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ECONOMIC GEOLOGY 12

HYDROLOGY OF THE STATE OF NEW YORK

BY
GEORGE W. RAFTER

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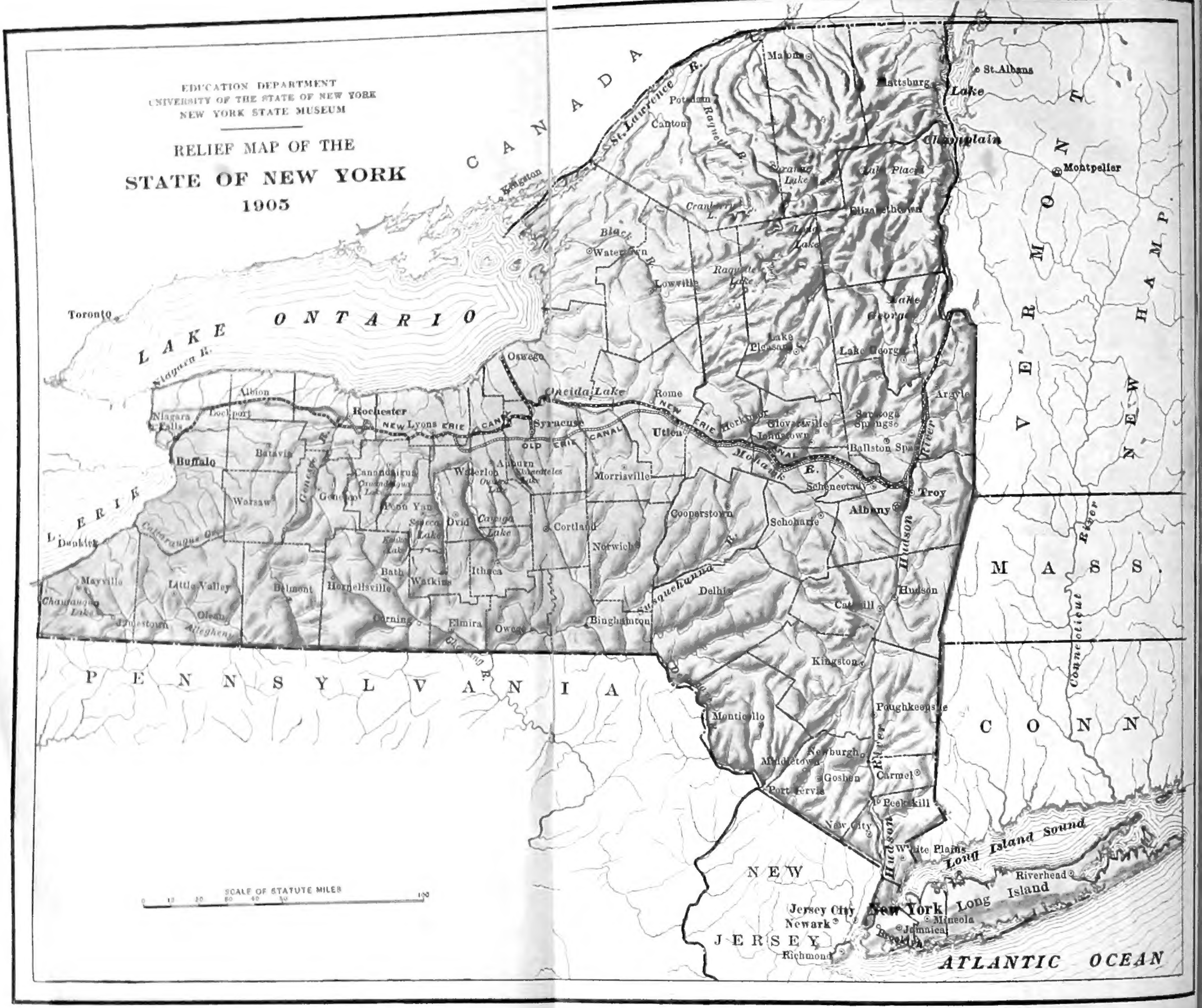

