Water-Supply and Irrigation Paper No. 88 Series M, General Hydrographic Investigations, 6

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE PASSAIC FLOOD OF 1902

BY

GEORGE BUELL HOLLISTER
AND
MARSHALL ORA LEIGHTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of the United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Part II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Part III.

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WS 33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls.
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WS 58. Storage of water on Kings River, California, by J. B. Lippincott. 1902. 100 pp., 32 pls.
WS 68. Water storage in Truckee Basin, California-Nevada, by L. H. Taylor. 1902. 90 pp., 8 pls.
WS 73. Water storage on Salt River, Arizona, by A. P. Davis. 1902. 54 pp., 25 pls.
WS 86. Storage reservoirs of Stony Creek, California, by Burt Cole. 1903. 62 pp., 16 pls.

The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Part IV.

SERIES K—PUMPING WATER.

WS 1. Pumping water for irrigation, by Herbert M. Wilson. 1896. 57 pp., 9 pls.
WS 8. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls.
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WS 20. Experiments with windmills, by T. O. Perry. 1899. 97 pp., 12 pls.
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WS 41. The windmill; its efficiency and economic use, Part I, by E. C. Murphy. 1901. 72 pp., 14 pls.
WS 42. The windmill, Part II (continuation of No. 41). 1901. 73-147 pp., 15-16 pls.

SERIES L—QUALITY OF WATER.

WS 3. Sewage irrigation, by G. W. Rafter. 1897. 100 pp., 4 pls.
WS 22. Sewage irrigation, Part II, by G. W. Rafter. 1899. 100 pp., 7 pls.
WS 72. Sewage pollution in the metropolitan area near New York City and its effects on inland water resources, by M. O. Leighton. 1902. 75 pp., 8 pls.
WS 76. Observations on the flow of rivers in the vicinity of New York City, by H. A. Pressey. 1903. 108 pp., 13 pls.
WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp.

(Continued on third page of cover.)

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WASHINGTON

GOVERNMENT PRINTING OFFICE

1903

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., March 30, 1903.

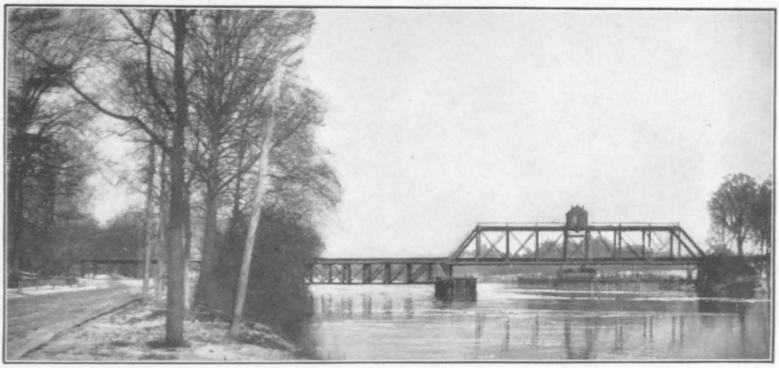
SIR: I have the honor to transmit herewith a manuscript by George B. Hollister and Marshall O. Leighton, relating to a serious flood in the Passaic River basin in northern New Jersey in February and March, 1902, and recommend its publication in the series of Water-Supply and Irrigation Papers.

The region affected by the flood, although a limited area, contains, approximately, one-third of the population of the entire State. Owing to its proximity to the city of New York and to its natural advantages of tide-water frontage and water powers, it contains not only many attractive residential suburbs, but also important commercial and manufacturing centers. The vested capital and community interests are large, and it is therefore desirable that the occurrence and progress of great floods in the drainage area be thoroughly understood. This investigation into the most disastrous flood ever known in the Passaic Valley is of timely interest to all classes of citizens dwelling on lowlands subject to floods.

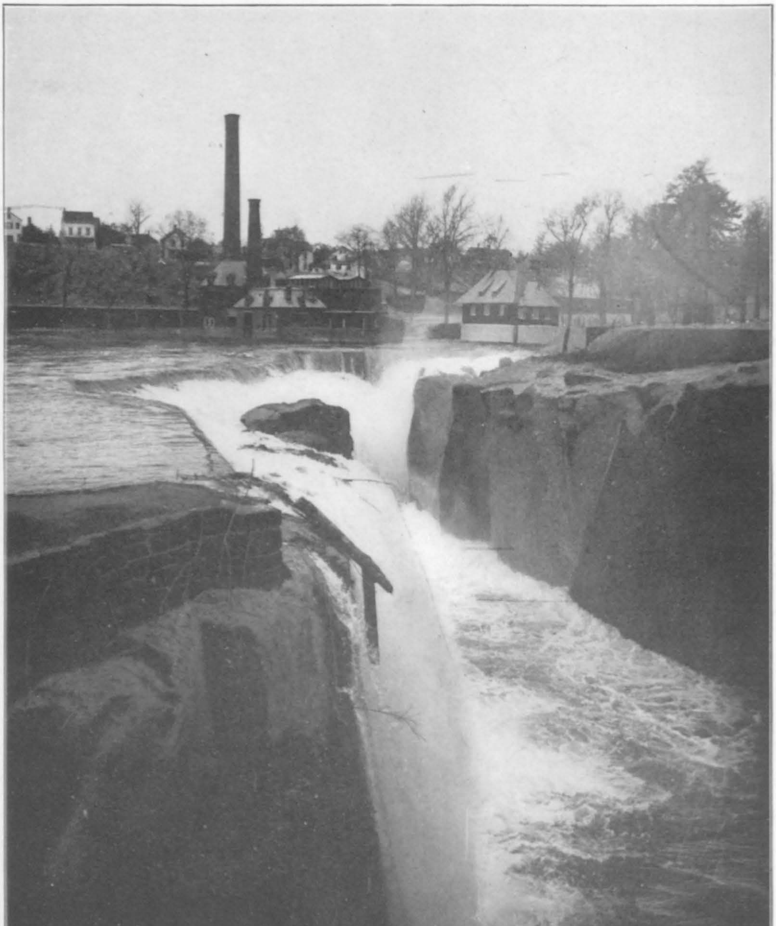
Very respectfully,

F. H. NEWELL,
Hydrographer.

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



A. RAILROAD BRIDGE AT PASSAIC BRIDGE.



B. PASSAIC FALLS AT PATERSON.

THE PASSAIC FLOOD OF 1902.

By G. B. HOLLISTER and M. O. LEIGHTON.

INTRODUCTION.

Late in February and early in March, 1902, there occured upon the drainage basin of the Passaic River in northeastern New Jersey the most disastrous flood in the history of the region. Not only was the discharge the largest recorded, but the flood was the most destructive to life and property in the settlements ever known along the valley.

In the following pages it is proposed to outline the history of this flood, describe the conditions under which it occurred, give the estimated volume of its discharge, and indicate as well as possible the nature and extent of the damage resulting from it.

The data and information embodied in the following report were obtained by personal observation while the flood was in progress and after it had subsided and from various water companies, manufacturers, and residents of the flooded areas. Acknowledgments are especially due to Mr. J. H. Cook, of Paterson, engineer for the Society for the Establishment of Useful Manufactures; to Mr. M. R. Sherred, engineer of the water department of the Newark board of public works; to Mr. R. M. Watson, of Wise & Watson, engineers of Passaic; to Mr. C. C. Vermeule, from whose valuable report on the water supply of New Jersey much data have been taken regarding the physical condition of the watersheds, and to others whose help or suggestions have been of value.

As the region under discussion, though comparatively restricted, is an important one owing to its dense population and rapidly increasing industrial development, and as the physical and physiographic conditions governing high-water stages on the Passaic watershed are peculiar, it is deemed necessary for a full understanding of the present flood to describe briefly their most important features.

DESCRIPTION OF PASSAIC BASIN.

The Passaic River is the most important stream in the State of New Jersey. Its drainage basin covers 949.1 square miles, about 818 of which are in the northeastern portion of the State of New Jersey, while

132 are in the State of New York. On or near its banks are located the cities of Paterson, Passaic, Newark, Orange, East Orange, and Jersey City, the population of which combined with that of adjacent towns and boroughs equals over 500,000, or about one-third the population of the State of New Jersey. The quantity of sewage discharged from this district, with its great population, centered in the lower part of the drainage area, is extraordinary, and the industries carried on in the different communities contribute enormous amounts of manfacturing refuse, all of which is turned into the stream. The results of this wholesale deposit of filth are that for the last 20 miles of its course the river presents one of the most aggravated cases of pollution to be found in the United States.[a]

The water powers of the Passaic were among the first used in the country. The Society for Establishing Useful Manufactures was formed in 1791, for the purpose of developing the large power existing at the Great Falls of the Passaic in the city of Paterson (Pl. I, *B*). Other powers of less extent are found and improved at Pompton, Boonton, Little Falls, Dundee, and elsewhere on the drainage area.

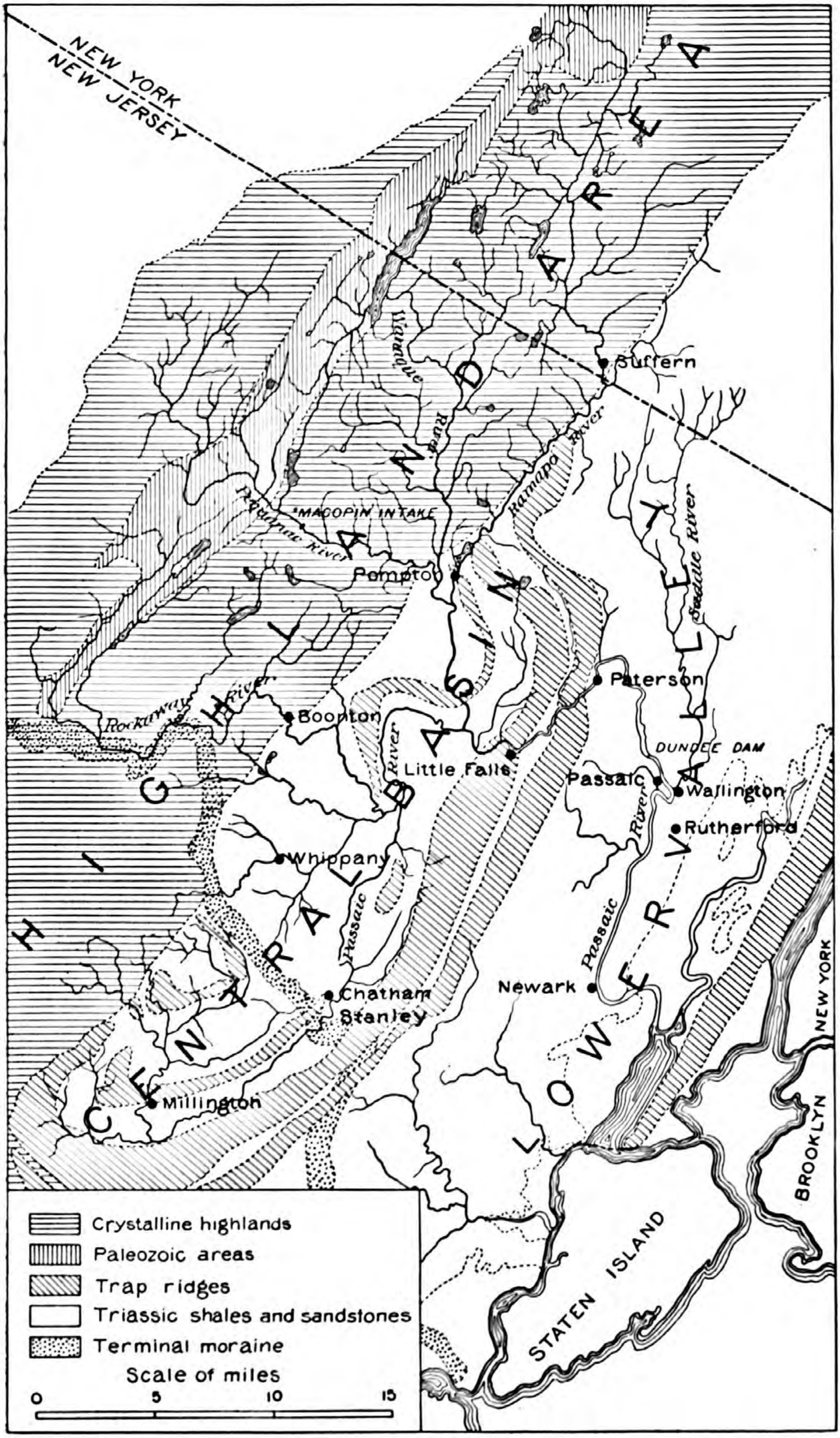
The water of the river is, however, of greatest value for municipal supply. It is already largely used for this purpose, and the demands of a rapidly growing population in the cities of northern New Jersey require that a proportionately greater amount shall be set aside from year to year.

The drainage area, as seen from Pl. II, falls naturally into three broad topographic divisions, viz, the Highland area, the central basin, and the lower valley.

THE HIGHLAND AREA.

The Highland area is the main gathering ground of the tributaries, whose united catchment basins cover 510 square miles or 53 per cent of the entire drainage area. It is a mountainous region composed of granitic and crytalline rocks which extend in a belt running northeasterly through northern New Jersey into New York State, with a width in New Jersey of from 15 to 20 miles. The region has a general altitude of from 1,000 to 1,500 feet above sea level, and represents the remnant of an old and much dissected plateau. Owing to intense metamorphism and folding of the rocks and to subsequent erosion, the highlands lie in ridges which follow a generally northeast-southwest trend. These ridges are transversely trenched by the the main arteries of the tributaries in steep-sided valleys whose bottoms lie from 300 to 600 feet below the crests. The most important tributaries which occupy this region are the Ramapo, Wanaque, Pequanac, Rockaway, Whippany, and a small portion of the upper waters of the Passaic proper. Upon it are also a number of lakes and artificial reservoirs, the latter built by water companies, which afford considerable storage.

[a] See Water-Supply and Irrigation Paper No. 72.



DRAINAGE AREA OF PASSAIC RIVER.

Much of the area has a covering of glacial drift, which is thick in some localities. In the southern portion, closely following the gorge of the Rockaway River, the terminal moraine of the great continental glacier crosses the Highland area.

The Highlands are of little value for farming purposes, except in the portion composed of Paleozoic rocks (see Pl. II). Their rugged topography, their thin soil, and the prevalence of large glacial bowlders, which in places literally cover the surface, are discouragements too great to be overcome, and the region has thus of necessity been left in forest. This lack of agricultural development is doubtless also due to the fact that large tracts are controlled by individuals and corporations looking toward the development of the extensive iron-ore deposits which are present in the region.

From the hydrographic standpoint the presence of forests is of much value, as the Highland tributaries are all clear-flowing streams with a minimum of sediment as contrasted with the more turbid waters of the main stream.

The percentage of forests over the Highland region varies, being greatest north of the terminal moraine, where it ranges from 75 to 90 per cent. South of the moraine the territory is well cultivated, and the forests occupy 30 per cent of the area.

Owing to the general rugged nature of the region and the thin soil, the population amounts to only 64 to the square mile, and is largely concentrated in a few towns, the most important of which are Boonton, Dover, Rockaway, Butler, Bloomingdale, and Newfoundland; the remainder of the area is practically unsettled.

THE CENTRAL BASIN.

Adjoining the Highlands on the southeast lies the central basin, a marked depression 8 to 12 miles wide and 32 miles long, bounded on the west by the easterly escarpment of the Highlands, which rise in bold relief about 700 feet from the floor of the basin, and on the northeast and south by the crescent-shaped and concentric ridges of the Watchung or Orange Mountains, which rise with almost equal boldness, but to an altitude somewhat less. Geologically the floor of the basin is composed of Triassic sandstones and shales, which are much softer than the hard rocks of the surrounding crystalline Highlands and the trap ridges of the Watchung Mountains. A few small trap ridges are found within the basin. Pl. II shows the general relations of these rocks.

Through processes of erosion several hundred feet of the Triassic sandstones have been washed away in this area, so that in general the floor now stands at an elevation of about 180 feet above tide water.

An important feature of the central basin is the large area occupied by marsh or wet lands, which are easily flooded even in moderate rises of the stream, and which become widely submerged in extraordinary floods. Their extent is 29,308 acres, or 17 per cent of the area of the basin. The distribution of the wet lands is as follows:[a]

Wet lands in Passaic Basin.

	Acres.
On Passaic River above Chatham	14,754
On Passaic River from Chatham to Two Bridges, including Whippany and Rockaway	12,851
On Pompton River above Two Bridges	1,140
On Passaic River from Little Falls to Two Bridges	563
Total above Little Falls	29,308

It has been satisfactorily demonstrated that during and for an indefinite period after the Glacial epoch the basin was occupied by a large body of water, approximately 200 square miles in extent, which has been geologically designated as "Lake Passaic."[b] Extensive morainal deposits at the outlet of the basin near Little Falls and Paterson, with the possible assistance of masses of ice, formed the barrier which kept the waters of the lake in place. Evidence of this phase of the region's history is found in the widespread lacustrine deposits, which are responsible for the remarkable flatness of the surface over the northern half of the basin, the striking contrast of which to the surrounding mountains has already been mentioned. Further evidences of the Glacial lake stage are also found in the great marshes which have remained to the present day. Pl. III, taken from Second Mountain at Singac, looking north to west, shows the portion of the wet lands in the middle part of the central basin; it also shows the central section of the valley formerly occupied by Lake Passaic.

