is most generally followed in the case of large rivers like

A. DEVASTATION IN HEBREW QUARTER, PATERSON, N. J.

B. A COMMON EXAMPLE OF FLOOD DAMAGE.

A. INUNDATED LANDS AT PASSAIC, N. J.

B. UNDAMAGED BRIDGE ACROSS PASSAIC RIVER AFTER PARTIAL SUBSIDENCE OF FLOOD.

the Mississippi, where the contributing area is enormous and the conservation of the waters would be impracticable even if the nature of he country would admit of the construction of reservoirs. In Switzerland, where the torrents occasioned by the rapidly melting snows are especially destructive, the flood waters are confined by a series of parallel dikes on each side of the river, which have the effect of dividing the flow into several parallel streams. As the main river channel fills and overflows the inner dikes, the overflow water collects into the first series of parallel channels, and when a height is reached at which the second dikes are overflowed the water collects into the third, and so on. This gives an enormous carrying capacity, the limit of which is approached slowly, and therefore abundant opportunity is afforded for preparation upon the part of the riparian owner.

The drainage basin of Passaic River is admirably adapted to the development of the conservation system. At its headwaters in the mountains of northern New Jersey are numerous sites for reservoirs. The comparatively limited area draining into Passaic River makes such a scheme relatively inexpensive. On the other hand there is abundant opportunity for effective work in removing obstructions and straightening and deepening the channel of the lower river. So that, all things considered, the prevention of flood damages in the Passaic Basin can be best accomplished by a combination of the two general methods above outlined.

LOWER VALLEY IMPROVEMENTS.

The channel of Passaic River below Great Falls, at Paterson, is of limited capacity. To anyone making an inspection, especially within the city of Paterson, it is readily apparent that the river bed has for years been considered a legitimate field for encroachment. Owners of lands fronting on the river have increased their holdings by filling in beyond the channel line. Buildings have been erected upon these tracts and the builders have not hesitated to extend retaining walls still farther into the river bed. Refuse from the city's streets, light and unstable in character, has been freely deposited upon the bank to be carried out into the river. Thus the channel has been constricted laterally, the bottom raised, and there is left for the flood waters no alternative than that of extending themselves in the upward direction. It would seem that this, at least, should have been unobstructed. Such, however, is not the case.

The bridges across the Passaic have apparently been erected without reference to channel capacity. The authorities have evidently considered it more important to retain established approach levels than to provide proper capacity for river water. As an example the following instance may be cited: During the flood of 1902 a steel truss bridge across the river in Paterson was carried away. The point of crossing was one of the narrowest places in the stream and it should have been clear to everyone that the space beneath the bridge was not large enough to carry flood waters. It should have been apparent that a new bridge, if erected at that point, must be higher than the old one, to be thoroughly safe. Notwithstanding, the new bridge was erected at the level of the old one, and in addition to this, it was a concrete arch structure, and the great piers and low arch springs reduced the former channel capacity about 15 per cent. This new bridge, as might be expected, collapsed during the October flood.

Along the entire course of the stream in the lower valley we find a continuation of instances of unreasonable encroachment and ill-considered bridge engineering, and there is opportunity for relieving a large part of the purely local obstructions by straightening the channel at chosen points.

Although this matter has not been thoroughly investigated it is readily apparent to one traversing the river bank that considerable relief may be secured in this manner. Damage, however, can not be prevented by this means alone. It would, of course, be possible to erect high and resistant levees along the entire course of the river, but this would be extremely expensive and would destroy the water front for commercial purposes. In fact, such a plan is quite visionary. At the present time there are no obstructions in lower Passaic River the removal of which would give relief in the event of floods like those of 1902 and 1903. When one considers the amount of water which was carried into the lower valley, the heights which it reached, and the area which it inundated, the futility of any local improvement except levee construction is emphasized. The present channel of the river will not carry without damage the amount of water recently thrown into it, and while it is important to provide regulations which will in the future prevent encroachment, and which will correct the evils now present along the channel, these measures can not, operating of themselves, give relief from flood devastation. Immunity from flood destruction in the Passaic must come, if it ever comes, from the construction of flood-catchment reservoirs in the uplands.

It is not necessary to spend any great amount of time in determining the cause of floods upon the Passaic. A review of the flood history of this river shows that in every case floods arise from extraordinary precipitation. High waters occur through the melting of snows and during periods of abundant rain. The heavy floods which have been regarded as extraordinary are clearly the result of unusual conditions of precipitation. The river carries the usual flood waters, and no damage is done until the water poured into it is far beyond its carrying capacity. Therefore the provisions which are made for preventing damage by floods must, if they be effective, be designed to meet extraordinary conditions, and means which would prove effectual in ordinary cases will not stand the test. In order to appreciate the extent of the flood in the lower valley it is necessary to visit the flooded area and observe the points of flood height. Unless one does this he will be very readily deceived when he considers means of flood prevention.

FLOOD CATCHMENT.