EDUCATION DEPARTMENT
UNIVERSITY OF THE STATE OF NEW YORK
NEW YORK STATE MUSEUM

RELIEF MAP OF THE
STATE OF NEW YORK
1905

STATE OF NEW YORK

EDUCATION DEPARTMENT

University of the State of New York

New York State Museum

JOHN M. CLARKE Director

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INTRODUCTORY NOTE

The great importance of water as an economic mineral is becoming daily more and more fully appreciated by the commercial public, though its recognition as a source of power in engineering enterprise is a matter of great antiquity. It therefore seemed appropriate that the geologic work of the New York State Museum should make some contribution to the sum total of public knowledge on this matter. Accordingly my predecessor in office, Dr Frederick J. H. Merrill, invited Mr George W. Rafter to write a general discussion of this important subject in its relations to New York. As a result the following report is offered to the citizens of the State, with the feeling that Mr Rafter's wide repute as a specialist in this branch will make this publication a communication of much value to engineering and to commerce.

JOHN M. CLARKE,
State Geologist

Albany, N. Y., April 15, 1904.

PREFACE

This report is a revision of Water Supply and Irrigation Papers of the United States Geological Survey, Nos. 24 and 25—Water Resources of the State of New York, published in 1899. In regard to calling the revised report the *Hydrology of New York* rather than continuing the title previously given, it may be stated that the information has been considerably extended and, while it is true that it still pertains to the water resources of the State, it seems to the writer that, on the whole, *hydrology* better expresses the meaning than does the former title.

Broadly, hydrology may be defined as that branch of physical geography treating of water, and it is in this sense that the term is used herein. Physical geography is an exceedingly elastic term, and it is quite as proper to treat of the effect of restrictive laws upon the development of the State as to treat of purely political divisions in an ordinary textbook on geography. Anyone writing upon geography, physiography, hypsography, geology or hydrology knows that the lines separating these several divisions are not very closely drawn and that one runs into the other. Physiography treats in a general way of the present condition of the waters of the earth, while geology treats in some degree of their former condition, or at any rate of the effects produced by water in a former condition. It is quite as appropriate, therefore, for the State Museum to publish a paper on the hydrology of the State as to publish those relating more specially to geology.

What may be termed the geologic phase of the physiography of New York has been treated by Professor Tarr, but his work is incomplete in this—it does not treat of the flow of streams. This report is intended to, in some slight degree, supplement Professor Tarr's work. Moreover, hypsography is not extensively treated, nor is hydrography. Tides and their effects, etc. are, aside from a short reference to Hudson river, entirely omitted. Only enough geology is given to illustrate the subject.

The data herein embodied have been gathered from many sources—the reports of the State Engineer and Surveyor, the Superintendent of Public Works, the Forest Commission, the State Board of Health, the State Weather Service, and other public documents. The data in the reports on the water power of the United States, Tenth Census, have been used in some cases where later data are not available. During the years 1896 and 1897, the writer, in addition to his regular duties in the State Engineer's Department, gathered a large amount of information bearing on the hydrology of the State and not published in the reports of the State Engineer. Much of this was in the way of piecing out earlier information and bringing the subject up to date.

Some of the figures as to the catchment areas have been obtained by checking those given in the reports on the water power of the United States, Tenth Census, so far as they are available, and by planimeter measurement on the topographic quadrangles of the State made by the United States Geological Survey. Bien's atlas of the State of New York has also been used as a check, and a number of areas have been taken from the report of the Deep Waterways Commission, while a large number of catchment areas have been taken from the report of the United States Board of Engineers on Deep Waterways.

After completing the original report to the United States Geological Survey, the writer continued the collection of data, and specially in 1898 and 1899, when he undertook for the Board of Engineers on Deep Waterways the investigation of a water supply for enlarged canals through the State of New York. The report to this Board includes a detailed study of the hydrology of central New York, covering three hundred and eighty octavo pages. This report was published as an executive document of Congress, but only a few hundred copies were issued. It results, then, that most people have not seen this report, and accordingly considerable use has been made of the matter contained therein. The report is, however, in most of the leading libraries and may be consulted by any one interested.

In 1899 the writer was consulting engineer to the Canal Committee, and added very greatly to his knowledge of the hydrology of the State.