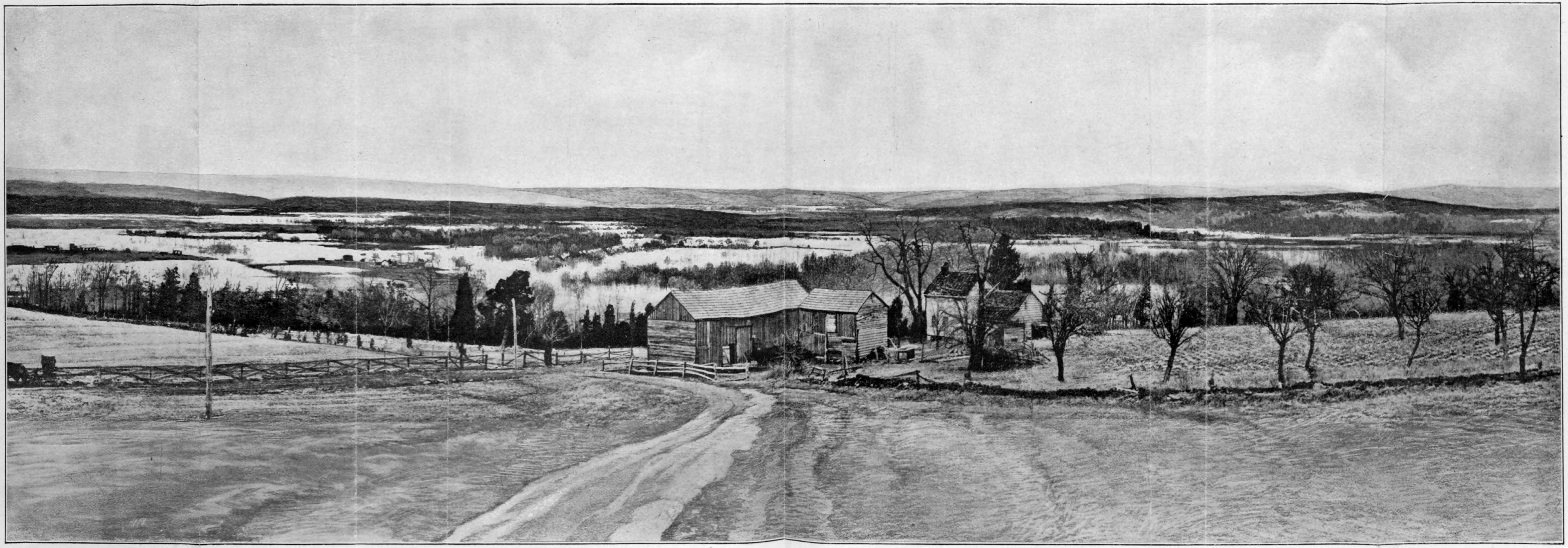
The Passaic River proper passes through this basin, entering it as a small stream in the southwestern portion and flowing generally northward in a meandering course until it crosses the barrier of Second Mountain at Little Falls, and First Mountain a few miles farther north, at Great Falls, Paterson. The drop in the first instance is about 40 feet, and in the second 70 feet. (See Pl. IV, *A* and *B*.)

Into this central basin the principal tributaries, with one exception, discharge their waters, and as the gradients of all of them are steep, after heavy rains they quickly pour into the flat area such a volume of water that it is unable to pass the outlet at Little Falls, and for days and even weeks large portions of the wet lands remain under water.

The terminal moraine of the great glacier, which was noticed in the Highland area, is also found in this portion of the watershed, which it crosses in a line of low and much confused hills extending from Summit to Morristown.

The central basin is an agricultural country with relatively large centers of population, the most important being Morristown, Summit,

[a] Final Report New Jersey Geological Survey, Vol. III.
[b] Kümmel, Report of the State Geologist of New Jersey, 1893.



PART OF FLOODED AREA IN CENTRAL BASIN NEAR FAIRFIELD.

Chatham, Madison, Morris Plains, Pompton, and Whippany. The population is 120 to the square mile, and 29 per cent of the area is in forest. The East Jersey Water Company maintains a pumping station at Little Falls, from which point approximately 63,000,000 gallons of water per day are taken.

The physiographic features most affecting the hydrography of this portion of the watershed are, first, the narrow gorge of the river at Little Falls, which quickly becomes congested in times of flood (Pl. V, *A* and *B*), and, second, the large expanse of the wet lands and of the level-lying valley floor, which are easily submerged when the congestion at Little Falls takes place (Pl. III).

Although the frequent flooding in the central basin works considerable hardship and even loss to the farming class there located, it is nevertheless, a feature which has a beneficial effect upon the lower section of the valley beyond Paterson, as it provides natural storage for accumulated waters and prevents widespread floods in the thickly inhabited manufacturing and suburban districts in the lower valley.

THE LOWER VALLEY.

After leaving the short series of rapids, falls, and quiet stretches from Little Falls to Paterson, the river enters the lower valley through which it flows to its mouth at Newark Bay. The drainage area of this section to Little Falls is 178 square miles, the main stream being 29.1 miles long. Nine and one-quarter miles below Paterson it receives its only important tributary in the lower valley, viz, Saddle River, which has a drainage area of 60.7 square miles. Just above the mouth of this stream, at Dundee, the waters of the river are held by a dam 450 feet long, whose crest is 27 feet above mean tide. For 4 miles below this dam the river has a total drop of 6 feet to Passaic, from which point 13½ miles to Newark Bay it is a narrow tidal estuary.

The right bank of the river at Passaic is a low bench and it is flooded in times of very high water. A large portion of the manufacturing section of the city of Passaic is located here, and most of the injury sustained by the 1902 flood was caused by the destruction of merchandise on the lower floors of the factories and warehouses. On the left bank of the stream, opposite the city of Passaic, is another low-lying area, forming a basin which was evidently occupied by the stream in earlier stages. The general level of this area lies but a few feet above tide water, and is likewise subject to overflow. It is the site of the borough of Wallington, a residence district. About midway in its extent from north to south this flat is crossed by the main line of the Erie Railroad on an embankment of gravel and other material. The embankment ends at the left bank of the river.

One of the important features of the lower valley is its great population, which has been concentrated there by reason of the natural advantages of its water front on the lower Passaic, the powers at Paterson and Passaic, and the proximity to New York City. In the district, which has an area of about 60 square miles, there are over forty cities, towns, and boroughs, representing a combined population of about 4,200 per square mile. Municipal improvements which accompany the growth of population influence the drainage of the area to some extent, by reason of the construction of large areas of paved and macadamized roads which constitute "quick spilling" surfaces.

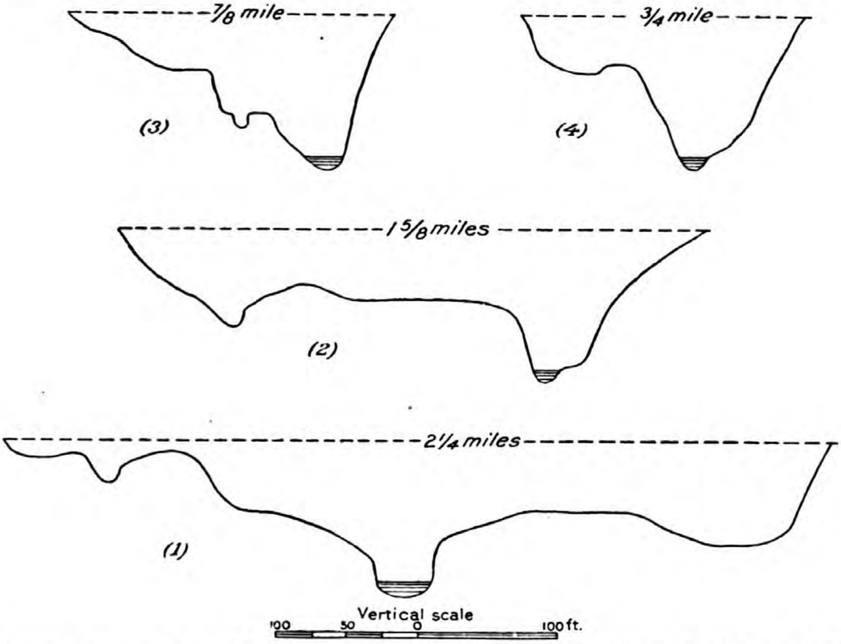


FIG. 1.—Cross sections of Passaic Valley from Clifton to Newark. 1. At Clifton. 2. At Delawanna, 5¼ miles below Clifton. 3. At North Newark, 10¼ miles below Clifton. 4. At Newark, 11¼ miles below Clifton.

A striking feature of the lower course of the river, which especially affects it in times of flood, is found in its physiographic relations. From Paterson to Passaic the stream flows in a wide open "old valley;" but from Passaic to its mouth, contrary to usual conditions, its valley assumes more and more the aspect of younger topography, until when near its mouth, just above Newark, it follows a narrow canyon-shaped opening whose sides, especially on the eastern bank, are precipitous. Attention in this connection is called to the several profiles in fig. 1, made at different points from Clifton and Newark, and to the accompanying table of widths at the 100-foot contour from which the cramping of the valley is readily appreciated.

Physiographic phenomena in the neighborbood of Passaic and Rutherford, together with the striking aspect of the lower valley, seem to indicate that in pre-Glacial times the stream discharged its waters through the gap in the low sandstone ridge at Rutherford now occupied by the Erie Railroad, and that the lower valley, from Newark to Passaic, drained northward through a small tributary which joined the main stream at Rutherford, but owing to the obstruction of the river by extensive glacial filling across its bed in the notch at Rutherford, it was forced to seek a new outlet through the valley of a tributary meeting it from the south.

Whether this be the explanation of the narrowness of the lower valley or not, the restricted limits of this section have an important bearing upon the action of the stream in times of flood, producing a congestion of the waters in excessive freshets which has been of great pecuniary damage to the city of Passaic and the surrounding districts. The building of docks at Newark and the erection of solid masonry piers for bridges, together with a number of elevated causeways for turnpikes crossing the stream and flat lands adjacent, have still further narrowed the already too limited outlet below Passaic.

Like the central basin, the floor of the lower valley is composed of soft Triassic sandstones, more or less overlain by glacial drift.

TRIBUTARIES OF PASSAIC RIVER.

SADDLE RIVER.

In ascending the Passaic from its mouth, Saddle River is the first and only tributary of size in the lower valley. This stream rises in New York, 3 miles north of the State line, flows almost due south for 17 miles, and reaches the Passaic at Garfield. Its course is wholly in the red-sandstone area, which is thickly covered with glacial drift. It has an average fall of 34.1 feet per mile. Its catchment area amounts to 60.7 square miles. The country which it drains is a fertile farming land, with a population of 122 to the square mile, and 28 per cent of its area is still forest. Floods on this stream rise rapidly, remain high but a few hours, and decline as quickly as they arise; the most severe floods occupy from one to two days.

RAMAPO RIVER.

The Ramapo rises in Orange County, N. Y., upon the crystalline highlands and Paleozoic areas; it cuts the trend of the crystalline ridges in a deep gorge, falling 280 feet in 16 miles, from Turners to Suffern, above which point it drains 112.4 square miles. Entering New Jersey at Suffern, it reaches the sandstone area and flows 12 miles to Pompton along the contact of the sandstone and the crystalline rocks, with a fall of 5.7 feet to the mile. Its tributaries in this stage are few, and are mostly from the precipitous slopes of the highlands on its right bank, so that the river as a whole may be regarded as a highland stream. At Pompton, 10 miles below Suffern, the river passes over a natural fall, increased by a dam to 23 feet in height (Pl. VI, *A*); above this dam there is a pond 202 acres in extent.

After passing the dam at Pompton the Ramapo enters the central basin and joins the Pequanac and Wanaque to form the Pompton River. The stream is well adapted to the development of power, and several hundred horsepower upon it are already improved; 75 per cent of the area is in forest, and the population is 58 to the square mile.

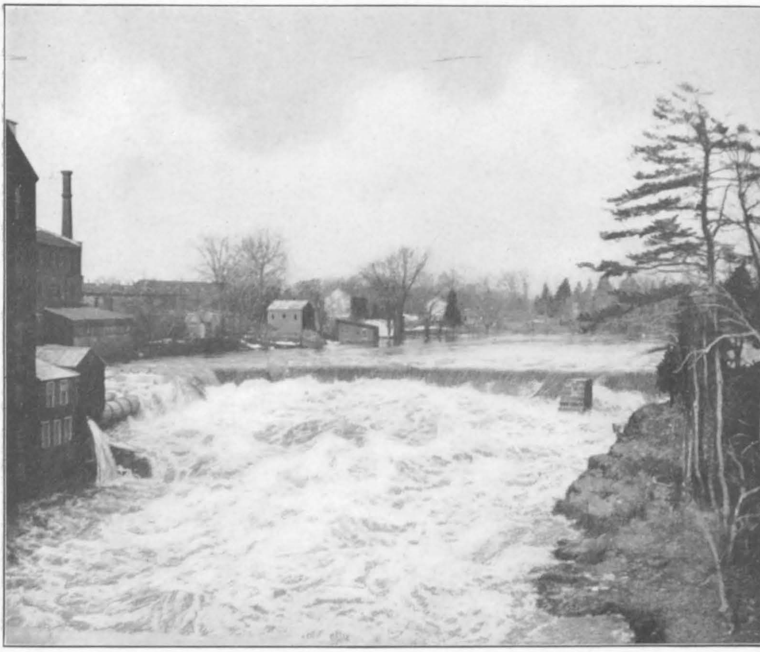
WANAQUE RIVER.

Joining the watershed of the Ramapo on the south and west lies the drainage basin of the Wanaque; the topography of its watershed is almost identical with that of the former stream, and its waters are gathered entirely from the Highland area; its source is Greenwood Lake, a lake of glacial origin, which lies between heavily wooded mountains and was formed by the accumulation of drift across a narrow valley. It is 6 miles long with a uniform breadth of five-eighths of a mile. It has a surface area of 1,920 acres and an altitude of 621 feet above sea level. At its outlet is a stone dam 181 feet long and 14 feet high. From Greenwood Lake the river has a length of 18 miles with a general southerly course, mostly through longitudinal valleys of the crystalline Highlands, until it emerges at Pompton and enters the Central Basin, where it joins the Pequanac and Ramapo to form the Pompton. From Greenwood Lake to its junction with the Pequanac it falls 451 feet, or about 26 feet to the mile; 80 per cent of the area of its watershed is in forest, and its population is but 30 to the square mile.

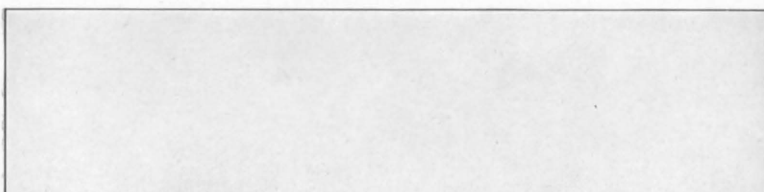
PEQUANAC RIVER.

The watershed of the Pequanac also lies entirely in the Highlands and adjoins that of the Wanaque on the south; in the topography of its watershed and in its general characteristics it closely resembles the area drained by the Wanaque and Ramapo. The Pequanac has a length of 31 miles and rises on the western portion of the Highland belt, which it crosses to the east in a narrow gorge; it has an average drop of 35.1 feet to the mile, falling about 1,100 feet from source to mouth. From a point 2 miles above its mouth to Newfoundland, a distance of 12½ miles, the fall is 45 feet to the mile.

The Pequanac River has been extensively utilized as a source of public water supply; it has natural storage in several ponds of moderate size upon its drainage area, and in the following three large reservoirs built by the East Jersey Water Companies; Oak Ridge reservoir, 16 miles from its mouth, with an area of 383 acres; Clinton reservoir, 13 miles from its mouth, with an area of 423 acres, and Canistear reservoir, about 23 miles above its mouth, with an area of 350 acres. The water collected in these reservoirs is conducted in the open stream to the Makopin intake, a small reservoir 9.5 miles above the mouth, having an area of 12 acres; from this point it is conducted to the city of Newark in a steel conduit. Seventy-five per cent of the area of its watershed is in forest.



A. DAM AT LITTLE FALLS.



B. PASSAIC FALLS AT PATERSON.

ROCKAWAY RIVER.

A third tributary on the Highland area, whose drainage area lies almost wholly in the Highlands, is the Rockaway; its area adjoins that of the Pequanac on the south; it is 40 miles long from source to mouth and has a fall of 780 feet or 19.5 feet per mile. It has extensive storage facilities in natural ponds, among them Splitrock Pond, Dixons Pond, Denmark Pond, Green Pond, and Opennaki Lake.

Power is developed at Boonton on the edge of the Highlands 9 miles above its mouth, and is second only to those at Paterson and Little Falls. Like the Pequanac its course is across the Highland ridges, but its fall is less uniform than that of the last-named stream. Above Boonton the stream drains 118 square miles, the population of which is 113 to the square mile; 82 per cent of the area is in forest. As the stream leaves the Highlands at Boonton it has a rapid fall to Old Boonton, 240 feet in 1.5 miles; at Old Boonton it enters the central basin, and for 2 miles has a fall of 32 feet per mile; 6 miles below it joins the Passaic, with a fall of 2.3 feet per mile. The area of the entire watershed is 138.4 miles.

WHIPPANY RIVER.

This is a small stream which heads in the Highlands, with most of its course in the morainic hills north of Morristown. It is about 17 miles long, and from its highest source has a fall of 640 feet; it has a drainage area of 71.1 square miles, with a population of 124 to the square mile; 36 per cent of its area is in forest; 25.4 square miles of its area lie in the Highland area and 45.7 square miles in the central basin. The Whippany is known as a quick-spilling stream.

UPPER PASSAIC RIVER.

The Upper Passaic heads in the Highland area and descends into the upper portion of the central basin as a very small stream; in this part of the basin flat lands are found subject to overflow, covering an area of nearly 10,400 acres; they are confined on the north by the terminal moraine, on the west by the Highlands, and on the south and east by Long Hill or Third Watchung Mountain, the western member of the concentric series of trap ridges. The Passaic drains this basin in a narrow gorge cutting the Third Mountain at Millington, from which point it descends to Chatham, a distance of 17 miles, where it crosses the terminal moraine and enters the central basin proper.

Under present conditions the characteristic functions of the three main divisions above described may be stated as follows: The Highland area is the chief gathering ground; the central basin, the reservoir area; the lower valley, the discharge artery. These functions are greatly intensified in times of flood.

SUMMARY.