Among the highland tributaries of Passaic River there are three principal areas where storage reservoirs for flood catchment may be placed: (1) The Ramapo, Wanaque, and Pequanac drainage basins, from which the waters are carried into the central basin by Pompton River; (2) the Rockaway drainage basin, and (3) the upper Passaic drainage basin. The remaining principal tributary of Passaic River, the Whippany, is not well provided with storage reservoir sites. The combined capacity of catchment reservoirs which could be constructed in these drainage areas is considerably more than the volume of the heaviest known rainfall, that of October 8–11, 1903.

In the description of reservoir possibilities in the following pages the data with reference to many of the basins are computed from planimeter and other measurements, the United States Geological Survey topographic maps being used as a base. The measurements are therefore not of refined accuracy but suffice for the purpose in view—that of showing flood catchment possibilities.

POMPTON RESERVOIR.

There are in the Pompton system several sites on Ramapo, Wanaque, and Pequanac rivers which, if utilized, would afford sufficient storage for flood catchment purposes, but the entire flow of the river system may be conserved in what has been described as the Pompton reservoir. This project was first presented by Mr. C. C. Vermeule in the year 1884, the details being described at some length in the Engineering News, of April 12 of that year, pages 169–171. In this article Mr. Vermeule presented the possibilities of Pompton reservoir for use as an additional water supply for the city of New York, at the time when the Quaker Bridge reservoir on the Croton watershed was being considered. A few pertinent quotations from this article may be of interest:

> This basin, subdivided by minor ridges which cross it, furnishes several admirable sites for large storage reservoirs, with catchments from 50 to 400 square miles in area, lying above on the primitive rock of the Highlands. About 6 miles of the northeastern end of the basin is cut off by Hook Mountain, a small ridge of trap which crosses it from east to west, inclosing a basin 21 square miles in area, known as Pompton Plains, having its outlet at Mountain View, 5 miles west of Paterson, at a pass in Hook Mountain, through which the Pompton River flows to join the Passaic, 2 miles below. This pass is the gateway by which the Delaware, Lackawanna and Western Railroad, the New York and Greenwood Lake Railway, and the Morris Canal enter the plains. The basin is also crossed near its head, above Pompton, by the New York, Susquehanna and Western Railroad.

The Pompton River has a drainage area above Mountain View of 420 square miles. It is formed near the head of the basin by the confluence of the Pequanac from the northwest, the Wanaque from the north, and the Ramapo from the northeast. * * * The entire flow from this watershed may be stored by building a dam across the gap at Mountain View and converting Pompton Plains into a great lake covering an area of 21 square miles. The elevation of the river at the gap is 168 feet. The slopes in the basin being gentle up to an elevation of 220 feet and abrupt beyond it, it will be advisable to take this as the minimum or low-water level of our reservoir. It is generally estimated that 25 per cent of the volume of the mean annual rain on a given catchment is sufficient reservoir capacity to fully utilize the flood flows. We have long series of observations of rainfall at three points, which may be taken to fairly represent the Passaic catchment. At Newark the mean annual rainfall is 46.2 inches, at Paterson, 50 inches, and at Lake Hopatcong, 42. The last being on the Highlands, like most of our watersheds, is perhaps the safest to use. Now, 25 per cent of 42.5 inches, 10.62 inches, which, on 420 square miles, give a volume of 10,362,000,000 cubic feet, the necessary capacity of reservoir.

By raising our reservoir to 240 feet when full we secure a capacity of 10,493,000,000 cubic feet, or ample to utilize the heaviest floods of the watershed. This gives a beautiful sheet of water 21.1 square miles in area, with bold, rocky shores, and a depth at dam of 72 feet. We secure the above capacity by uncovering but 22 per cent of the reservoir bottom; and, as we shall presently see, we shall rarely need more than half this storage, and probably not oftener than once in ten years will we expose over 10 per cent of the area. By building side dams to keep certain flats always flowed this may be reduced to 5 per cent; and this area will be pretty evenly distributed around 36 miles of uninhabited shore line, leaving the reservoir open to no valid sanitary objections. On the contrary, by relieving the remainder of the Passaic Basin of the flood waters of the Pompton, which now flow large areas of flat land during wet seasons, the sanitary condition of the valley would be much improved.

In constructing this reservoir Mr. Vermeule stated that the following work would be necessary:

The removal of the Delaware, Lackawanna and Western Railroad from the basin by changing the alignment for 6 miles. It may be done without increase of length or detriment to the alignment.

Three and one-fourth miles of the Morris Canal must be rebuilt. No engineering difficulties are involved.

Of the New York and Greenwood Lake Railway, 9 miles would have to be rebuilt.

The New York, Susquehanna and Western Railroad would be slightly shifted or raised for $3\frac{3}{4}$ miles.

A dam 2,400 feet long and 80 feet in height, with tunnels, wasteweir and accessory works would be required at Mountain View. The situation is such that an ample wasteweir may be built at a low-side dam on the solid rock of Hook Mountain remote from the dam, and outlets may be had by tunneling the same ridge. Hence the dam may be a plain, heavy earthen embankment; built, of course, with every precaution but subject to less than the usual dangers of such works. However, a masonry dam might readily be substituted.

There would be 14,000 acres of arable land, swamps, and rough mountain land flowed.

The works are estimated to cost as follows:

Railroad and canal diversions	$505,000
Dam and accessory works	1,162,000
Land damages	1,400,000
Total	3,067,000

A recomputation of the drainage area above Mountain View, made by the northern New Jersey flood commission, shows that it is 380 square miles in extent. It was decided by this commission that the construction of this reservoir would be the most approved method of preventing disastrous floods in the lower valley of the Passaic. By raising a dam to a height of 202 feet above tide, 8 inches of water on the drainage area above might be held back, which, it was believed, would be a sufficient maximum for flood catchment. With this amount of storage the estimates of the flood commission showed that the remainder of the drainage area would not turn a sufficient amount of water into the lower valley channel to cause flood damages.

It was also demonstrated by the flood commission that by increasing the height of the dam an opportunity would be afforded for conserving water, and at the maximum height of 220 feet above tide sufficient storage capacity would be available to provide 5,000 horsepower at Little Falls, Great Falls, and Dundee dam throughout all dry seasons. The value of such a storage reservoir for municipal water-supply purposes is self-evident.

The cost of Mountain View reservoir would be about $3,340,000. Developed for flood catchment with the spillway of the dam at 202 feet above sea level the area of the reservoir would be 13.4 square miles, and the storage capacity 7,200,000,000 cubic feet.

RAMAPO SYSTEM.

Along the Ramapo Valley there are alternative propositions, one of which involves the construction of a dam below Darlington and another across the head of Pompton Lake.

In either case the water might be raised to the 300-foot contour, and if the dam across Pompton Lake were constructed a continuous lake would be formed extending 10½ miles to Hillburn, N. Y. The improvement in either case would be positive, for as the country surrounding is hilly or mountainous it affords excellent opportunity for the location of summer homes and parks, the lake being a potent factor in beautifying the situation and increasing the value of the surrounding region. There are, nevertheless, several things to be taken into consideration, the most important of which are the improvements which have been made by wealthy residents along the valley where it has already been developed as a summer resort.

By the construction of a dam at Darlington 1,100 feet long and 70 feet high, the water would be raised to the 300-foot contour. The reservoir would have a water area of 2,064 acres, and the approximate storage capacity of 2,325,000,000 cubic feet.

A dam across the head of Pompton Lake 2,850 feet long and 100 feet high would raise the surface of the proposed lake to the 300-foot contour. This reservoir would have an area of 6.19 square miles and a capacity of 6,300,000,000 cubic feet, equal to 17.5 inches run-off from the drainage area. Here the measure of safety is wide, and if there were drawn from the lake an amount of water equal to 12 inches on the drainage area there would still be 5.5 inches which could be used for compensating purposes.

The construction of either one of the above-described reservoirs would involve interstate complications, as the 300-foot contour in Ramapo Valley includes a considerable part of the State of New York. This obstacle was deemed insurmountable by the northern New Jersey flood commission, and that commission directed studies to a reservoir which at the time of maximum flood would not back water into New York State to a greater height than it already rises during such floods. The following description is taken from the report of the engineering committee of the flood commission:

> An admirable dam site is offered on Ramapo River about 2 miles above Oakland village. The drainage area tributary to this point is about 140 square miles in extent, the country for the most part being quick-spilling and upland. By constructing there a dam 700 feet long and 65 feet high a reservoir with a water surface of 2.8 square miles would be afforded, the flow-line elevation being 280 feet above tide. The capacity of such a reservoir would be 1,768,000,000 cubic feet, equal to about 5.5 inches on the drainage area.

WANAQUE SYSTEM.

Near the headwaters of Wanaque River is Greenwood Lake, a large body of water described in Water-Supply Paper No. 88. Its value as a flood catchment basin is somewhat uncertain, as it is used as a storage feeder for Morris Canal. The surface level of this lake is controlled by gates, which naturally are operated by the canal authorities for the benefit of the canal. Therefore it is the object to store as great a volume of water as possible, and the water falls below the dam crest at the outlet of the lake only when the dam opens in dry seasons and makes it necessary Under such conditions there is no certainty that storage capacity will be available during the time of a great storm, and in fact Greenwood Lake has been overflowing at the commencement of the storms which caused both of the recent floods.

In view of the condition expressed above it will be necessary in providing for flood catchment in the Wanaque drainage area to omit entirely from consideration the possibility of assistance from Greenwood Lake. Below this point in the basin are several sites at which could be raised dams, which would effectually retain a large proportion at least of storm run-off. They may be described as follows:

Midvale reservoir.—By building a dam 60 feet high and 1,200 feet long across Wanaque River near Midvale, a reservoir would be formed which would have a water surface of 2.1 square miles and a capacity of 1,491,000,000 cubic feet. The drainage area above this site is 83 square miles, and the storage capacity would therefore be equal to about 7.7

inches on the drainage area. The construction of this project would involve the relocation of about 4½ miles of the New York and Greenwood Lake Railroad; the damages apart from this would be nominal, the cost of the entire reservoir construction being about $1,000,000.