For the better understanding of the more important relations of the Passaic system the profile of the river and its tributaries is inserted. Attention is particularly called to the important features which control flood conditions as they are illustrated in this diagram. The first of these is the rapid gradient of the tributaries which enter the central basin from the Highland area. The diagram, especially in the cases of the Pequanac and Rockaway rivers, admirably shows the rapid fall from the mountains to the flat valley in the last few miles of their course. The same is true to a lesser extent of the Wanaque, Whippany, and Ramapo rivers. The effect of these comparatively steep grades is emphasized in times of flood by the still steeper valley sides and the high pitch of the small lateral runs and by the abundance of the exposed rock surface of the region. When to these conditions are added a covering of snow or ice and a frozen soil, as was the case at the time of the flood under discussion, the whole region becomes exceedingly "quick spilling" in spite of its large percentage of forests, and pours its waters into the central basin with great rapidity.

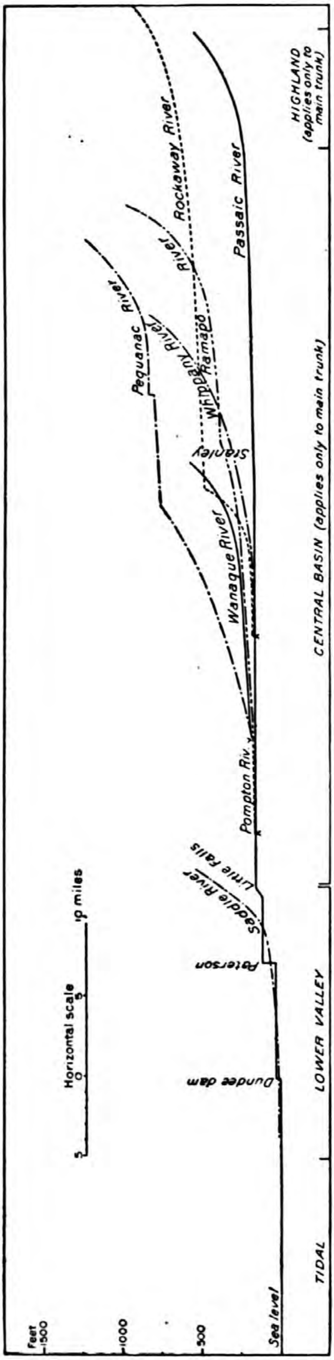


FIG. 2.—Profile of Passaic River and tributaries.

The second important condition indicated by the profile is the exceedingly flat nature of the central basin. From Two Bridges, the mouth of the Pompton River, to Lower Chatham Bridge, 21.5 miles above by stream, the total fall is only 7 feet, and from Little Falls to Stanley, the limits of the flat part of the central basin, a distance of 27 miles, the total fall is only 19 feet. In this portion of the watershed occur the great swamp areas which overflow and remain submerged under flood discharges.

The third important feature is found in the fact that the tributaries which furnish the largest percentage of water to the main stream enter it in the central-basin area and above the gorge at Little Falls, which, as has been described, is but a narrow outlet.

The fourth interesting and suggestive feature is that from the outlet of the central basin the main trunk of the river reaches sea level by three quick descents at Little Falls, Paterson, and Dundee, between which lie stretches having very little fall. The effect of these level reaches in each case is to retard and accumulate waters which are poured into them, thus helping to produce local overflows which during floods are often disastrous.

As a summary of the important features of the drainage area the following table is added, which shows the total drainage area of the whole system in square miles as well as that of the individual tributaries; also their lengths, proportion of forested areas, fall in feet, and other features.

Table showing drainage areas, forest areas, fall in feet, and gradient of the Passaic and its tributaries.

	Drainage area.	Length of river.	Forests upon watershed.	Drainage area on crystalline highlands.	Drainage area in upper basin.	Drainage area in lower valley.	Fall.	Average gradient.
	Square miles.	*Miles.*	*Per cent.*	*Square miles.*	*Square miles.*	*Square miles.*	*Feet.*	*Feet per mile.*
Passaic proper	299.0	83.5	44	10.0	[a]129.9	115.5	580	6.9
Saddle River	60.7	17.0	28	0.0	0.0	60.7	540	31.8
Pompton River	24.8	6.0	69	0.0	24.8	0.0	10	1.66
Ramapo River	160.7	34.0	72	136.0	24.7	0.0	650	18.8
Wanaque River	109.6	16.5	83	109.6	0.0	0.0	550	33.9
Pequanac River	84.8	31.0	78	83.8	1.0	0.0	1,090	35.1
Rockaway River	138.4	40.0	80	118.2	20.2	0.0	1,030	25.7
Whippany River	71.1	20.0	36	25.4	45.7	0.0	680	34.0
Total	949.1			483.0	289.9	176.2		

[a] 43.6 square miles above Chatham.

FLOW OF PASSAIC RIVER.

Various short-term measurements of the flow of the Passaic River have been made by engineers, and the records appear scattered through reports which have not received wide distribution. Much information regarding the stream was collected and compiled by Mr. C. C. Vermeule, and included in his admirable report to the geological survey of the State of New Jersey.[a] In this report is a series of flow curves covering the years 1877 to 1893.[b] The values represented by these curves were computed from gage-height records, maintained during

[a] Water Supply: Geol. Survey New Jersey, Vol. III, 1894.

[b] Ibid., p. 154.

the period mentioned above, along the river between Little Falls and Dundee dam. A tabulation of these values appears in Water-Supply and Irrigation Paper No. 72, and for convenience is reproduced below:

Daily flow of Passaic River at Paterson and Dundee.

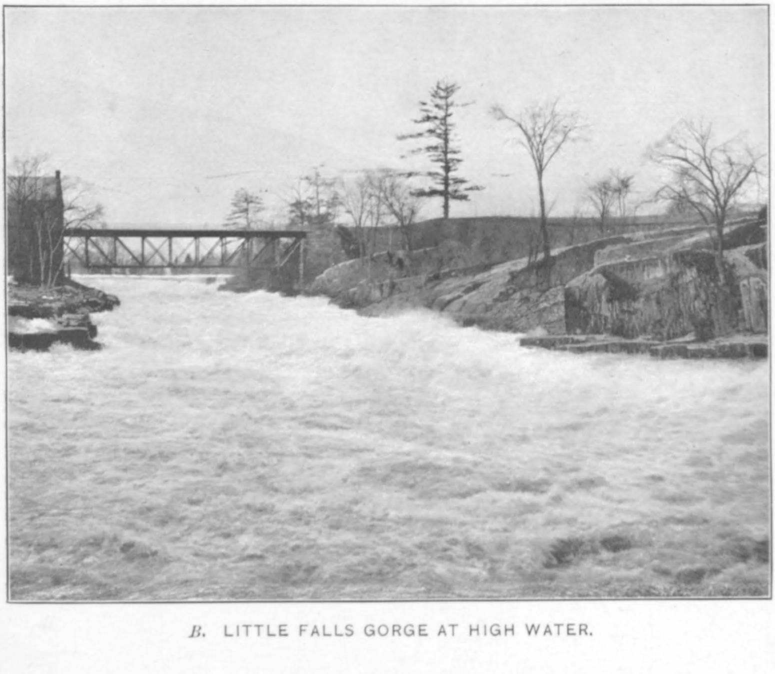
[Inches on watershed.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly average.
1877	0.029	0.081	0.202	0.107	0.032	0.021	0.015	0.015	0.013	0.096	0.164	0.081	0.071
1878	.084	.138	.126	.046	.055	.054	.027	.053	.018	.019	.058	.237	.076
1879	.027	.071	.182	.143	.055	.034	.035	.051	.031	.010	.012	.075	.061
1880	.115	.092	.080	.030	.036	.012	.013	......	.012	.011	.027	.021	.041
1881	.037	.131	.215	.042	.029	.056	.037	.010	.010	.010	.018	.052	.054
1882	.069	.171	.127	.117	.105	.061	.061	.018	.197	.043	.019	.038	.094
1883	.031	.115	.106	.098	.053	.024	.033	.013	.013	.047	.044	.024	.050
1884	.092	.215	.157	.094	.067	.022	.043	.030	.010	.019	.035	.011	.066
1885	.137	.081	.066	.115	.054	.016	.015	.026	.010	.027	.089	.102	.063
1886	.109	.189	.097	.114	.113	.034	.017	.018	.010	.018	.082	.037	.066
1887	.105	.171	.118	.087	.039	.069	.080	.052	.014	.027	.021	.109	.074
1888	.145	.138	.166	.195	.024	.014	.013	.034	.160	.015	.105	.138	.096
1889	.192	.087	.104	.137	.104	.059	.088	.145	.142	.055	.215	.148	.123
1890	.066	.118	.107	.099	.087	.051	.031	.035	.151	.084	.047	.051	.077
1891	.192	.205	.169	.076	.029	.015	.014	.023	.023	.012	.026	.065	.071
1892	.158	.052	.065	.054	.045	.038	.019	.019	.014	.011	.048	.039	.046
1893	.121	.203	.227	.130	.155	.077	.025	.023	.020	.041	......	.056	.098
Monthly average	.101	.133	.136	.099	.064	.039	.033	.035	.050	.032	.067	.070	....

Discharge measurements of Pompton River at Two Bridges, N. J.

Date.	Gage height.	Discharge.
1901.	*Feet.*	*Second-feet.*
May 4	3.35	1,837
May 24	2.20	952
June 15	1.60	543
July 11	1.35	304
August 15	1.78	350
August 26	8.32	5,425
October 26	1.30	283
November 22	1.00	195

A. LITTLE FALLS GORGE AT LOW WATER.



B. LITTLE FALLS GORGE AT HIGH WATER.

Discharge measurements of Passaic River at Two Bridges, N. J.

Date.	Gage height.	Discharge.
1901.	*Feet.*	*Second-feet.*
May 4	3.88	1,345
May 4	4.20	1,198
May 24	3.05	626
June 15	2.50	522
July 11	2.20	337
August 15	2.75	589
August 26	9.35	3,882
October 26	2.20	230
November 23	1.92	181

Estimated monthly discharge of Passaic River at Two Bridges, N. J

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May [a]	2,000	623	1,105	3.07	3.54
June 1–22			779	2.16	1.76
July	1,007	137	448	1.24	1.43
August	3,858	363	1,409	3.91	4.51
September	1,650	271	632	1.76	1.96
October	959	225	472	1.31	1.51
November	719	181	321	.89	.99
December	4,445	225	1,015	2.82	3.26

[a] Approximate.

Estimated monthly discharge of Pompton River at Two Bridges, N. J.

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May [a]	2,751	893	1,529	4.25	4.90
June 1–22			1,015	2.82	2.30
July	1,254	195	541	1.50	1.73
August	5,342	255	1,834	5.09	5.86
September	2,240	221	848	2.35	2.62
October	1,181	221	533	1.48	1.71
November	1,001	195	322	.89	.99
December	6,328	300	1,441	4.00	4.61

[a] Approximate.

Daily gage height, in feet, of Pompton River at Two Bridges, N. J., for 1901.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	......	3.90	1.20	1.70	4.00	2.30	1.10	1.30
2	3.10	3.75	1.85	1.45	3.80	2.00	1.10	1.30
3	3.50	3.70	2.05	1.55	3.50	2.00	1.10	1.35
4	3.35	3.40	2.25	1.35	2.95	2.00	1.10	1.75
5	2.95	3.05	2.45	1.20	2.60	1.75	1.10	1.90
6	2.65	2.80	2.60	1.20	2.45	1.65	1.10	1.95
7	2.45	2.60	2.65	3.25	2.20	1.50	1.10	1.75
8	2.15	3.51	2.65	3.90	2.00	1.40	1.10	1.70
9	2.20	3.50	1.85	3.15	2.85	1.30	1.10	1.60
10	2.85	2.80	1.50	2.65	1.65	1.30	1.10	1.16
11	4.50	2.45	1.30	2.45	2.65	1.30	1.10	2.25
12	4.70	2.15	1.45	2.25	2.65	1.30	1.15	2.05
13	4.30	1.95	1.60	2.05	1.70	1.25	1.25	1.00
14	3.60	1.60	1.60	2.00	1.50	1.95	1.45	2.45
15	3.55	1.50	1.40	1.85	1.50	2.55	1.20	3.40
16	3.20	1.50	1.15	1.55	1.85	2.45	1.20	5.90
17	2.85	1.45	1.35	1.50	2.05	2.30	1.20	4.90
18	2.60	1.45	2.65	3.20	2.00	2.15	1.20	4.20
19	2.65	1.25	1.65	4.55	2.00	2.00	1.10	3.90
20	2.45	1.20	1.60	4.25	1.85	1.75	1.10	3.65
21	2.50	1.15	1.20	3.60	1.45	1.60	1.00	3.30
22	2.15	1.00	1.00	5.15	1.40	1.50	1.00	3.10
23	2.30	1.00	1.00	5.00	1.40	1.40	1.00	2.60
24	2.15	1.15	1.00	6.50	1.40	1.30	1.10	1.95
25	2.40	1.10	1.00	8.25	1.30	1.30	1.65	1.80
26	2.75	1.15	1.00	7.15	1.20	1.30	2.30	1.55
27	2.80	.90	1.00	6.10	1.10	1.25	1.95	2.35
28	3.50	.90	1.00	5.15	1.10	1.20	1.90	2.70
29	3.50	.90	1.30	4.55	1.50	1.20	1.70	2.80
30	4.00	.90	1.75	4.05	2.50	1.10	1.55	7.10
31	4.00	......	1.75	3.85	......	1.10	......	9.60

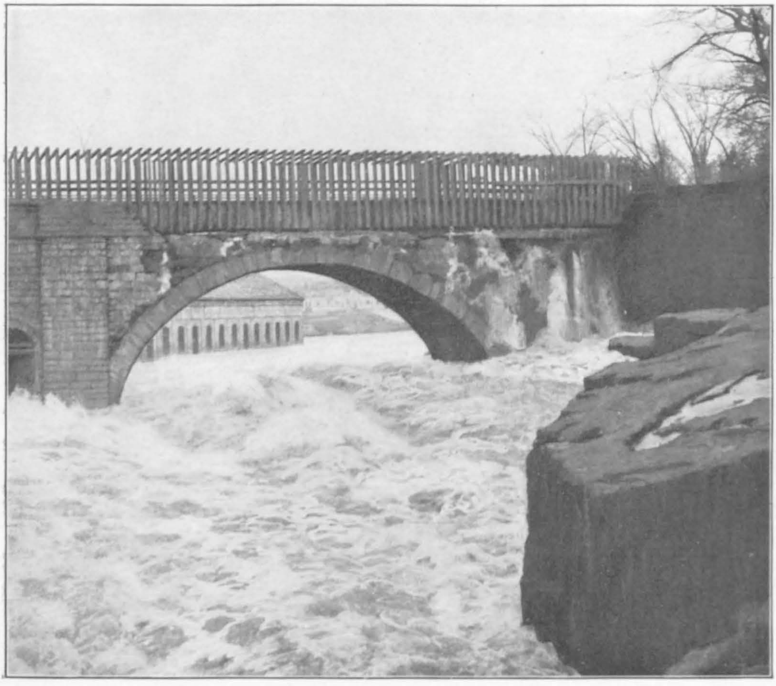
Daily gage height, in feet, of Passaic River at Two Bridges, N. J., for 1901.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	......	4.75	1.80	2.75	4.95	3.15	2.00	2.00
2	3.90	4.55	2.10	2.50	4.80	3.00	2.00	2.00
3	4.25	4.55	2.30	2.50	4.40	3.00	2.00	2.05
4	4.20	4.30	2.70	2.50	4.10	3.00	2.00	2.60
5	4.05	3.95	3.10	2.30	3.75	2.85	2.00	2.95
6	3.60	3.65	3.60	2.30	3.50	2.65	2.00	2.85
7	3.30	3.45	3.65	4.20	3.20	2.45	2.00	2.70
8	3.05	4.35	3.45	4.80	3.00	2.40	2.00	2.65
9	2.95	4.05	2.70	4.00	2.90	2.30	2.00	2.50
10	3.65	3.85	2.25	3.70	2.60	2.25	2.00	2.40
11	5.65	3.40	2.20	3.45	2.50	2.20	2.00	2.95
12	5.60	3.15	2.45	3.25	2.60	2.20	2.05	2.85
13	5.15	2.95	2.55	3.05	2.60	2.20	2.20	2.80
14	4.85	3.00	2.50	3.00	2.55	2.85	2.30	2.85
15	4.45	2.50	2.30	2.75	2.45	3.55	2.10	3.20
16	4.05	2.40	2.25	2.50	2.65	3.45	2.10	6.80
17	3.90	2.30	2.40	2.50	2.85	3.20	2.10	5.90
18	3.40	2.15	3.55	4.10	2.80	2.95	2.10	5.15
19	3.50	1.95	2.60	5.55	2.65	2.80	2.00	4.85
20	2.95	1.95	2.50	5.20	2.50	2.60	2.00	4.20
21	3.15	1.90	2.15	4.50	2.45	2.50	2.00	3.00
22	3.00	1.85	2.00	6.15	2.40	2.50	2.00	3.00
23	3.00	1.90	2.00	6.00	2.20	2.20	1.90	2.95
24	3.05	2.00	2.00	7.05	2.20	2.20	2.35	2.70
25	3.25	2.05	2.00	9.30	2.20	2.20	2.65	2.55
26	3.60	1.90	2.00	8.50	2.10	2.10	3.05	2.40
27	3.95	1.90	2.00	7.35	2.10	2.05	3.00	3.20
28	4.40	1.80	2.00	6.35	2.10	2.00	3.00	3.80
29	4.40	1.80	2.20	5.45	2.40	2.00	2.65	3.70
30	4.65	1.80	2.70	5.00	3.35	2.00	2.30	8.70
31	4.90	......	2.75	5.10	......	2.00	......	10.45