Ringwood reservoir.—Ringwood Creek runs through a gorge about 1 mile above its confluence with the Wanaque. Above this is a well-defined basin. A dam about 70 feet high and 585 feet long would create a lake having an area of 520 acres, the surface of which would be 380 feet above sea level. The drainage area tributary to this point has an area of about 20 square miles, and as the proposed reservoir would have a capacity of 915,800,000 cubic feet, there could be conserved a run-off of 20 inches. Allowing for a flood run-off of 12 inches there would still be available for compensating purposes 8 inches on the basin, equal to 373,550,000 cubic feet. The construction of this reservoir would involve the relocation of about 2 miles of the Ringwood branch of the New York and Greenwood Lake Railroad, and the condemnation of comparatively valuable improvements in the proposed basin.

West Brook reservoir.—The drainage from 5.7 square miles might be conserved by the erection of a dam on West Brook, a tributary of Wanaque River, which enters it from the west. There is an available site at which a dam 280 feet high might be erected. At this elevation the length along the top would be about 1,150 feet and about 2,330,000,000 cubic feet of water would be impounded. Little benefit would be derived from such a reservoir, as the limited drainage area affords a comparatively small proportion of flood run-off that might be well cared for at a lower point. For compensating purposes, however, a reservoir might be constructed here, the capacity of which could be adjusted to the actual demands. If the dam were raised to a height of about 280 feet from the base the storage afforded would be equal to 176 inches on the watershed, or about four average years of precipitation, which is far beyond all probable storage necessities. The maximum available storage capacity is given in this case merely to show possibilities.

PEQUANAC SYSTEM.

There are few available reservoir sites of large size along the lower reaches of Pequanac River. In the upper basin, however, there is a sufficient available storage capacity to afford almost complete control of destructive floods from that part of the drainage area. Large tracts are already reserved by the city of Newark for collection of municipal supply, and the storage capacity developed is sufficient to serve the city throughout the driest seasons. The total capacity of Clinton, Oakridge, and Canistear reservoirs is about 1,155,000,000 cubic feet. These basins are not available for flood catchment, as the water is used for city purposes and an endeavor is made to have in storage at all times the largest possible amount. The condition is exactly similar to that described in the case of Greenwood Lake. In considering the means for the construction of flood-catchment reservoirs in Pequanac Basin there must be taken into account the conservation and delivery of the Newark supply. The adjustments with reference to the amount of water available at Macopin intake would have to be met, and if the system were interfered with compensation therefor would be taken into consideration.

Newfoundland reservoir.—Pequanac River passes through a deep gorge between Copperas and Kanouse mountains, just below the village of Newfoundland. This point has been considered an excellent site for the construction of a dam, and in the installation of the present water-supply system of Newark it is proposed that the entire valley in which Newfoundland is situated be overflowed. The site is one of the most advantageous known for the creation of a flood-catchment basin. If a dam 50 feet high were erected across this gorge, a lake would be formed which would have a surface area of 3.15 square miles and a capacity of 3,267,200,000 cubic feet, equal to a storage of about 30.5 inches on the 46.12 square miles of contributing drainage area. This would afford complete protection in case of a sudden run-off of 12 inches, would provide for the supply of the city of Newark without greatly disturbing the present storage system of that city, and would still yield a large amount of water for compensating purposes in dry seasons.

The construction of Newfoundland reservoir would be very expensive, as it would involve the flooding of Newfoundland Village, in which there is considerable improved property. About 3 miles of the track of the New York, Susquehanna and Western Railroad would be submerged, as well as a considerable mileage of macadamized highways. On the whole, however, the Newfoundland reservoir project is the most favorable which can be found on the Pequanac Basin. There are above this point numerous reservoir sites, but their combined capacity would not be equal to that of the proposed Newfoundland reservoir, and the construction would be probably quite as expensive.

Stickle Pond reservoir.—Below Newfoundland there are few available places at which water could be stored. Stickle Pond is probably the best adapted of any of those available. If a dam 1,050 feet long and 80 feet high were erected across the river about 1 mile below the present outlet of Stickle Pond, a lake would be formed having a surface area of 422 acres and a storage capacity of about 800,000,000 cubic feet. The drainage area above this dam would be approximately 4 square miles. This is a comparatively small amount of storage, yet it would provide for all flood catchment in that comparatively limited area and would be of assistance at times in compensating the dry flow of the Pequanac.

ROCKAWAY SYSTEM.

Rockaway River offers a greater number of available reservoir sites than either of the other highland tributaries of the Passaic. Some of the reservoirs which could be constructed could be used solely as catchment areas to hold back flood waters, while the capacity of others would be so much greater than any single flood run-off that they might serve also as compensating reservoirs. A large dam is now in process of erection at Old Boonton, conserving a considerable amount for the water for the municipal supply of Jersey City. This reservoir can not be depended upon as a flood-catchment area, as it will be the aim of those in authority to maintain the water in it as high as possible.