Daily gage height, in feet, of Pompton River at Two Bridges, N. J., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.35	3.00	10.40	4.35	3.30	2.15	2.50	2.75	1.30	4.55	2.75	1.20
2	7.55	3.50	14.40	4.15	3.05	1.75	2.25	2.65	1.20	4.95	2.70	1.45
3	6.45	3.70	14.00	3.40	2.80	1.30	2.00	2.55	1.10	4.70	2.70	1.70
4	6.25	3.50	10.80	3.25	2.95	1.30	2.10	2.30	1.10	4.45	2.65	2.00
5	5.15	3.40	9.75	3.15	2.55	1.20	2.00	2.10	1.10	4.45	2.55	2.00
6	4.00	3.30	8.40	3.00	2.40	1.20	1.85	2.00	1.10	4.75	2.35	2.10
7	3.30	2.60	7.15	3.15	2.15	1.10	1.65	1.85	1.00	4.50	2.25	2.10
8	2.95	2.10	6.15	3.65	2.00	1.10	1.45	1.70	1.10	4.25	2.20	2.20
9	2.55	1.90	6.55	5.30	2.00	1.10	1.40	1.60	1.10	3.95	2.05	2.35
10	2.35	1.70	7.35	6.60	1.85	1.00	1.40	1.50	1.20	3.60	1.90	2.25
11	2.25	1.50	7.70	6.60	1.50	1.00	1.35	2.55	1.25	3.30	1.80	2.10
12	2.35	1.50	7.45	6.15	1.30	1.00	1.30	2.95	1.30	4.60	1.55	2.10
13	2.30	1.40	7.30	5.80	1.30	1.05	1.20	3.60	1.40	5.05	1.45	2.00
14	2.20	1.40	7.50	4.55	1.30	1.25	1.20	3.50	1.50	4.85	1.35	1.90
15	2.05	1.30	7.15	4.05	1.20	1.30	1.20	3.50	1.50	4.65	1.30	1.85
16	1.50	1.20	7.00	3.60	1.20	1.30	1.20	2.25	1.40	4.[illegible]5	1.30	2.30
17	1.60	1.20	5.90	3.40	1.20	1.30	1.10	3.05	1.15	3.65	1.30	5.65
18	1.50	1.20	6.60	3.10	1.15	1.30	1.20	2.70	1.10	3.00	1.20	8.25
19	1.45	1.10	5.55	2.60	1.10	1.25	1.30	2.55	1.10	3.00	1.20	8.20
20	1.30	1.20	4.65	2.50	1.20	1.25	1.30	2.65	1.10	2.95	1.20	8.00
21	1.30	1.30	4.35	2.50	1.20	1.35	1.35	2.45	1.10	2.80	1.20	8.00
22	5.75	1.50	4.10	2.40	1.20	1.70	1.50	2.25	1.10	2.65	1.10	7.55
23	7.75	1.70	3.75	2.40	1.10	1.65	1.45	2.15	1.00	2.40	1.00	7.90
24	6.85	1.85	3.40	2.30	1.10	1.50	1.40	1.90	1.10	2.05	1.00	9.55
25	5.45	2.45	3.15	2.20	1.20	1.50	1.75	1.60	1.25	1.85	1.20	9.25
26	4.35	4.30	2.85	1.80	1.75	1.50	2.15	1.45	2.70	1.75	1.30	8.30
27	4.30	7.20	2.60	1.65	2.15	1.6[illegible]	2.20	1.20	3.30	1.65	1.45	8.05
28	4.05	8.60	2.45	1.60	2.75	1.55	2.20	1.35	3.95	2.40	1.50	7.20
29	3.45	......	3.30	2.40	2.80	1.35	2.15	1.40	4.60	2.85	1.40	6.65
30	3.15	......	4.55	3.00	2.45	2.45	2.70	1.30	4.55	3.00	1.30	6.65
31	3.20	......	4.45	......	2.25	......	2.85	1.30	......	3.90	......	6.55

A. FALLS, POMPTON LAKE.



B. LITTLE FALLS GORGE, LOOKING UNDER MORRIS CANAL VIADUCT, HIGH WATER.

Daily gage height, in feet, of Passaic River at Two Bridges, N. J., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	9.25	3.70	11.55	5.25	4.40	3.10	3.30	3.75	2.30	5.55	3.75	2.20
2	8.25	4.35	13.50	5.15	4.10	2.70	3.25	3.65	2.20	5.95	3.70	2.45
3	7.45	4.50	12.80	4.65	3.80	2.40	3.00	3.55	2.15	5.70	3.65	2.70
4	7.40	4.30	11.80	4.40	3.95	2.30	3.10	3.30	2.00	5.55	3.55	3.00
5	7.05	4.15	10.75	4.15	3.55	2.20	3.00	3.10	2.00	5.45	3.35	3.00
6	6.90	4.00	9.40	4.00	3.40	2.15	2.85	3.00	2.00	5.75	3.30	3.10
7	4.50	3.80	8.15	4.15	3.15	2.10	2.65	2.85	2.00	5.50	3.20	3.10
8	3.90	3.60	7.20	4.60	3.00	2.10	2.55	2.70	2.10	5.25	3.20	3.20
9	3.50	3.40	7.50	6.25	3.00	2.10	2.40	2.60	2.10	4.95	3.05	3.35
10	3.20	3.20	8.35	7.65	2.85	2.00	2.40	2.45	2.20	4.60	2.90	3.25
11	3.00	3.20	8.70	7.65	2.50	2.00	2.35	3.50	2.25	4.30	2.80	3.10
12	3.40	2.90	8.45	7.15	2.30	2.00	2.30	3.95	2.30	5.55	2.55	3.10
13	3.25	2.60	8.30	6.70	2.30	2.20	2.20	4.60	2.40	6.05	2.45	3.00
14	3.10	2.30	8.50	5.55	2.30	2.30	2.20	4.50	2.50	5.85	2.35	2.90
15	2.80	2.10	8.15	5.10	2.30	2.30	2.20	4.50	2.50	5.65	2.30	2.85
16	2.50	2.10	8.00	4.60	2.20	2.20	2.20	4.25	2.40	5.15	2.30	2.80
17	2.50	2.10	6.90	4.40	2.20	2.30	2.10	4.05	2.15	5.65	2.30	6.65
18	2.50	2.10	7.55	4.10	2.15	2.30	2.20	3.70	2.10	4.40	2.20	9.25
19	2.45	2.20	6.75	3.40	2.10	2.25	2.25	3.55	2.10	4.00	2.20	9.20
20	2.40	2.30	5.65	3.50	2.20	2.25	2.30	3.60	2.10	3.95	2.20	9.00
21	2.00	2.45	5.35	3.50	2.20	2.40	2.35	3.35	2.10	3.80	2.20	9.00
22	5.65	2.65	5.10	3.40	2.20	2.80	2.50	3.20	2.10	3.65	2.10	8.55
23	8.80	2.70	4.75	3.40	2.10	2.75	2.45	3.05	2.00	3.40	2.00	8.95
24	7.95	3.40	4.40	3.30	2.10	2.60	2.40	2.90	2.10	3.05	2.00	10.55
25	6.80	3.90	4.15	3.20	2.25	2.60	2.75	2.60	2.25	2.85	2.20	10.25
26	5.80	5.45	3.75	2.80	2.60	2.50	3.15	2.35	2.85	2.75	2.30	9.45
27	5.70	8.15	3.50	2.65	2.95	2.65	3.20	2.20	3.60	2.65	2.45	9.05
28	5.45	9.60	3.35	2.65	3.35	2.55	3.20	2.35	4.55	3.40	2.50	8.20
29	4.75	......	4.25	3.30	3.65	2.40	3.15	2.40	5.60	3.60	2.40	7.65
30	4.40	......	5.55	3.90	3.45	3.30	3.70	2.30	5.55	4.00	2.30	7.65
31	3.80	......	5.35	......	3.25	......	3.85	2.30	......	3.90	......	7.55

Estimated monthly discharge of Passiac River at Two Bridges, N. J.

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1902.					
January	3,832	225	1,616	4.49	5.18
February	4,011	271	1,003	2.79	2.91
March	[a] 11,600	863	2,863	[a] 7.95	[a] 9.16
April	3,016	527	1,424	3.96	4.42
May	1,375	271	618	1.72	1.98
June	839	225	408	1.13	1.26
July	1,103	271	550	1.53	1.76
August	1,475	317	808	2.24	2.58
September	1,975	225	488	1.36	1.52
October	2,200	527	1,467	4.08	4.70
November	1,055	225	534	1.48	1.65
December	4,496	317	2,071	5.75	6.63
The year	[a] 11,600	225	1,154	3.21	43.75

[a] Estimated.

Estimated monthly discharge of Pompton River at Two Bridges, N. J.

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1902.					
January	5,415	300	2,080	5.78	6.66
February	5,598	221	1,180	3.28	3.42
March	[a] 11,600	1,109	[a] 4,050	[a] 11.25	[a] 12.97
April	4,138	505	1,867	5.19	5.79
May	1,729	221	703	1.95	2.25
June	1,109	195	376	1.04	1.16
July	1,400	221	583	1.62	1.87
August	1,948	255	969	2.69	3.10
September	2,678	195	569	1.58	1.76
October	3,006	540	1,927	5.35	6.17
November	1,327	195	575	1.60	1.79
December	6,291	255	2,795	7.76	8.95
The year	[a] 11,600	195	1,473	4.09	55.89

[a] Estimated.

Miscellaneous measurements in Passaic watershed.

Date.	Stream.	Locality.	Discharge.
1902.			*Sec.-feet.*
June 26	Ramapo River	Mahwah, N. J	123
Oct. 29	do	do	678
Sept. 24	Rockaway River	Old Boonton, N. J	33
Aug. 23	do	do	146
Sept. 11	do	do	164
Sept. 23	do	do	102
Oct. 30	do	do	488
Oct. 30	Pompton River	Pompton Plains, N. J	1,066
Sept. 26	Passaic River	Stanley, N. J	195
Oct. 30	do	do	431
Sept. 26	do	Millington, N. J	92
Aug. 28	Whippany River	Whippany, N. J	35.3
Sept. 23	Pequanac River	Pompton, N. J	90
Aug. 22	Wanaque River	do	97

During the past year the Division of Hydrography has made current-meter measurements on both the Pompton and Passaic rivers near their junction at Two Bridges, and for low-water stages of the rivers these measurements show with fair accuracy the volume of both streams.

During the progress of floods, however, measurements taken at these stations can not be relied upon to furnish complete data of the discharge, for the reason that the Pompton, a comparatively swift-flowing stream, enters the Passaic, a sluggish stream, at nearly right angles, cutting across its current and acting as a temporary dam in backing up its waters to a greater or less extent. In this way the gage-height readings on the Passaic, which are taken just above the junction, do not in flood time bear their true value to the discharge of the stream.

Another feature which detracts from the accuracy of flood measurements at Two Bridges is the fact that both rivers overflow their banks and spread over a wide section of flat lands during high freshets; so that while the gage readings have a certain interest and value, they do not accurately record the true height of the water which should pass between the banks. Therefore in this discussion neither the discharge measurements nor the gage-height records have been considered.

Attention is particularly called to the fluviographs of the Passaic and Pompton rivers (figs. 3 and 4) made from daily gage heights and frequent current-meter discharge measurements at Two Bridges, at the junction of these streams. They clearly reveal several important features in the flow of the rivers above mentioned. In the consideration of them it should be borne in mind that the drainage areas of both the Passaic and Pompton rivers above the point of measurement are nearly equal in extent, and, furthermore, that they are adjacent. There is, however, this important difference between them with respect to topography and physical conditions, namely, that the catchment

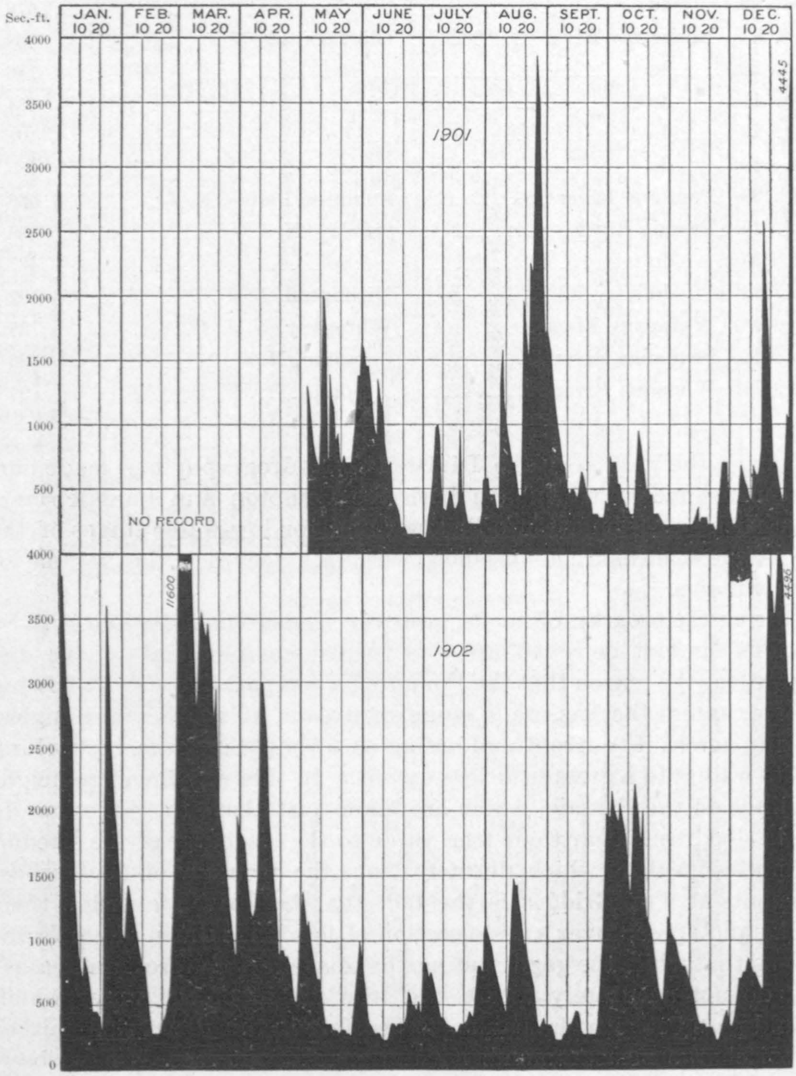


FIG. 3.—Discharge of Passaic River at Two Bridges.

basin of the Pompton lies almost entirely in a mountainous and heavily forested area of the Highlands, while that of the Passaic lies mainly in the comparatively flat cultivated area of the central basin.

The fluviographs show in a striking way the great irregularity in the flow of the streams. The quick and violent rises occur in all months of the year, being naturally more prolonged in the spring than in the summer season, and the normal and comparatively small flow of the stream is during intervals between these rises.

The rises occur on both streams simultaneously, as is to be expected from the proximity of the drainage areas, which naturally would

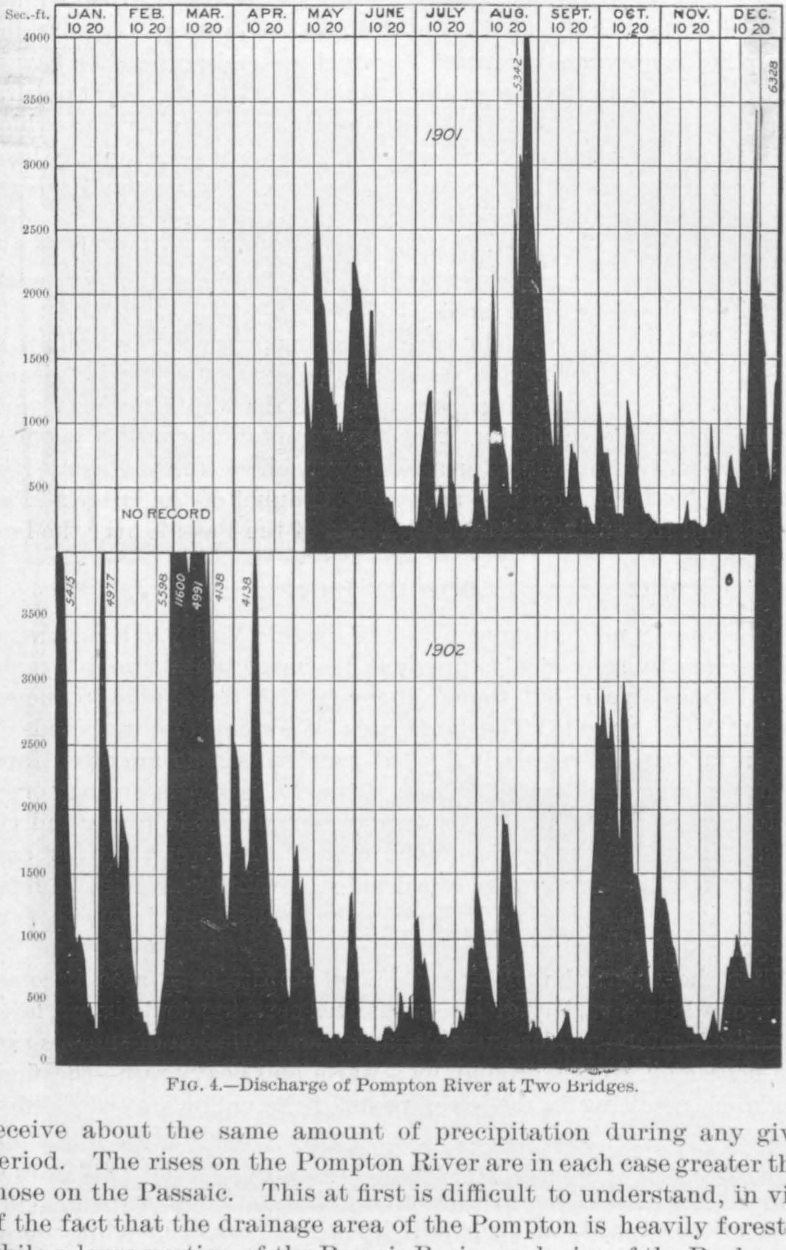


FIG. 4.—Discharge of Pompton River at Two Bridges.

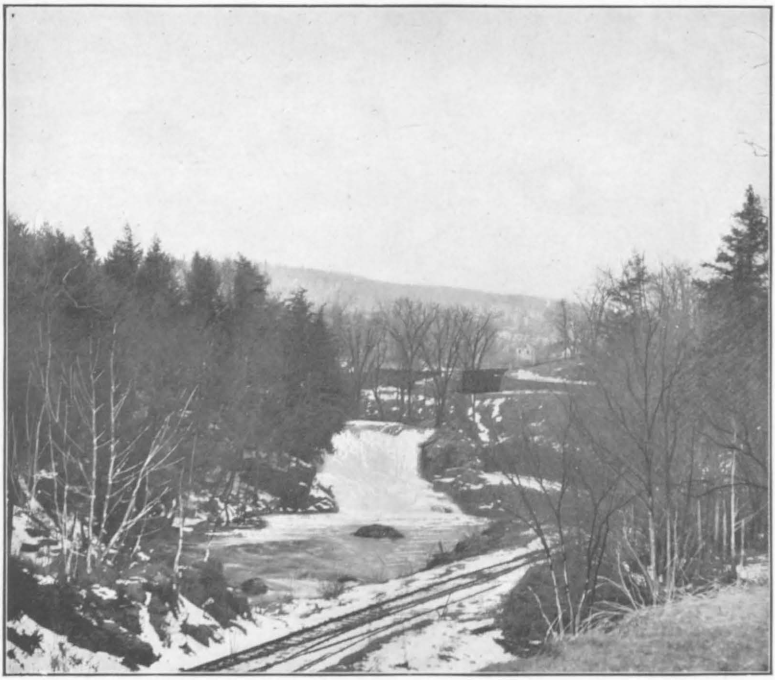
receive about the same amount of precipitation during any given period. The rises on the Pompton River are in each case greater than those on the Passaic. This at first is difficult to understand, in view of the fact that the drainage area of the Pompton is heavily forested, while a large portion of the Passaic Basin, exclusive of the Rockaway, whose waters in this instance are included, contains a comparatively small proportion of forests. In other words, the Pompton as compared with the Passaic watershed is quick spilling. A moment's inspection of other conditions serves to explain the anomaly of the flow; for not only are the grades on the Pompton watershed much steeper than those on the Passaic, the Rockaway River excepted, but this part of the Passaic Basin contains also the large areas of flat and swamp lands previously referred to, which not only retard the flow of the streams, but, in the case of the swamp areas, act as a great natural reservoir for the waters at all times, absorbing the high waters which readily flood their surface, and contributing a constant supply back to the main stream in times of low-water flow. Owing to this regulating effect of the wet lands in the central basin, it is easy to account for the lower rises of the Passaic, as well as for the greater volume of its low-water flow, as compared with that of the Pompton, so clearly brought out by the fluviographs.

These characteristics of flow are, of course, greatly emphasized at times of extraordinarily high water, as during the flood under discussion. In such times, of course, the action of the waters becomes more complicated owing to the fact that the Pompton discharges its flood crest so rapidly that it acts as a temporary check to the Passaic, the waters of the former cutting across the channel of the latter at Two Bridges and increasing the flooding effect of the Passaic over the lowlands above.

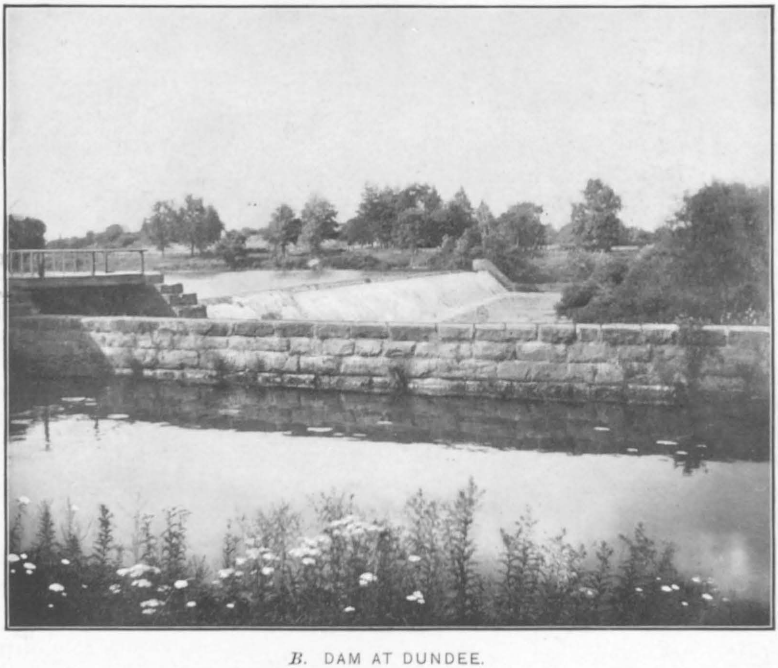
FLOOD OF 1902.

High water is not uncommon in the Passaic Valley. It occurs, as will be seen by reference to previous discharge tables and diagrams, several times a year, but though it comes with reasonable frequency it is not often violent. The large area of swamp and wet lands in the central basin is regularly flooded each spring, as are often farm lands adjoining these tracts. Lower down the valley waters may often rise to low bench lands and give some inconvenience in towns and villages. As far as the sewage pollution of the lower valley is concerned, these high waters are of a decided advantage, serving to flush that portion of the river and temporarily cleansing it from excess of sewage.

When, however, the precipitation on the drainage area becomes great, or when a variety of circumstances combine to deliver a large amount of water—as, for example, an accummulation of snow is rapidly melted on frozen ground by a warm and heavy rain—the flood conditions resulting in the lower parts of the valley are quite different in character. The central basin is widely flooded by a quick discharge of the highland tributaries, resulting in hardship and loss to the farming population of this area. The narrow gorge at Little Falls, whose capacity is made still less by the constricted opening of the old masonry span which supports the Morris Canal aqueduct (see



A. ROCKAWAY RIVER AT BOONTON.



B. DAM AT DUNDEE.

Pl. VI, *B*), is unable to discharge its waters fast enough to keep them from flooding the lands above, while in the lower valley the waters invade both the cities of Paterson and Passaic, doing great damage to the manufacturing and residential properties and threatening the smaller settlements located on the lower portion of the river.

Floods of this nature have periodically occurred in this region and have resulted in widespread suffering and damage. Such a flood took place from February 25 to March 9, 1902, reaching its height at noon on Sunday, March 2. It was the highest flood within the memory of the oldest inhabitant of the region, and owing to the fact that population and manufacturing interests have greatly increased in portions of the valley during recent years, it was probably the most destructive. The limits of the flood will be taken as the time during which the water level was above full bank. In the previously mentioned report of the New Jersey geological survey on the water resources of the State, the full bank flow at Dundee dam has been determined at 4,000 cubic feet per second; our measurements and observations lead us to believe that 5,000 cubic feet is more nearly correct. In any case the difference is not sufficient to effect any significant discrepancy in determining the duration of the flood.

The discharge measurements hereinafter set forth were made with a small Price current meter, according to the methods practiced by the Division of Hydrography, except in the cases of Little Falls and Dundee dams. At the latter points gages were read at short intervals and the amount of water was determined by Bazin's series modified to conform with the local conditions and requirements.

PRECIPITATION IN THE PASSAIC VALLEY.

The records of numerous weather observation stations in the Passaic drainage area and those of other stations in the country immediately surrounding afford a trustworthy basis of measurement of precipitation over the basin. The following table is a statement of the normal amount of precipitation at the various stations during the month of February, 1902. It should be borne in mind that the month of February is usually marked by considerable precipitation and that the normal for that period is, in most places, comparatively high. This result is a relatively large flow in river channels. Therefore an increase over the normal of 2 inches in the month of February means more, from the standpoint of damage by river floods, than it would in a dry season when the river had been in low stages. In other words, the addition of 2 inches of rainfall to the flow of a stream while it was running fairly high would cause more damage than would the addition of a similar amount to the river at a low stage.

Precipitation in inches in the Passaic Valley and adjoining country in February, 1902.

Station.	County.	Normal.	Total for month.	Departure from normal.	Greatest in 24 hours.	Total snowfall unmelted.
HIGHLAND REGION.						
Dover	Morris	4.16	6.93	2.77	2.80	18.0
Chester	do	4.30	5.31	1.01	1.70	18.6
Charlotteburg	do	4.97	6.85	1.88	2.65	13.0
Ringwood	Passaic		6.70		1.90	20.7
RED SANDSTONE PLAIN.						
Paterson	Passaic	4.63	8.15	3.52	3.03	25.5
Hanover	Morris	3.75	8.44	4.69	3.30	20.5
Rivervale	Bergen	4.89	7.53	2.64	1.60	21.0
Roseland	Essex		6.90		1.64	15.2
Newark	do	3.65	5.35	1.70	1.30	15.4
South Orange	do	4.22	5.69	1.47	1.64	18.5
New York City	New York	3.80	5.78	1.98	1.47	13.4
Plainfield	Union	3.96	7.65	3.69	1.72	23.2
Elizabeth	do	4.55	7.83	3.28	1.60	23.0
Average		4.26	6.85	2.60	1.89	18.9

The record of these stations show that during the month of February, 1902, the precipitation was heavy, and that the storms occurred on eight days of the month, namely, the 1st, 2nd, 17th, 21st, 22d, 25th, 26th, and the 28th. There was in various places an insignificant amount of rainfall on other days, but the total is so small in comparison with the precipitation for the month that it may be disregarded without introducing errors. In the following table the amount of rainfall is recorded at the various stations during the eight days mentioned.

Daily precipitation in inches in and adjoining the Passaic Valley in February, 1902.

	Day of month.							
	1.	2.	17.	21.	22.	25.	26.	28.
HIGHLAND REGION.								
Dover	(a)	0.73	0.90	(a)	2.80	(a)	0.90	1.60
Chester	0.20	.65	.96	1.70	.20	0.40	.70	.40
Charlotteburg	(a)	.62	.60	(a)	2.00	(a)	.98	2.65
Ringwood	.15	.70	.95	.45	1.90	.06	.54	1.81
RED SANDSTONE PLAIN.								
Paterson	.62	.61	1.10	3.03	.20	1.15	.05	1.39
Hanover	.27	.77	.90	(a)	3.30	.75	.65	1.60
Rivervale	(a)	1.58	1.30	(a)	2.30	(a)	1.60	.75
Roseland	.10	.55	.74	1.64	1.20	.61	.81	1.25
Newark	.12	.40	1.30	(a)	1.28	.55	.60	1.10
South Orange	(a)	.60	1.00	1.64	.20	.78	.30	1.13
New York City	.19	.54	.93	1.02	1.47	.19	.98	.42
Plainfield	.18	.61	1.72	1.21	1.33	.34	.88	1.35
Elizabeth	.36	.53	1.60	(a)	2.70	.60	.64	1.40
Average	.91	.68	1.08	.82	1.61	.45	.74	1.30

[a] Included in record for following day.

Examination of the two tables above set forth shows clearly, first, that the month of February, 1902, was characterized by heavy precipitation, which exceeded the normal, and at many stations to an extraordinary degree; second, the precipitation occurred on eight days of the month, and by far the largest part of it on the 17th, 21st, 22d, 25th, 26th, and 28th. Closer examination will show that the precipitation at the stations within the Passaic Basin was heavier than at the stations outside of the same, and while the latter undoubtedly served to steady the general average, they also make an actual reduction when computed with the former. Therefore there can be no question that the adoption of the general average for all the stations as a measure of the amount of precipitation in the Passaic Valley is safe and conservative.

Our interest chiefly centers upon the last twelve days of the month; that is, from the 17th to the 28th, inclusive. During that period there was a fall of 6 inches over the whole basin. This average will not serve in any calculation of the relation of run-off to the rainfall during the flood, because of the fact that there were so wide differences in the amount of precipitation in places not widely distant from one another. The average of 6 inches over the whole basin is but an approximation and does not represent accurately the actual amount of water precipitated, hence any estimation of the proportion of rainfall to run-off must be precarious and, in all probability, incorrect.

The character of this enormous precipitation as it fell is an important consideration. The heavy snow of the 17th, equivalent to 1.08 inches, had not melted to any extent by the 21st and 22d, when it was reenforced by a destructive sleet equivalent to 2.43 inches over the drainage area, and at some stations to over 3 inches. There was a general rise of temperature on the 23d and 24th, during which a small amount of snow was melted, and about the same temperature was maintained during the 25th and 26th, on which days the total precipitation was 1.19 inches. On the 28th there was a short but tremendous downfall, amounting to 1.22 inches, and at the end of this storm the snow of the 17th had practically all disappeared. This means that from the 23d to the 28th, or during six days, nearly 6 inches of water were heaped upon the Passaic Basin, the greater proportion of which fell or was released through the melting of snow during the last four days.

GAGE HEIGHTS.

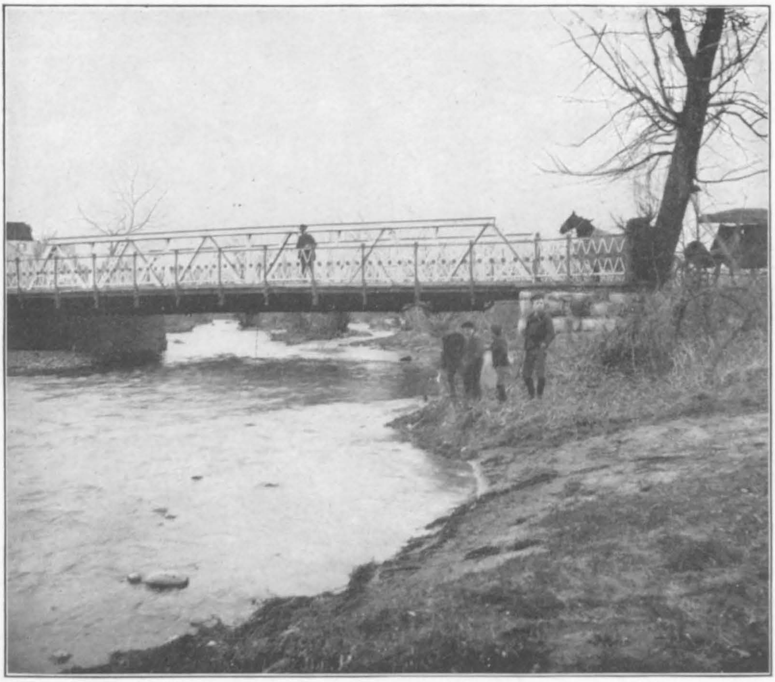
A precipitation so great and so rapidly delivered over an area the surface of which was frozen could not fail to produce extraordinary results. We find that on the Upper Passaic River, at Chatham, the water began to rise on Thursday, February 27, reaching a maximum on the afternoon of Saturday, March 1. On the Whippany River, at Whippany Village near the mouth, the water began to rise on Friday about noon and reached a maximum at 10 o'clock p. m. on the same day, falling almost immediately. On the Rockaway River at Boonton (see Pl. VII, *A*) occurred the highest water since February 6, 1896, when the recorded height was 6 feet above the crest of the Boonton dam. On the present occasion the rise of water began on the afternoon of Friday, February 28, and reached its highest point March 1 at 3 a. m., at 5.55 feet above the crest. For seven hours, beginning on February 28 at 8 p. m., the rise was 2 inches per hour. The appreciable decline in flood flow began Monday, March 3, and by March 4 the water had lowered to 1 foot over the dam crest.

At the feeder of the Morris Canal at Pompton Plains, below the junction of Pequanac, Wanaque, and Ramapo rivers, the following gage readings were reported by Mr. L. M. Le Fevre:

Height of water at feeder of Morris Canal.

	Feet.
February 28, 4 p. m	4.4
March 1, 6.10 a. m	7.4
March 2, 5.10 p. m	5.4
March 3, 2.30 p. m	5.5
March 4, 2.20 p. m	4.2
March 5, 7.40 a. m	3.9
March 6, 4.10 p. m	3.4
March 7, 6.50 a. m	2.0
March 8, 1.20 p. m	2.0

A. MEASUREMENT STATION AT STANLEY ON PASSAIC RIVER.



B. MEASUREMENT STATION AT WHIPPANY ON WHIPPANY RIVER.

On the Ramapo River at Pompton Furnace the highest water was observed at 6 p. m. on March 1, where it reached 4.1 feet above the dam crest. The combined flow of the Wanaque and Pequanac rivers was measured at the Van Ness farmhouse in Pompton Plains, and indicated a beginning of rise on February 28 in the early afternoon, reaching a maximum on March 1 shortly before noon. The high water was maintained fairly steady during March 1 and 2 and by March 5 had retreated within its banks.

The great volume of water poured out upon the central basin raised the level to such a height at Two Bridges, the junction of the Passaic and Pompton rivers, that the gages maintained there by the Division of Hydrography were submerged and the water flowed around the bridges and inundated the neighboring fields.

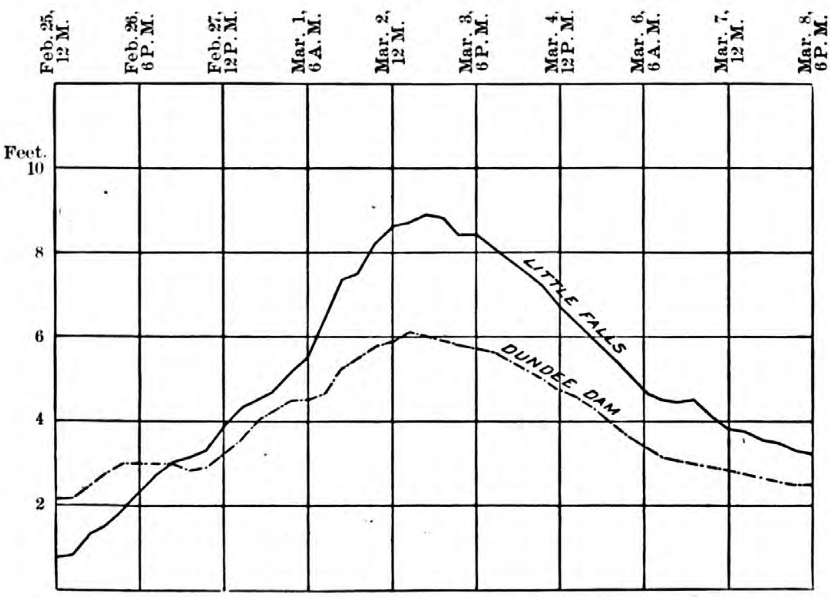


Fig. 5.—Diagram of gage readings at Little Falls and Dundee dam during flood of 1902.

At Little Falls and at Dundee dam, just above Passaic, gage readings have been preserved and are diagrammatically shown in fig. 5.