Powerville reservoir.—A short distance above Boonton the erection of a comparatively small dam would flood a large, irregular, flat basin having an area of a little more than 4½ square miles and extending up the Rockaway Valley to Rockaway Village, up Beaver Brook to Beech Glen, and north and south for considerable distances. The probable capacity of this reservoir has been estimated, and it is fairly certain that it is considerably more than would be sufficient for flood catchment. Its construction would, moreover, improve the entire valley and be of advantage to many interests.

The northern New Jersey flood commission has selected for investigation a reservoir site on Rockaway River at Powerville. By the erection of a dam across the stream at this point, 28 feet in height and 470 feet long, a reservoir 4.6 square miles in area, with a capacity of 1,565,000,000 cubic feet, would be afforded. The drainage area above this point is 114 square miles. The cost of such a reservoir is estimated at $600,000.

North from Powerville, near the confines of the proposed Powerville reservoir, there is an available reservoir site along Stony Brook. By the erection of a dam 1,100 feet long and 120 feet high a lake would be formed 645 acres in extent, which would serve as a flood-catchment basin and a compensating reservoir. This reservoir would hold approximately 850,000,000 cubic feet. The construction of a reservoir at this place offers no engineering difficulties, and the project may be regarded as extremely favorable.

Dixons Pond, west of Rockaway Valley and northwest of Powerville, is a small sheet of water which lies in a valley which might be flooded to a greater height. By the erection of a dam 450 feet long and 30 feet high a lake of 136 acres would be created, which would form a part of the flood catchment and compensating service.

Longwood Valley reservoir.—A large storage basin is afforded in Longwood Valley which, if developed to its full extent, would extend from a point about a mile below Lower Longwood 7 miles up the headwaters and reach to about 1½ miles above Petersburg. An alternative proposition is afforded which involves the submerging of less than half this area.

A dam 800 feet long and 55 feet high might be erected across a gorge about 1 mile south of Petersburg. There would be formed a lake of about 1.247 square miles, or 800 acres in extent. The hamlet of Petersburg would be submerged, but the damages from the destruction of improved property would not be very great, as the improvements and the land are not especially valuable. This reservoir would have a capacity of about 964,000,000 cubic feet and the surface would be at a height of 800 feet above sea level.

The alternative plan, that of using a longer stretch of the valley for reservoir purposes, would involve the construction about 1 mile below Lower Longwood of a dam 1,300 feet long and 110 feet high. The reservoir thus formed would be 1,900 acres in extent and contain approximately 3,447,000,000 cubic feet. The drainage area above this dam is limited, and if the reservoir were drawn down to an amount equivalent to 15 inches upon the drainage area there would still remain an enormous amount of water which could be used in a compensatory way to tide over dry seasons.

Splitrock Pond.—By erecting a dam 550 feet long and 30 feet high across a gorge at the outlet of Splitrock Pond, a lake could be formed having an area of 625 acres and adding to the present storage capacity of the lake an amount approximately equal to 475,000,000 cubic feet, equivalent to 38.75 inches on the drainage area.

Thus it is seen that if this reservoir were drawn down an amount equivalent to 15 inches on the drainage area, which would without doubt give sufficient protection from all floods, there would still remain a storage capacity of 23.75 inches for compensating purposes in addition to the amount now available in Splitrock Pond. This project is one of the most attractive in the Rockaway Basin, as the damages which would be caused by flooding would be, comparatively speaking, nil. The property is, however, now owned by the East Jersey Water Company, and is prized highly as a reservoir site by that corporation.

UPPER PASSAIC BASIN.

Millington reservoir.—There is an area of swamp land, comprising a part of the drainage area of upper Passaic River above Millington, which is known as Great Passaic Swamp. It is bounded on the south by a long, narrow trap ridge known as Long Hill, the summit of which ranges from 400 to 500 feet in elevation, or roughly 200 feet above the border of this swamp. To the northwest the land rises gradually toward Trowbridge Mountains, while to the northeast is the terminal moraine. The outlet of Passaic River at Millington is by a narrow gorge, which offers natural facilities for the erection of a dam.

The whole situation is exceptionally good, and the surface of a reservoir might be fixed at any elevation between 240 and 300 feet above sea level. With the surface of the reservoir at 300 feet a dam 1,600 feet long and 90 feet high would be required. This lake would have an area of 28.46 square miles. The drainage area above Millington has, however, an area of only 53.6 square miles, and the proposed reservoir would therefore cover more than half of this. Therefore the conservation of so large a quantity of water would not be necessary nor advisable, unless the beautifying of the surrounding country were an object to be taken into consideration, which might be profitable.

A better project, however, would be to construct a dam at Millington 900 feet long and 50 feet high, the crest being about 260 feet above sea level. There would be formed a lake with an area of 19.41 square miles, and a capacity of 1,477,600,000 cubic feet, equal to 9.864 feet on the drainage aréa. This project is too great for the necessities here presented, and would not be wisely considered unless it were found advantageous to improve the country generally as a place of suburban residence. The land which would be flooded with the reservoir crest at 260 feet is of a wet, swampy character, and its value for agricultural purposes is somewhat doubtful. Such construction would involve the flooding of 13 miles of road, which, however, would not involve a great loss of invested capital, as the roads generally are of a poor character.

A second alternative would involve the construction of a dam across the Millington gorge, 550 feet long and 30 feet high, raising the water to 240 feet above sea level and creating a lake of 14.40 square miles. This would conserve 4,026,000,000 cubic feet, equal to 2.69 feet on the drainage area. This would be ample for flood purposes and would still afford a large impounded area, as the drawing off of an amount equal to 10 or even 15 inches on the watershed would not reduce the size of the lake to any great extent.

The whole project here presented involves few difficulties, and as the drainage area above is of small extent, the mere question of conserving the flood waters could be met without great difficulty. The natural advantages, however, are so great and the land included within Great Passaic Swamp is of so little value that the surrounding country would be improved and beautified by the construction of such a reservoir. The opportunity for varying the character of the reservoir to meet the ideas of those interested seems unexampled, and as a whole it presents an extremely interesting field which may be profitably exploited.

SADDLE RIVER.

This stream has been described in the report on the flood of 1902, already referred to. It contributes a large amount of water to the main artery of the Passaic below Dundee dam, and as the river channel at that point is overburdened under the present conditions because of lack of slope and numerous catchments, together with what is known as the Wallington Bend, it increases very materially the damage caused by floods.

The most effectual remedy in the case of Saddle River floods is that of construction of flood catchments. No studies have been made of the situation in the Saddle River drainage area, but a superficial inspection of the basin shows that opportunities for the construction of flood-catchment reservoirs are not numerous.

SUMMARY OF FLOOD-CATCHMENT PROJECTS.

By following the plans described in the preceding pages absolute flood catchments may be provided above Little Falls on the Passaic Basin for 551.7 square miles, leaving only 221.2 square miles from which flood run-off would flow immediately. The accomplishment of this would involve the construction of Pompton reservoir, which would withhold all flood waters from the northern tributaries. It would leave unprovided for 20.2 square miles on the Rockaway, 71.7 square miles on the Whippany, 46.2 square miles on the upper Passaic, and 83.7 square miles tributary to the Central Basin and not included above.

Leaving Pompton reservoir out of consideration, and conserving flood run-off on the Ramapo, Wanaque, and Pequanac rivers, there would be absolute flood catchment up to a 12-inch run-off over 494.8 square miles above Little Falls. This would leave 278.1 square miles unprovided for, the run-off from which would not overburden the channel in the lower valley, provided, of course, that channel were improved to a maximum carrying capacity.

PREFERABLE RESERVOIR SITES.

The following table and discussion of preferable sites for flood prevention are taken from the report of the engineering committee of the northern New Jersey flood commission:

Table showing detailed facts regarding possible reservoir sites on Passaic drainage basin.

Reservoir.	Area of watershed.	Area of reservoir.	Height of dam.	Length of dam.	Elevation of flow line.	Storage, watershed.	Storage capacity.	Total cost.
	Sq. mi.	*Sq. mi.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*	*Million c.f.*	
Ramapo	140	2.8	65	1,700	280	5.5	1,768	$900,000
Wanaque	83	2.1	60	1,200	275	7.7	1,491	1,000,000
Newfoundland	52	1.8	40	430	780	8	966	1,800,000
Rockaway	114	4.6	28	470	520	6	1,565	600,000
Millington	56	15.8	25	220	245	31	4,060	370,000
Great Piece	773	37	21	1,500	178.5	[a] 9	8,950	2,625,000
Mountain View	380	13.4	42	2,150	202	8	7,200	3,340,000
Do	380	13.9	44	2,380	204	9	7,900	3,460,000
Do	380	14.3	46	2,470	206	10	8,700	3,590,000
Do	380	17.4	60	3,000	220	17	15,000	5,260,000

[a] Including water discharged through fixed openings, in a flood similar to that of October, 1903. Maximum discharge, 12,000 cubic feet per second.

With the exception of the Millington reservoir site where the cost of the dam is a small factor, the elevation of flow line in the various reservoirs which determines the capacity was fixed so as to afford an approximate storage equal to a run-off of about 8 inches from the drainage area above each dam site. This amount is somewhat in excess of the run-off for the flood of October, 1903. It was found impracticable on the Rockaway reservoir site to provide for a storage greater than 6 inches. On the Wanaque the amount which can be stored falls slightly under 8 inches, while on the Ramapo it is possible to obtain only 5½ inches, by reason of the fact that with a greater storage capacity the slack water would reach into New York State. The economical height for a dam at the lower end of the Great Piece Meadow, if such dam is provided with fixed discharge openings which will carry a maximum outflow of 12,000 cubic feet per second, will provide a reservoir which will dispose of a run-off of 9 inches on the drainage area above.