A brief description of the two dams and the conditions surrounding them will be desirable in connection with the consideration of fig. 5. The Little Falls dam is constructed with two wings adjoining the main dam, which occupies a transverse position across the center of the stream. Fig. 6 shows the plan of the site to good advantage, while the general appearance during flood is faithfully represented in Pl. IV, *A*. The main dam is 160 feet in length, with an elevation of 157.18 above tide; the north wing is 64 feet long and has an elevation of 157.81 feet, while the south wing, constructed parallel to the channel, is 61 feet long, the crest being at an elevation 157.56 feet above tide. The dam at Dundee is built of stone, the crest being 27 feet above mean tide. It is 480 feet in length and has a width of 3 feet at the crest, holding back a pond of 224 acres. (See Pl. VII, *B*.)

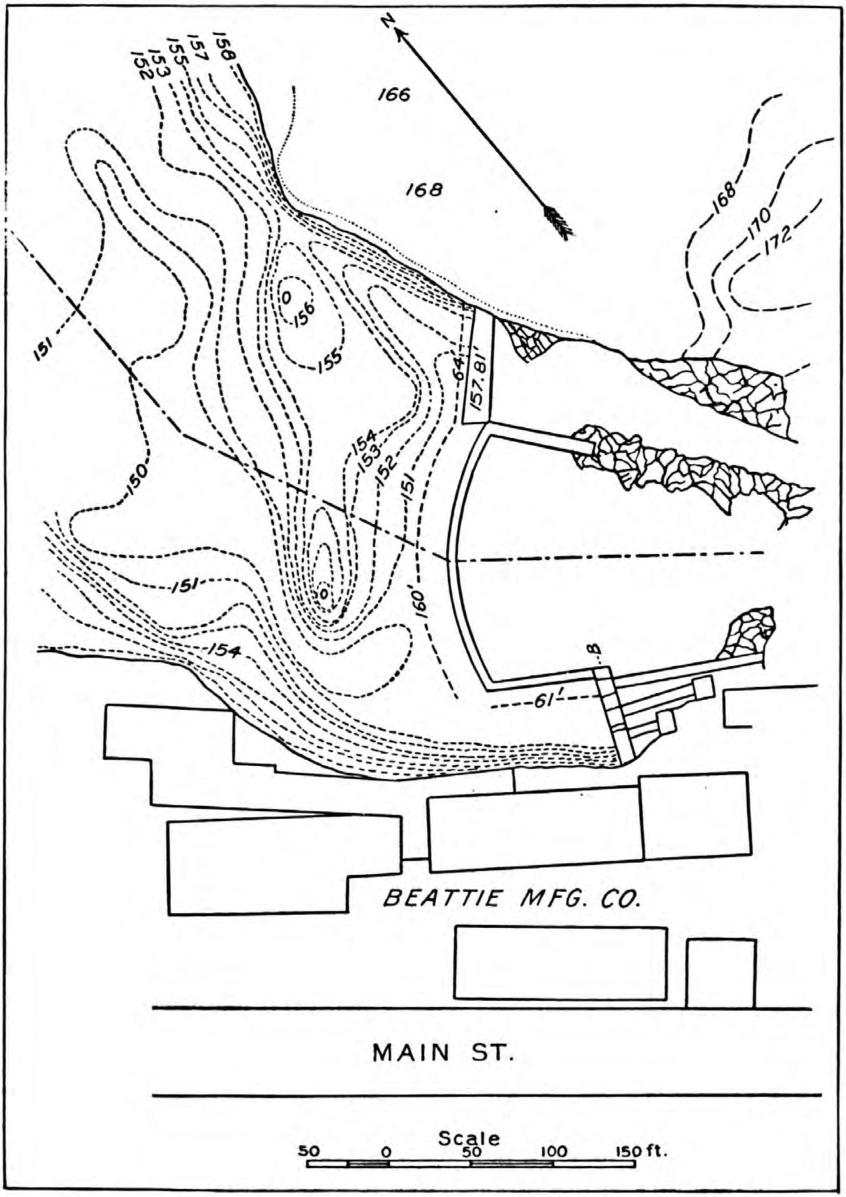


FIG. 6.—Plan of Beattie's dam, Little Falls.

FLOOD FLOW OF HIGHLAND TRIBUTARIES.

From the records of two series of current-meter measurements taken at different gage heights during the two weeks following the flood, and the marks made by eyewitnesses during the flood period, rating tables have been constructed for each of the Highland tributaries which seem to bear the test of reasonable analysis and to furnish valuable information concerning the discharge of the various streams. This discharge in second-feet for six-hour periods during the flood—that is, from February 25 to March 9—is set forth in the table below.

Average flow in second-feet of Highland tributaries during six-hour periods, February 25 to March 9, 1902.

Date.	Time of day.	Upper Passaic.[a]	Whippany.	Rockaway.	Pequanac.	Wanaque.	Ramapo.	Total.
February 26	12- 6 a. m	134	95	185	110	148	216	888
	6-12 a. m	218	155	302	185	239	351	1,450
	12- 6 p. m	379	270	520	322	416	573	2,480
	6-12 p. m	523	372	725	444	574	842	3,480
February 27	12- 6 a. m	560	430	800	500	650	850	3,790
	6-12 a. m	590	490	850	650	745	865	4,190
	12- 6 p. m	625	550	900	800	954	880	4,709
	6-12 p. m	650	610	1,000	970	1,145	890	5,265
February 28	12- 6 a. m	670	650	1,050	1,000	1,237	900	5,507
	6-12 a. m	700	712	1,300	1,440	1,745	1,200	7,097
	12- 6 p. m	728	846	1,436	1,660	2,300	1,700	8,670
	6-12 p. m	875	1,071	1,636	2,225	2,600	3,100	11,507
March 1	12- 6 a. m	1,050	1,505	2,535	2,725	3,050	4,400	15,235
	6-12 a. m	1,440	1,470	2,780	3,350	3,900	5,000	17,940
	12- 6 p. m	1,630	1,430	2,780	3,900	3,900	5,150	18,790
	6-12 p. m	1,630	1,380	2,780	4,215	3,900	5,225	19,130
March 2	12- 6 a. m	1,600	1,340	2,780	4,280	3,900	5,280	19,180
	6-12 a. m	1,550	1,300	2,780	4,350	3,900	5,120	19,000
	12- 6 p. m	1,500	1,260	2,780	4,330	3,525	4,000	17,395
	6-12 p. m	1,440	1,220	2,780	4,050	3,075	3,450	16,015
March 3	12- 6 a. m	1,400	1,180	2,527	3,400	2,875	3,050	14,432
	6-12 a. m	1,355	1,140	2,690	3,275	2,750	2,850	14,060
	12- 6 p. m	1,310	1,100	2,645	3,150	2,675	2,780	13,660
	6-12 p. m	1,250	1,060	2,565	3,050	2,490	2,790	13,205
March 4	12- 6 a. m	1,200	1,020	2,400	2,825	2,300	2,780	12,525
	6-12 a. m	1,155	980	2,420	2,625	2,100	2,760	12,040
	12- 6 p. m	1,090	940	2,360	2,400	1,900	2,720	11,410
	6-12 p. m	1,045	900	2,295	2,200	1,725	2,620	10,785
March 5	12- 6 a. m	1,000	860	2,220	2,000	1,500	2,530	10,110
	6-12 a. m	960	810	2,150	1,775	1,350	2,370	9,415
	12- 6 p. m	905	760	2,085	1,600	1,245	2,250	8,845
	6-12 p. m	845	710	2,015	1,440	1,150	2,120	8,280
March 6	12- 6 a. m	800	660	1,940	1,330	1,060	1,960	7,750
	6-12 a. m	750	610	1,870	1,240	1,000	1,810	7,280
	12- 6 p. m	700	520	1,805	1,200	940	1,700	6,865
	6-12 p. m	650	490	1,740	1,140	800	1,650	6,470
March 7	12- 6 a. m	600	440	1,670	1,100	800	1,600	6,210
	6-12 a. m	550	390	1,605	1,080	760	1,650	6,035
	12- 6 p. m	500	340	1,535	1,065	750	1,600	5,790
	6-12 p. m	450	300	1,465	1,055	785	1,620	5,675
March 8	12- 6 a. m	400	260	1,400	1,050	780	1,660	5,550
	6-12 a. m	350	210	1,335	1,050	811	1,700	5,456
	12- 6 p. m	300	160	1,265	1,060	920	1,750	5,455
March 9	12- 6 a. m	250	160	1,125	1,075	1,100	1,800	5,510

[a] At Chatham.

Total run-off, 8,960,248,000 cubic feet.

The measurement station established upon the Upper Passaic River at the village of Stanley, near Chatham, is shown on Pl. VIII, *A*. It lies about 300 feet below the Stanley dam, which was carried away during the flood. No appreciable overflow of the banks occurred, and the results obtained by current-meter measurements are trustworthy. After the destruction of the dam the millrace carried no water, and there was therefore no necessity for taking the race discharge into account. The station established at Whippany Village, near the mouth of Whippany River (Pl. VIII, *B*), is probably the least satisfactory of the Highland stations. During the height of the flood the water left the banks of the stream and overflowed the road for a few hours. The time limits and the depth of water so overflowed were, however, accurately observed and the measurements are sufficiently trustworthy for the present purposes.

The station on the Rockaway River, about 2¼ miles below Boonton, was established on a cross section of the channel, in the center of which an island is situated, necessitating the measurement of two channels (see Pl. IX, *A*). The records obtained at this point do not include the entire flow of Rockaway drainage area, as the station is about 7 miles above the watershed limits. A large part of this area, however, is included in the wet lands described in the introduction, over which the water rose during the flood. This station, although serving fairly well in high water, is useless during dry seasons, and it has since been abandoned.

The measurements upon the Pequanac River are more trustworthy than those on any other highland tributary, because accurate gage readings were maintained by the water department of the city of Newark, at the Macopin dam during the entire flood period (see Pl. IX, *B*). This dam has been accurately rated by Mr. John R. Freeman, and the results of weir measurements can be depended upon. Additional measurements were also made with the current meter at the New York, Susquehanna and Western Railroad bridge, a few miles above the mouth of the river. The combination of the two series serve to give an approximately correct estimation of flow in the Pequanac River during the flood. In the table on page 37 the stated flow of the Pequanac River embraces only that volume of water which actually passed into the Pompton, and does not include the daily draught of 371 second-feet for the supply of the city of Newark, withdrawn at the Macopin intake.

A short distance above the mouth of the Wanaque the channel forks, and the two divisions are crossed by a highway bridge built in two sections to conform with the channels (see Pl. X, *A* and *B*). The distribution of the flow of Wanaque River into two comparatively wide channels gives shallow water even during floods, and the broken, uneven surface on the bottom renders good current-meter measurements somewhat hard to obtain.

A. MEASUREMENT STATION ON ROCKAWAY RIVER NEAR BOONTON.

B. MACOPIN DAM.

The measurement station on the Ramapo was located near the mouth of the river on a highway bridge just below Pompton Falls (Pl. VI, *A*). The channel here is deep and well defined, and the measurements given in the table are trustworthy. The flow of water in the raceway running from the head of Pompton Falls has been measured and proper allowance therefor has been made in the table.

A study of the table on page 37 will show that in each of the Highland tributaries the rise of water during the flood was rapid and the crest was not long sustained, recedence following almost as quickly as the rise. The combined flow of the tributaries must, therefore, during a short period, have been enormous, and it is readily inferred that a channel of great capacity would have been necessary in order to carry away immediately the waters delivered into the central basin. It has been stated, however, that the channel at Little Falls is a narrow one and is artificially constricted by the aqueduct of the Morris Canal, as shown in Pl. VI, *B*. The area contributing to the flow of the Highland tributaries is approximately 636.2 square miles, or 82.2 per cent of the total area above Little Falls. The run-off from the remaining 17.8 per cent could not be measured and can be estimated only by taking the proper proportion of the entire run-off of the area. Bearing this in mind, let us consider briefly the flow of water over Beattie's dam at Little Falls, a plan of which is shown in fig. 6.

FLOOD FLOW AT LITTLE FALLS.

The rating table for Beattie's dam consists of three parts, which are adjusted to conform with the conditions existing at the main dam and the north and south wings. Back of the main dam the river has been filled with stone to a considerable distance, affording a very gradual slope forward from the bottom of the stream to the crest of the dam, the grade being approximately 5 to 1. Bazin's series for wide-crested weirs was used in the flow calculations at this point, the coefficients which appeared to be most applicable being those determined in Cornell University Experiment No. 3, under the date of May 26, 1899. The north and south banks have vertical faces, the crest in each case being about 7 feet from the bottom of the stream. The series of Bazin most nearly conforming to these conditions is No. 114, developed for greater heads at Cornell University June 1, 1899, and denoted as Experiment No. 10.

Calculating the flow of water over Little Falls dam during the flood period, the results diagramatically represented in fig. 7 are secured.

Inspection of the accompanying diagram does not reveal any unusual characteristics. It is a conventional flow curve such as is usually found upon investigation of any flood. The rise of water is considerably sharper than the decline, and the height of the flood is maintained for a considerable period, arriving at an apex at noon on March 2. It will be noted that the flow curve is ended with the value for March 9 at 6 a. m. This is because a second rise in the waters took place as a result of a storm which was entirely distinct from those which occasioned the flood under discussion. Pl. V, *A* and *B* shows clearly

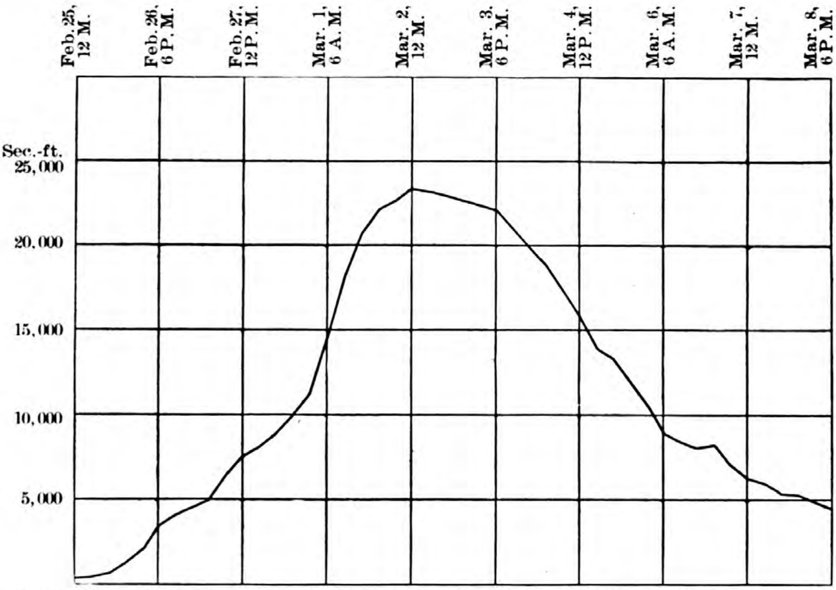


FIG. 7.—Flow of Passaic River over Beattie's dam at Little Falls February 25 to March 9, 1902.

the comparative conditions existing in the gorge during low water and at the time of the flood under consideration. It will be seen that the

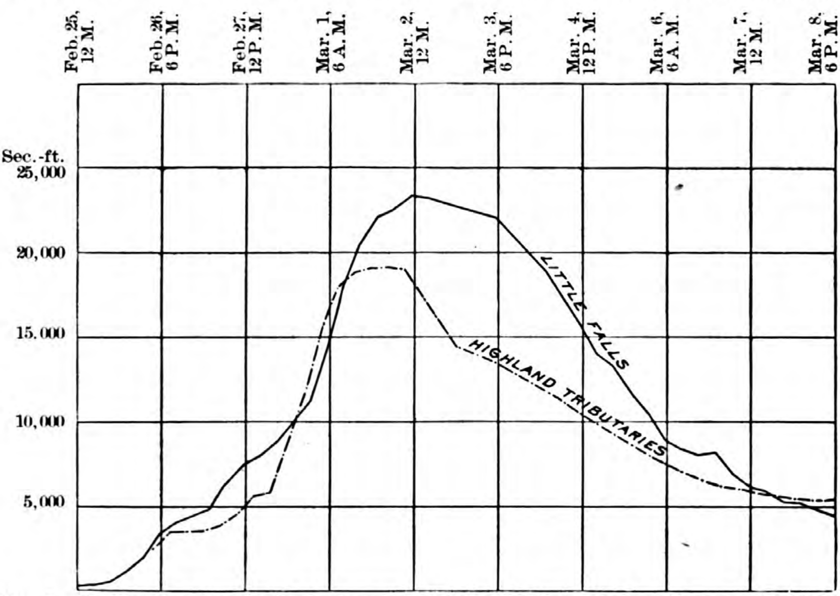


FIG. 8.—Comparative diagram of the flow from Highland tributaries into the central basin of the Passaic and the flow from Beattie's dam at Little Falls.

rise here is considerably greater than over Beattie's dam, a short distance above, denoting a carrying capacity even less than the dam.

Having now considered the flow of water from the Highland tributaries into the central basin through Little Falls gorge during the flood period, it will be instructive to compare the two flow curves and show the relations, so far as possible, between the flow of the water into the basin on the one hand and the flow out on the other.

Inspection of the table on page 37 indicates that the rush of water from the Highland tributaries into the central basin during the crucial part of the flood was greater than the flow of the river at Little Falls. This condition is indicated from 3 p. m. on February 28 to 12 m. on March 1. It is clear that if, to this flow from Highland tributaries, we add the estimated run-off not represented in the Highland tributary curve, the excess of water delivered upon the central basin during this short period, over that passed through the Little Falls gorge, would be still greater. It is interesting to note that the excess of flow at Little Falls indicated in the diagram, during the period between 12 o'clock noon on March 1 and 6 o'clock p. m. on March 7 is nearly equal to the calculated flow from the central basin, the 17.8 per cent of the drainage area above Little Falls not represented in the Highland tributary curve. It should also be borne in mind that in the central basin the precipitation causing this flood was heavier than elsewhere in the surrounding country,[a] and this would in a large degree compensate for the excess which still appears after deducting the calculated flow of the 17.8 per cent from the excess of the Little Falls readings over those of the combined Highland tributaries.