The following combinations of reservoir sites, with their respective drainage areas, proportional storage, and estimated costs, give the facts necessary for final deductions:

Site.	Drainage area.	Water collected.	Equivalent area retarded.	Cost.
	Square miles.	*Inches.*	*Square miles.*	
Ramapo	140	5.5	96.25	$900,000
Wanaque	83	7.7	80	1,000,000
Pequanac	52	8	52	1,800,000
Rockaway	114	6	85.5	600,000
Total	389	....	313.75	4,300,000
Ramapo	140	5.5	96.25	900,000
Wanaque	83	7.7	80	1,000,000
Rockaway	114	6	85.5	600,000
Millington	56	31	56	370,000
Total	393	....	317.75	3,870,000
Great Piece	773	4.5	435	2,625,000
Mountain View	380	8	380	3,340,000

The necessity to retard the flow of or provide storage for approximately 380 square miles of highland drainage area has been determined after careful study, and there has been deduced an amount which may safely be expected to represent the maximum for the highest floods. When the highland tributaries are sufficiently checked the natural storage on Great Piece Meadow in its effect upon flood control becomes more apparent. Our investigations show that the holding back of the flood flow—that is, 8 inches run-off on approximately 380 square miles of flashy drainage area above Great Piece Meadow—is necessary to reduce the discharge in the river through the city of Paterson to 14,000 cubic feet per second for a flood similar to that of 1903.

From the foregoing table, in which different reservoir projects are compared, it is seen that only the reservoirs designated as Great Piece and Mountain View will fulfill the requirements within a reasonable limit of cost. It is also shown that a combination of any other available sites would involve the expenditure of more money for their construction and the control of less tributary drainage area than is fulfilled by the demands of the Passaic drainage basin. We are therefore brought to the conclusion that only two of the projects above set forth will be effective. First, the construction of a regulating dam on the main stream above Little Falls, which we have called the "Great Piece" Meadow Reservoir, and second, the building of a dam at Mountain View across Pompton River. The relative cost of these reservoirs, constructed for flood control exclusively, is $2,625,000 for that on Great Piece Meadow and $3,340,000 for the Mountain View site. Details of these estimates are as follows:

Estimate of cost of Great Piece Reservoir, dam at Little Falls.

[Elevation of flow line, 178.5 feet. Storage and disposal of 9 inches collected.[a]]

Earth excavation, 17,600 cubic yards, at 35 cents	$6,160
Rock excavation, 8,800 cubic yards, at $2	17,600
Rubble masonry, 29,100 cubic yards, at $5	145,500
Ashlar masonry, 1,800 cubic yards, at $12	21,600
Facework of rubble masonry, 2,850 square yards, at $1.50	4,275
Concrete masonry, 250 cubic yards, at $6	1,500
Slope paving, 300 cubic yards, at $2	600
Crushed stone, 150 cubic yards, at $1.50	225
60-inch cast-iron pipe in place, 360 tons, at $35	12,600
Relocation of railroads, Erie, 5 miles, at $20,000; Delaware, Lackawanna and Western, 4.5 miles, at $40,000	280,000
Relocation of highways	170,000
Real estate:	
Above Mountain View	500,000
Additional for village of Singac	100,000
22,000 acres, at $50	1,100,000
	2,360,000
Add for engineering and contingencies	240,000
	2,600,000
Protection of pipe lines, Newark and Jersey City	25,000
	2,625,000

The effectiveness of a reservoir built upon the lines proposed in the case of Great Piece Meadow depends upon the adjustment of outflow so that the channel below will not be overborne, while at the same time sufficient storage capacity is afforded to hold temporarily the water which enters above the dam in amount greater than the carrying capacity of the outflow apertures. The dam across Passaic River above Little Falls would be provided with apertures which would discharge 12,000 cubic feet per second under the maximum head in the storage basin. As the flood rises these apertures would discharge a constantly increasing amount of water to the maximum, and for a considerable time thereafter the maximum would be maintained, the discharge decreasing after the flood according to the height of water remaining in the reservoir.

[a] Includes water discharged through fixed openings for a flood similar to that of October, 1903. Maximum flow, 12,000 cubic feet per second.

Estimated cost of Mountain View Reservoir.

[Elevation of flow line, 202 feet. Storage of 8 inches on watershed.]

Earth excavation:	
Stripping dam base, 83,500 cubic yards, at $0.30	$25, 050
Core wall trench, 24,900 cubic yards, at $1	24, 900
Rock excavation, 10,100 cubic yards, at $2	20, 200
Rock fill in dam, 197,000 cubic yards, at $1.25	246, 250
Rubble masonry, 23,200 cubic yards, at $5	116, 000
Concrete, 30,000 cubic yards, at $6	180, 000
Gate chambers and tunnels	65, 000
Reconstruction of highways	142, 400
Reconstruction of railroads	815, 000
Real estate	1, 360, 000
	2, 994, 800
Engineering and contingencies	325, 200
	3, 320, 000
Protection of Newark pipe line	20, 000
Total cost	3, 340, 000

[Same for elevation of flow line, 204 feet. Storage of 9 inches on watershed.]