Considering fig. 8 as it stands, however, it gives clear testimony that until a certain height of water was raised over the central basin, inducing, of course, a heavy pressure upon the outlet at Little Falls, the gorge did not carry anything like the amount which was subsequently observed to be flowing over Beattie's dam.

GENERAL FLOOD-FLOW STATISTICS IN HIGHLAND TRIBUTARIES.

In the table below are given the general flood-flow statistics in Highland tributaries:

General flood flow in Highland tributaries.

Measurement station.	Contributing drainage area.	Percentage of contributing area to total above Little Falls.	Total run-off for each station.	Run-off per square mile.	Run-off in inches on watershed.
	Sq. miles.		*Cubic feet.*	*Cubic feet.*	
Passaic, at Chatham	99.8	12.9	825,847,200	8,275,022	3.5
Whippany, at Whippany	55.9	7.6	716,364,000	12,281,510	5.5
Rockaway, below Boonton	125.4	16.6	1,737,841,600	13,850,411	5.9
Pequanac, below Bloomingdale	84.8	10.9	1,829,352,600	21,572,240	9.3
Wanaque, at Pompton	109.6	14.2	1,645,250,400	15,011,411	5.8
Ramapo, at Pompton Lake	160.7	20.8	2,205,619,200	13,725,073	5.9

[a] See table on p. 32

SUBMERGED LANDS IN CENTRAL BASIN.

Among the notable features of the flood were the effects of the rush of water into the central basin, the submerged area, 32,000 acres, being of unusual extent. It will be observed by inspection of the shaded portions of Pl. XI that the impounded waters were divided into two distinct areas. The widely extended and irregular tract embracing what is known as the Great Piece Meadow, Troy, Black and Long meadows, Hatfield Swamp, and the Bog and Vly meadows has an area of 22,746 acres, while the Great Swamp, situated farther to the south and divided from the former accumulation of water by the terminal moraine, has an area of 9,376 acres. There is little question that the flooded area shown on Pl. XI was not entirely covered at one time. The water first collected in the upper

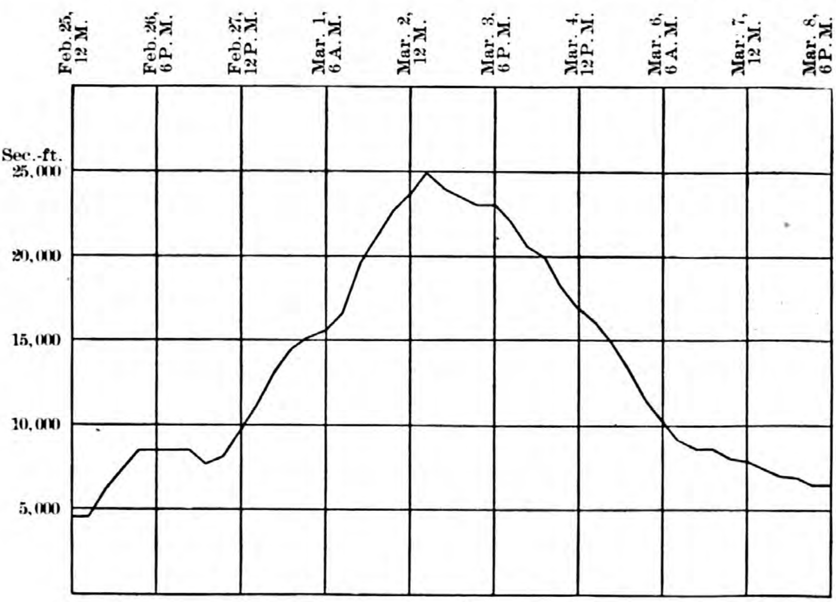
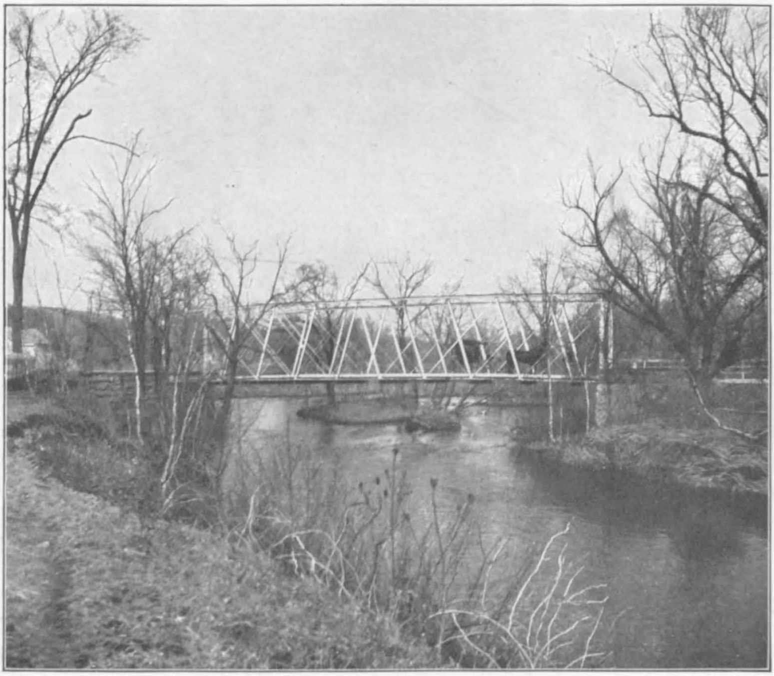


Fig. 9.—Flow of Passaic River over Dundee dam February 26 to March 9, 1902.

portions of the swamp land, and there was considerable slope toward the outlet at Little Falls. In the latter stages of the flood there was a greater area of submerged land near the outlet, while there had been a noticeable recedence above. The flooded lands will be further discussed under the section dealing with damages caused by the flood.

The point of flow measurement next below Little Falls is at Dundee dam, a diagrammatic representation of the gage heights of which was given in fig. 9. The dam has already been partly described. It extends directly across the bed of the stream, and the upper and lower faces slope from the crest. On the upper face of the dam there is a fairly uniform grade of 2–1 to the river bottom, while on the lower face the dam is built up of sixteen consecutive steps, with 1-foot

A. GAGING STATION NO. 1 ON WANAQUE RIVER AT POMPTON.



B. GAGING STATION NO. 2 ON WANAQUE RIVER AT POMPTON.

risers and 1-foot treads. This gives a slope of 1–1, but on account of the deterring effect of the steps during flood flow the coefficient to be applied in determining the volume of water passing over the dam must necessarily conform to that determined for a batter of gentler slope. The coefficients selected were those promulgated in Cornell University Experiment No. 8, dated May 30, 1899, which is an adaptation of the Bazin series No. 78 for greater heads. Fig. 9 shows diagrammatically the flow over Dundee dam during the flood of 1902.

FLOOD FLOW AT DUNDEE DAM.

Examination of the above flow curve reveals that there are peculiarities in the rise of the flood not noted in the flow curve for Beattie's dam, namely, two decided checks in the progress of the flood. From the examination of similar curves for previous floods over this

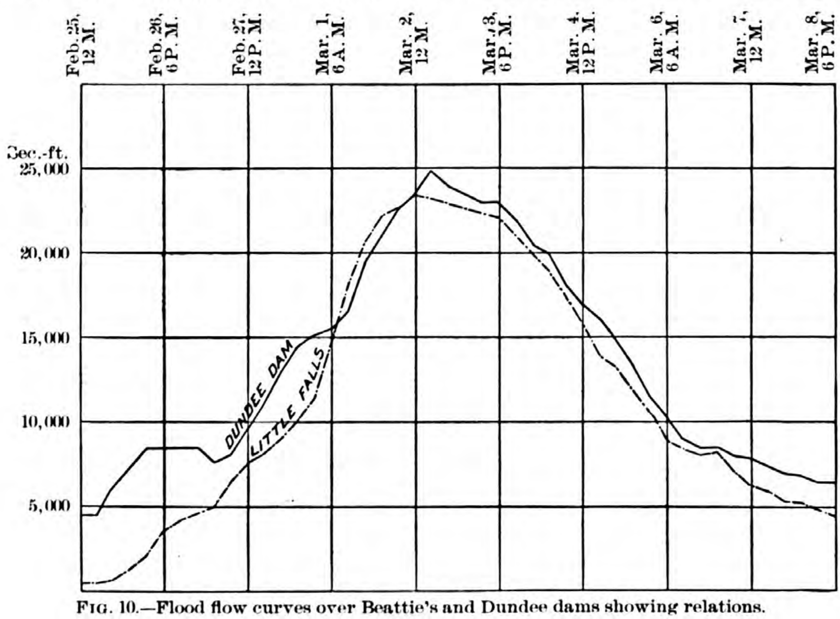


FIG. 10.—Flood flow curves over Beattie's and Dundee dams showing relations.

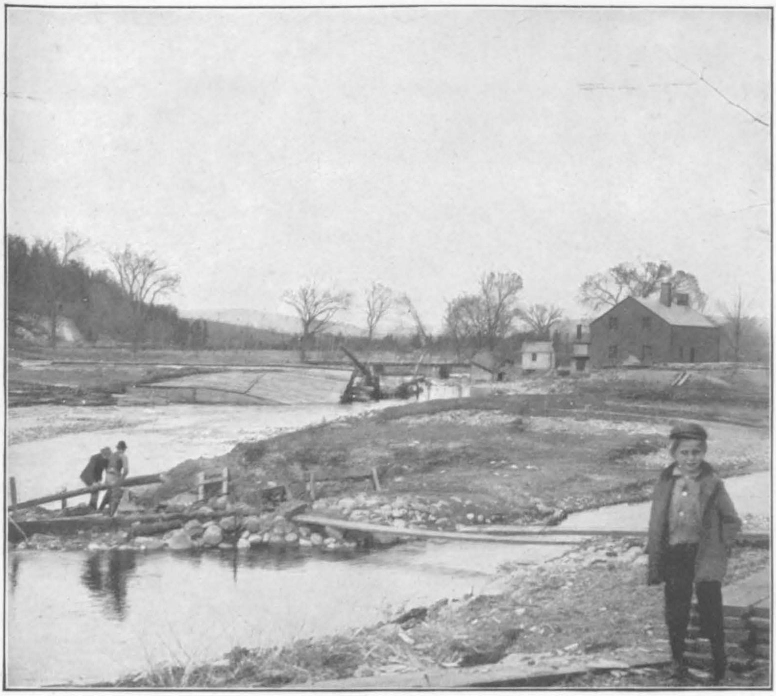
dam, checks of this nature appear to be a characteristic feature, the cause of which has not been definitely determined. It has been suggested that the decrease in the flow in former floods has been caused by the onrush of water from Pompton River which, as has been explained, flows into the central basin with the combined discharge of the Ramapo, Wanaque, and Pequanac rivers from steep grades, thus delivering its waters before those of the more sluggish Passaic can descend its sinuous course, and that when the force of the flood in the Pompton expends itself there is a temporary check in the progress of the rise of waters below. However true this may be in the case of other floods, it certainly does not apply in this instance. There is no evidence from the examination of the flow curve at Little Falls that any such phenomenon occurred, and what is more convincing, the check took place nearly two days before the flow from the Pompton River had reached its maximum. It is extremely probable that these peculiarities in the rise of the flood are the result of the run-off from the area between Little Falls and Dundee dam. It is naturally a quick-spilling area, having been divested of forests and containing a comparatively large expanse of macadamized roads and paved streets. The large city of Paterson and the surrounding area empties its entire run-off into the Passaic, and this in itself would have some effect upon the rate of increase after great precipitation.

Comparison of the flow curves in fig. 10 seems to support the contention advanced concerning the cause of the temporary checks in the progress of the flood curve over Dundee dam. It is expected that the increase in the flow over Little Falls dam would be a practically constant one because of the steadying effect of the great storage afforded by the meadow lands, and the steady rise in the Little Falls curve bears out this idea. The Dundee curve, on the other hand, shows at the beginning every indication of a flashy, quick-spilling contributing area, the effects of which are not overcome until the flood has advanced to within one day of its maximum. At that time the steady pressure from Little Falls seems to give more character to the Dundee curve, and the remainder of the diagram is conventional. It will be noted that the apex of the Little Falls curve falls twelve hours before that of Dundee dam, which is about the time which might be expected to ensue when we consider the comparatively large storage capacity afforded by Dundee Lake.

FLOOD BELOW DUNDEE DAM.

The action of the flood waters below Dundee dam was sufficiently different from those in the valley above this point to warrant special mention.

The physical character of the valley from the dam to the mouth of the river is strikingly different from that of its other sections. As has been stated, it consists of, first, a short reach of 4 miles through the city of Passaic, with a total drop of 6 feet. At this point the river turns sharply and returns to its former direction in a broad S-shaped bend. This peculiar bend is significant in connection with the supposed change of the stream's course during Glacial time. It also has a bearing on flood conditions in that it lies in a flat basin-like widening of the valley, and high waters, especially such as come with much force, are forced to leave the channel and invade the surrounding low-lying territory. The second distinguishing feature is that below this point the river becomes a tidal estuary 13½ miles in length, and lies in a constricted valley which becomes narrower as the mouth of the river is approached. At Passaic, Belleville, and Newark docks have been constructed, which still further decrease the natural width of the channel, and in addition to them a number of railway and



A. DAM ON PEQUANAC RIVER NEAR POMPTON.

B. SUBMERGED FLAT LANDS AT SINGAC.

highway bridges have been built across the stream, which by piers and abutments more or less obstruct the flow.

In this section of the valley population is dense, and with the single exception of the low-lying portion of the city of Paterson manufacturing and other interests are more seriously affected by high water than elsewhere upon the watershed.

The waters of the lower river fairly followed the gage heights at Dundee dam during the first part of the flood. On February 27 the waters were high; on the 28th they had arisen above the right bank at Passaic bridge and flooded the highway at this point. On March 1 the flats situated above Wallington and the areas adjacent to the river on both sides for several miles below were flooded. On this and the following day water rose above the floors of the highway bridges at Passaic, Rutherford, Avendale, and Belleville, and these bridges were in great danger of being carried away, while the bridge at Passaic, just below Dundee dam, was lifted from its foundations and completely wrecked (Pl. XV, *B*.) This danger was much increased by the amount of débris, especially in the form of driftwood from lumber yards, which became lodged against the piers and bridge spans. The Erie Railroad bridge at Passaic was threatened and trainloads of heavy iron and coal were placed upon it to add to its stability. On March 3 and the days following the waters gradually subsided until the normal stage was resumed.

FLOOD FLOW OF SADDLE RIVER.

In connection with the flood in the lower valley should be considered the discharge of the Saddle River, which enters the Passaic just opposite the city of that name. Although this stream joins the main trunk below the dam at Dundee, where one of the main flow computations was made, and though its volume was not included in the discharge curves given above, it still seemed to have an influence in swelling the volume of the waters near Passaic and Wallington and increasing the damage done at these points.

From evidence secured at Boetger Piece Dye Works at Lodi, the Saddle River began to rise on Friday, February 28, at about 6 p. m. It rose steadily until Saturday morning, March 1, between 2 and 3 o'clock, remaining high until 7 a. m. of the same day. By 5 o'clock p. m. on Saturday, March 1, the waters had receded within their banks, and gradually declined in volume for the next five or six days.

No measurement was made of its flood discharge, but on April 12, 1902, a current-meter measurement showed 221 second-feet flowing at Lodi, the water at the time of the flood being 7.6 feet higher than at the time of the measurement.

The flood on this river closely resembled previous floods in rising and retiring quickly, and the crest of its flood wave reached the main stream before the waters from the other tributaries entered the lower valley.

Although the flood crest of Saddle River did not play an important part in the flood on the main stream, its subsequent discharge, much larger than usual, coming in conjunction with the rising waters of the main stream, must have had its effect in increasing the damage in the Wallington-Passaic district.

At Passaic Bridge near the southern extremity of the flat extension of the valley just mentioned the main line of the Erie railroad crosses the flats on an elevated embankment and passes over the river on a drawbridge. This bridge has two piers in the river, as shown on Pl. I, *A*. Each of these piers is surrounded by piling which in times of high water catches much floating débris and acts as a temporary obstruction to the current. The distance from the abutment on the right bank to the main pier, that which supports the draw, is 209 feet and from the main pier to the abutment on the left bank, 81.5 feet. West of the main abutment, as seen on the left of Pl. I, *A*, a highway passes beneath the elevated tracks through a masonry culvert 60 feet wide at the base. The entire discharge from the watershed of over a thousand square miles is obliged to pass through these openings, which have a total width of 350.5 feet, and which in very high water are more or less contracted by the lodgment of débris against the piers. During the flood under discussion the water rose over the roadway shown on the left of Pl. I, *A*, and stood for some time above the level of the stone walls seen on the extreme left. The high-water mark on the bridge itself was about half way up on the middle drum of the draw plainly seen above the piling in the picture.

HIGH-WATER MARKS IN LOWER VALLEY.

By the courtesy of Mr. Robert M. Watson, of Wise & Watson, engineers, of Passaic, N. J., we are permitted to use the following levels taken at the time of high water at different points from Passaic to Belleville:

High-water marks in lower valley.

[Elevations given are reduced to the State's datum.]	Elevation in feet.
At Enameline's Works, southerly corner of Seventh and Worthen streets (Dundee district), in city of Passaic, near right bank Passaic River	15.85
In engine-room Passaic Lumber Company's mill, northerly corner Lester and Scott streets, in borough of Wallington, Bergen County, N. J	15.50
On northwesterly fence Standard Bleachery property, at a point about 200 feet northeast of Erie Railroad at Carlton Hill, Bergen County, N. J	15.98
On office building of Anderson Lumber Company, on right bank Passaic River, near foot of Gregory avenue, in the city of Passaic (and on River Road)	14.48
On entrance to Pagoda Hotel, near right bank of Passaic River on River Road, and about 150 feet southwest of Erie Railroad bridge across Passaic River, in the city of Passaic	13.65
On northwesterly corner piazza E. T. Galloway's house, at easterly corner River Road and Woodward avenue, in the borough of Rutherford, Bergen County, N. J	12.51
On Powell's front stoop, south side of Rutherford avenue, about 500 feet southeast of Passaic River	11.41

A. FLOODED AREA ON GREAT PIERCE MEADOWS.

B. FLOOD AT TWO BRIDGES.

	Elevation in feet.
On ground at carriage entrance to William R. Traviss's estate, on Valley Brook avenue, near southerly corner Valley Brook and Park avenues and River Road, at Lyndhurst, Bergen County, N. J	11.00
About three inches higher than wheel guard on Avondale bridge across Passaic River, between Essex and Bergen counties	10.31
Northwesterly pier Belleville bridge across Passaic River, between Essex and Bergen counties	9.21

From these a profile of the flood crest has been drawn and is also included (fig. 11). In the profile the heavy base line represents the ordinary mean water level of this part of the river, while the flood crest is represented by the irregular line above; at each point where levels were taken profiles of cross sections of the valley have been inserted to show the extent to which waters overflowed the banks.