Earth excavation:	
Stripping dam base, 85,200 cubic yards, at $0.30	$25, 560
Core wall trench, 26,000 cubic yards, at $1	26, 000
Rock excavation, 10,600 cubic yards, at $2	21, 200
Rock fill in dam, 214,000 cubic yards, at $1.25	267, 500
Rubble masonry, 24,500 cubic yards, at $5	122, 500
Concrete, 30,500 cubic yards, at $6	183, 000
Gate chambers and tunnels	65, 000
Reconstruction of highways	142, 400
Reconstruction of railroads	815, 000
Real estate	1, 435, 000
	3, 103, 160
Engineering and contingencies	336, 840
	3, 440, 000
Protection of Newark pipe line	20, 000
Total cost	3, 460, 000

The final recommendation of the committee involves the consideration of two projects for flood storage, one on Great Piece Meadow and the other above Mountain View on the Pompton. In making such recommendations the committee is of the opinion that it must take into account matters of engineering policy with regard to future needs and contingencies, as well as the bare necessities of the present.

If there were none other than the single problem of prevention the committee would advise the construction of the reservoir on Great Piece Meadow by reason of its smaller probable cost and its equal efficiency. It is plain, however, that there are many important features of public policy involved in the subject at hand. Population in the valley of the Passaic is developing so rapidly that in only a few years the present sources of water supply will be inadequate. The whole subject of water supply for northern New Jersey demands immediate consideration, and it would not be wise to take up the matter of prevention of flood damage in the Passaic without basing the value of every project upon its adaptability for use in future water-supply needs.

By expending $2,600,000 a great reservoir could be constructed upon Great Piece Meadow which could not be adapted for any purposes except to regulate floods; it would stand in season and out of season a huge feature of the valley and entirely useless and inoperative save on the occasion of high water. However great might be the needs of the inhabitants of the Passaic Valley for a conserved water supply, the construction on the meadows, representing an enormous expenditure, would furnish no solution of the problem. It would admit of no enlargement for water-supply storage and would be available for no purpose except flood regulation.

When we consider the Mountain View project, however, we find that as a measure for the prevention of flood damages it fulfills all the requirements and provides in addition all the possibilities and advantages demanded inevitably in the near future. The Mountain View site is an ideal one for the reservoir, and its initial development for flood catchment does not involve the expenditure of a dollar that would be lost in the development of the basin to greater capacities for water supply. From its lowest level, at 202 feet above tide, to its maximum capacity, at a level of 220, there would be no depreciation. Every dollar spent in the initial construction would be effective in the maximum development.

The probable cost of Mountain View reservoir, estimated at $3,340,000, exceeds that of Great Piece by $700,000. It is realized that to many persons this margin may seem very wide. Let us consider briefly just what it really represents.

Suppose, for example, that the Great Piece project is constructed at a cost of $2,600,000. After the elapse of a few years it will be necessary to provide additional storage in the Passaic highlands for water supply or the maintenance of water power. The Mountain View reservoir, or its equivalent in capacity and cost, will then be necessary. The situation will then be as follows: By constructing the Great Piece reservoir in preference to the Mountain View for flood catchment, $700,000 would be saved. We can consider that this amount might be expended to pay a part of the cost of additional conservation above referred to. If, on the other hand, Mountain View had been constructed, there would have been paid on the final cost of conservance the sum of $3,340,000, which, as stated in previous pages, would also have effected flood relief. There would then be the difference between $2,600,000 and $700,000, or $1,900,000, which represents the actual loss which would accrue by reason of the construction of Great Piece reservoir.

The engineering committee, after presenting the merits of both Great Piece Meadow and Mountain View projects, therefore recommends the adoption of the latter in spite of its greater cost, because it is believed that in the end the construction of the Great Piece project would involve an expenditure not warranted by public economy or general expediency.

GENERAL CONCLUSIONS.

1. Great floods in the Passaic Basin arise only after a specially violent precipitation.

2. Under present conditions floods may be expected at frequent intervals.

3. A part of the damage along the lower valley is the result of encroachments on the part of individuals and public and private corporations.

4. The channel in the lower valley may be improved at certain points by straightening it and judiciously making cut-offs.

5. Without the construction of numerous levees the lower valley channel can not be made to carry great flood waters without damage.

6. Immunity from floods can be effected only by the construction of catchment reservoirs in the highlands or levees in the lowlands.

7. Levee construction would involve more damage than is now caused by floods, and the cost thereof would be prohibitive.

8. Flood catchment reservoirs may be constructed economically and provide storage to compensate for the dry-season flow, thereby maintaining water power at Paterson, Passaic, and other points, and providing for municipal water supply in the future.

INDEX.

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