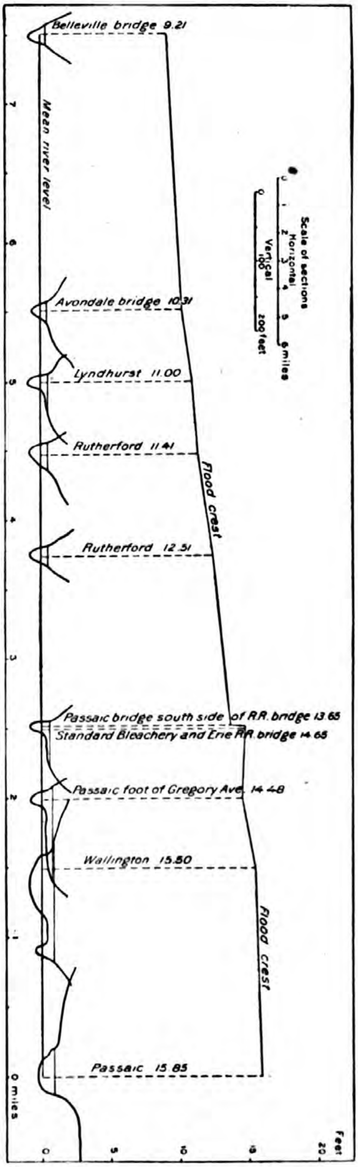


FIG. 11.—Profile of flood crest, Passaic to Belleville.

A striking feature, not brought out by this diagram, is found in connection with the levels at the Standard Bleachery and at Passaic bridge, just above and below the Erie Railroad bridge. The Standard Bleachery is located on the north side of the Erie Railway embankment (about one-third of a mile back from the stream at Passaic bridge), and at the eastern edge of the flat area on the left bank of the river on which also stands the borough of Wallington. The Bleachery level was 15.98 feet, while that on the north side of the bridge was about 14.65 feet, as taken from careful levels a few days after the waters had subsided. It has been suggested that the high level at the Standard Bleachery, which seems to be well authenticated, may have been due to the onrush of the waters of the main stream together with the heavy discharge of Saddle River, which forced the waters over the Wallington flats and temporarily piled it up against the obstructed embankment and the rising land near which the Bleachery is situated.

The next level was taken at Passaic Bridge, but a few feet below the Erie bridge and embankment. This level was recorded as 13.65 feet, a difference between that on the north side of the bridge of about 1 foot (see fig. 11). Eyewitnesses on the ground at the time of the flood testified that there was a striking difference in the height of the water on the north and south sides of the Erie abutments, and that the water poured between them as over a sloping bed.

The various section profiles of the valley accompanying fig. 11 show again the gradual narrowing of the valley which was before referred to in the general discussion of the river, and was there attributed to the possible change of drainage which has taken place in past geologic times.

LOSSES CAUSED BY THE FLOOD.

Floods of such magnitude as the one under discussion must of necessity cause great damage, but from the varying nature of the losses and the circumstances surrounding them it is impossible to make more than an approximation of their amount.

As might be expected, the losses were greater in the central basin and lower valley than on the tributaries in the Highland area. In the last-named section, the proportion of population being small, with few industries centering upon the rivers, there was little opportunity for extensive damage. The valleys are so narrow and steep-sided that there was comparatively little flooding of highways and valley floors. One or two dams were carried away, notably that at Pompton on the Pequanac (Pl. XII, *A*), and some of the highways in the mountain valleys were flooded.

In the central basin the losses were much greater, being occasioned by extensive flooding of farm lands (see Pl. XIV, *A* and *B*) involving considerable damage to stock and personal property. In many instances cattle and horses had to be removed to places of safety, and suffered much from exposure. Barns, cellars, and houses were flooded (see Pls. XII, *B*, and XIII, *B*) and the inmates were confined by the waters. The damage was furthermore much exaggerated by the unusual duration of the flood, the waters remaining on the flat lands of the basin for more than a week.

Three railroad lines cross this portion of the Passaic watershed—the Morris and Essex and Boonton branches of the Delaware, Lackawanna and Western Railroad and the Greenwood Lake Branch of the Erie Railroad. The first two lines traverse the basin for the most part at altitudes higher than the level of the flooded area; but the Greenwood Lake Branch runs for several miles over a section of the flat lands and was much affected by the flood conditions. The tracks of this road were flooded above Singac, also at Mountainview and below Pompton Plains. The water reached the ties of its bridge across the Passaic at Signac and the structure was only held in place

A. FLOODED FARMHOUSE IN CENTRAL BASIN.

B. FLOODED FARM LANDS IN CENTRAL BASIN.

by trains heavily loaded with iron and coal. Just above this point the track was washed over by the overflow from the left bank of the river and large portions of its gravel embankment were carried away. Fortunately there are no large towns located in the flooded lands of the upper basin, or the damage to individual property holders would have been much more serious.

In addition to the injury to private property the chief damage in this part of the drainage area consisted in that sustained by the bridges from débris and floating ice, the complete suspension of travel by the flooding of highways, and the loss and inconvenience due to the interruption of travel upon the railroad lines.

Some of the highways were passable with difficulty, but many of those most used, especially such as run near the main stream, were crossed in many places by swift currents of water from 3 to 6 feet in depth, through which passage was impossible except for the most heavily loaded wagons.

The total area of the flooded lands, as seen by reference to the map of the central basin, Pl. XI and various plates of the report, was approximately 32,000 acres. A number of dams were carried away on the tributaries near the edges of the central basin, notably that on the Passaic proper at Stanley. Fortunately the water confined by these structures was not enough in amount to seriously damage the lower portions of the valley below Little Falls, and from that point to the mouth of the river the damage was of a different character.

As has been described, the valley below Little Falls is comparatively narrow and thickly populated, Paterson, Passaic, and the intervening towns being closely built up to its banks. Between Paterson and Little Falls the roads on both sides of the stream were flooded, and the trolley line—much used by employees of factories at Little Falls who reside at Paterson and depend upon the line for transportation—was completely blocked for several days. The pumping station of the East Jersey Water Company, located at the foot of the main drop at Little Falls, was considerably damaged by the rise of waters, which flooded its main floor to a depth of several feet, stopping all operations and injuring the pumps and electric motors which were there installed. Pl. VI, *B*, shows the water standing at a higher level than the floor of the pumping station as seen looking downstream under the viaduct of the Morris Canal.

Below the main falls in Paterson the city closely confines the river on both banks. The left bank stretches back some distance from the stream as a low bench, which is built up with residences. This section was flooded for several blocks and remained under water a number of days. Many houses were damaged by the water, and while the individual losses were not heavy, they still amounted to considerable in the aggregate. On the right bank of the river the section extending several blocks east of River street was under water. This is a business portion of the city and considerable injury to the trade of the section resulted.

Below the Great Falls there are five bridges, some of which were damaged by ice and floating débris. In attempting to cross one of them, over which the water was flowing with great force, a horse and wagon was swept away and one man drowned.

Farther down the river heavy losses were sustained in the city of Passaic. This town stands on the right bank of the river, and for several blocks back from the stream the land lies but a few feet above the ordinary river level. Here are located many factories and mills, together with a large factory population. The waters rose so rapidly onto this bench that it was impossible for the owners to remove valuable goods from the floors of their storehouses, and in consequence the losses were very large. It is estimated that the mill owners in Passaic were losers to the amount of $600,000, and that there were personal losses from residents of the district of $200,000 more. Upward of 400 small shops are reported to have been flooded, the resulting loss to whose owners can not be estimated, for it consisted not only in damage done to stock but damage entailed from the length of time necessary to resume business.

In and below Passaic there are situated a number of lumber yards on the banks of the stream. Most of the stock there located was carried away, and some of it was lodged against the piers and framework of bridges below, making an additional cause of danger to these structures, and in the case of the county bridge at Passaic, throwing it completely out of position and rendering extensive repairs necessary. A large amount of lumber became lodged among the piles driven in front of the stone pier which supports the draw of the Erie Railroad bridge at Passaic. This accumulation so blocked the passage of the water between the abutments of the bridge that it may have been to some extent the cause of the difference of levels noted at this point.

On the other side of the river and opposite the city of Passaic is located a considerable settlement known as Wallington. This town also stands on a low river bench which marked a former bed of the stream. With the advancing waters the town was almost completely flooded, as shown by Pl. XV, *A*, and a damage of not less than $200,000 was sustained by the inhabitants. The foundations of the buildings, especially those of brick, seemed to have been undermined by the current which swept around them, and the buildings were, in some instances, thrown out of plumb. Altogether, the damage in the neighborhood of Passaic could not have been less than $1,000,000, and probably reached a much higher figure.

Along the lower course of the river to its mouth the immediate valley was flooded, but as the valley is much narrower in this portion than above and has no settlements to compare in size with Passaic

A. WALLINGTON DURING FLOOD.

B. FAILURE OF BRIDGE AT PASSAIC.

and Paterson, with the exception of the city of Newark, no great damage was done, though much inconvenience and several cases of severe personal loss resulted.

It is estimated that the value of the bridges which were swept away by the flood (Pl. XV, *B*) in various portions of the watershed amounts to not less than $300,000, in addition to the losses noted above.

COMPARISON WITH PREVIOUS FLOODS.

It will be of interest to compare the flood of 1902 in the Passaic Valley with those of other years. Previous to 1902 the greatest flood in the Passaic River for a century, at least, occurred in September, 1882. Mr. C. C. Vermeule, in the Report of the Geological Survey of New Jersey, Vol. IV, reports concerning this flood as follows:

The flood of 1882 was probably the highest of this century, consequently more flood marks are preserved and a better recollection prevails of this than of other floods. By inquiry and comparison of data of other floods which I have obtained I have been able to construct a fairly accurate history of this flood. The waters began to rise at Dundee and Little Falls in the afternoon of the 22d, and rose steadily for 33 hours, when they reached 16,049 cubic feet per second. They then fell off for about 10 hours to 13,000 cubic feet per second, and then rose until they reached a maximum 66 hours after the beginning of the rise of 18,265 cubic feet per second at Dundee and 19,100 cubic feet at Little Falls. The upper branches appear to have discharged their flood waters into the central valley within 72 hours, and to have subsided within their banks. They reached their maximum discharge in from 20 to 40 hours after the beginning of the rise on the Passaic. In the following tables the maximum flows are obtained from well-defined flood marks at dams. The total discharge is estimated to be 3.13 inches on the shed, as already determined.

Below are appended the leading facts regarding the flood of 1902, and also regarding previous recorded floods, which will serve as an interesting basis of comparison.

Comparative statements concerning Passaic floods, measured at Dundee dam.

[Drainage area, 822.7 square miles.]

Date of flood.	Duration of flood.	Duration of rise.	Maximum flow.	Duration of fall.	Run-off: Inches on drainage area.
	Days.	*Days.*	*Sec.-feet.*	*Days.*	*Inches.*
February 25 to March 9, 1902	[a] 12	5.00	[a] 24,800	[a] 7.00	7.1
September 25, 1882 [b]	8	2.75	18,265	5.25	3.71
December 12, 1878 [b]	8	2.50	16,592	5.50	3.47
February 14, 1886 [b]	8	2.50	12,452	5.50	3.00
January 3, 1888 [b]	8	2.80	11,880	5.20	2.77
January 24, 1891 [b]	8	2.50	11,701	5.50	2.56
March 14, 1893 [b]	9	2.90	11,245	6.10	3.56
May 6, 1893 [b]	8	3.00	11,155	5.00	2.77
September 21, 1888 [b]	8	2.75	11,126	5.25	2.89

[a] Estimated. [b] From Report of New Jersey Geological Survey, Part III, 1894.

SUMMARY.

From the foregoing discussion it is seen that the Passaic River is of importance, both on account of the large manufacturing interests which depend upon it to a certain extent for power, and on account of the cities which use it as a source of municipal water supply.

The Passaic drainage basin is peculiar in respect to its physical features. Unlike the ordinary habit of river systems, in which the tributaries join the main trunk at intervals on either side, resembling the veins of a leaf, the important tributaries of the Passaic deliver their waters to the main stream at points not far from the middle of its course. They, moreover, flow from a mountainous region with rapid fall, and meet the main artery in a flat, basin-like area which easily becomes flooded at even ordinarily high stages of the stream. It has been seen that the outlet to this basin is a narrow gorge at Little Falls, restricted at its lower end by a masonry viaduct, and that in times of very high water the gorge is too small to accomodate the discharge of the river, and extensive flooding of the basin above results. It has been observed that the low-lying portions of Paterson, Passaic, and the neighboring towns on the banks of the river in its lower course are subject to overflow during high freshets, which damage not only individual householders, but also the large manufacturing interests there located. The striking physical relations of the lower valley have also been touched upon, namely, that there is a gradual narrowing of the valley as the mouth is approached, which seems to have congested the outlet of flood waters in this portion of the drainage area.

With regard to the conditions preceding and accompanying the flood of 1902, it has been observed that during the latter part of February of that year approximately 6 inches of precipitation, composed of melted snow, sleet, and rain, were released upon the frozen drainage area, and that much of this water passed rapidly into the streams.

It was also seen that the mountain tributaries discharged large volumes into the central basin, flooding approximately 32,000 acres of its area and doing considerable damage to farming and railroad interests there located.

As indicated from gage heights, the rise of water began at Dundee dam about 6 p. m. on February 25, and, after subsiding slightly on February 26 and 28, reached its maximum of approximately 24,800 second-feet on March 2. The flow curve of the flood over Little Falls dam was quite similar to that at Dundee dam, the apex of the former occurring a few hours before that of the latter.

In regard to the damage done by the flood, the most general estimates only can be made, but in Passaic and vicinity, the section which probably suffered most severely, $1,000,000 is thought to be a small approximation of the losses sustained.

CONCLUSIONS.

Floods on the Passaic drainage basin have not been so frequent nor so destructive hitherto as to warrant careful study with a view to either prevention or control, but as property along the banks of the stream becomes more valuable for manufacturing and municipal purposes, and as population increases, the time may soon come when it will be necessary to consider seriously the habits of the Passaic's flood waters.

Owing to the great demand already being made upon the basin for municipal supply, the future will doubtless see a much better control than at present of the river's waters by storage reservoirs. But, unless great care is taken to keep the reservoirs low at such times of the year as floods are likely to occur, much the same conditions may exist in winter seasons as were found during the flood under discussion. At that time all the lakes and reservoirs on the watershed were full, and the surface of the ground was rendered so impervious by frost that when the excessive precipitation came it literally slid off the area and over the reservoirs without check. The discharge tables and fluviographs show not only great irregularity in the flow of the stream, but the occurrence of freshet waters at almost any time of the year. For example, excessive high water occurred in the last week of August, 1901, at which time it would have been considered unwise to have allowed the supply reservoirs to run low.

There is one way, however, in which control could probably be had over the severest floods likely to occur on the drainage area, namely, by the construction of a dam across the Pompton at Mountain View, between the eastern extremity of Hook Mountain and the continuation of the same ridge east of that stream at the above-named place. By this means the waters of the Ramapo, Wanaque, and Pequanac rivers united in the Pompton, draining approximately one-half the total area of the entire catchment basin, could be controlled. The value of such a dam for municipal supply has been pointed out by the State engineer[a] and others. It has been estimated that a dam 2,200 feet long and 57 feet high would flood the flat basin in the neighborhood of Pompton Plains, well illustrated in Pl. XI, which includes an area of about 18 square miles. It would be practicable to build the dam even somewhat higher, and thus secure a greater capacity for the reservoir. Such a dam would not only give sufficient storage capacity to regulate excessive floods, but would be of great advantage to those portions of the valley below Paterson, which are threatened by high waters. It would at the same time relieve the central basin by holding back a portion of floods until the waters from the remainder of the drainage area, approximately one-half of the total area, could escape through the gorge at Little Falls without seriously flooding the wet lands above that point.

[a]Ann. Rept. New Jersey Geol. Survey, 1894.

While the construction of such a reservoir is possible from an engineering standpoint, as the foundations and other features of the dam site are good, it would involve considerable expense in necessitating a new alignment of portions of the two railroads which traverse the region, namely, the Boonton Branch of the Delaware, Lackawanna and Western, and the Greenwood Lake Branch of the Erie, and in addition the condemnation of a considerable amount of village and farm property in and around Pompton Plains. In view of the expensive nature of these proceedings, there is slight probability that such a dam will ever be built, but its construction would, with little question, forever prevent the danger of heavy losses at points in the lower valley.

Destructive freshets may, therefore, be expected to occur on the watershed at intervals separated by an undetermined number of years, which without elaborate and expensive engineering works can hardly be fully controlled.

Although it may be impossible to satisfactorily control the flood waters, the danger from injury by them may be much reduced by employing some means of systematic warnings of their approach.

This could be done by establishing gaging stations on the tributaries near their junction with the main stream, where daily observations of water heights could be taken. In times of excessively high water the conditions at the various stations could then be telephoned to some central point, such as the office of the engineer of the Society for the Establishment of Useful Manufactures, who would compare the returns from the various tributaries, and if necessary give warning to manufacturers and others in the cities of Paterson and Passaic of the approach of dangerous flood conditions, thus allowing them several hours to remove valuable material from warehouses before the water reached the danger point.

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