In 1902 he was a member of the Water Storage Commission of New York and extensively considered a number of storage and power projects in the State.

Since 1900 he has been in general practice as consulting engineer, and during this time has been employed on power projects in this and other States, until at the present time there is hardly a phase of power development or water storage that has not at some time been before him for consideration.

During all this time he has been gathering information in regard to water power and allied subjects in New York. There is, however, still much to be learned, as, aside from the studies of the writer, very little has been done in the State, outside of the City of New York.

The elevations of points above tidewater have been compiled from all available sources of information, such as the Dictionary of Altitudes in the United States, Bulletin No. 76 of the United States Geological Survey; the reports of the New York State Survey and railway and canal profiles; the topographic quadrangles of the United States Geological Survey and the reports on the water power of the United States, Tenth Census, as well as the report of the Board of Engineers on Deep Waterways. Mr Freeman's report on the New York water supply, together with the report of the Merchants' Association, has been drawn upon in discussing the water supply of New York city.

It may be easily inferred that this report is not very even; that is, the information is more completely developed on some streams and on some subjects than on others. On the Genesee, Oswego, Salmon, Black and Hudson rivers and their tributaries, and on the Niagara river, the information is tolerably complete. It is also fairly complete on some of the smaller streams, although on the majority there is still a large amount of work to be done, but on the streams of the southern section—Allegheny, Susquehanna and Delaware rivers, with their tributaries—very little information has been gathered. These are still, so far as definite information is concerned, practically unknown, although a slight beginning has been made by the United States Geological Survey. The information given herein is therefore, such as is available, either from personal knowledge or the work of others.

The information as to the hydrology of New York has grown so rapidly in the last few years that considerable condensation was necessary in order to keep within the limits of even as great an extension of the original papers as is herewith included. The omission of some matters which may seem to the reader important is therefore no certain index that they have been overlooked, but merely indicates that they have not seemed to the writer important enough to mention. The report has been very largely rewritten and extended from an original length of 200 pages to 900 pages. The meteorological tables, as well as the tables of stream flow, have never before appeared in their present form. All these tables have been specially computed and rearranged for this report. The data of rainfall, temperature and stream flow have been arranged with reference to a water year beginning with December and ending with November. Cubic feet per second, inches on the catchment area and cubic feet per second per square mile are, except in some of the longer records, given in columns side by side, thus showing at a glance the comparative results and very greatly extending the value of the tables. The writer's thanks are due to his daughter, Myra Willson Rafter, for computing these tables.

The criticism has been made that the writer's views on some of the questions herein discussed are not the same now as formerly. On this point it may be stated that his work on the hydrology of New York has, aside from several formal reports, as on Genesee river, Hudson river, report to the Board of Engineers on Deep Waterways, etc. been largely a matter of opportunity, and such writing, while extensive enough, is scattered through a large number of miscellaneous papers. Nevertheless the writer has casually discussed in these papers a number of the most important questions confronting the people of New York. With more study some of his views have been slightly modified. The present report, therefore, wherever it differs from preceding papers or reports, must be taken to represent his latest views.

In order to make this treatise as complete as possible, the Report on the Relation of Rainfall to Runoff, published in 1903 by the United States Geological Survey, is herewith included, so far as applying to the State of New York. Extended excerpts on floods have been made from the report of the Water Storage Commission.

The discerning reader will observe an occasional repetition. A few such have been made, either to save too frequent reference to a preceding page, or where a different phase of a subject has been discussed. Where the subjects are similar, references thereto have been frequently made by a foot-note. The object of the repetition is to reduce the labor of reading to a minimum.

The writer is indebted to the Niagara Falls Hydraulic Power & Manufacturing Company, the Niagara Falls Power Company, the St Lawrence Power Company, the Hudson River Power Transmission Company, the Hudson River Water Power Company, the Empire State Power Company, the Utica Gas & Electric Company, the Hannawa Falls Power Company and the International Paper Company for photographic illustrations for this report.

The writer wishes to specially acknowledge his indebtedness to the Report on Stream Flow and Water Power, made since 1900 by the State Engineer and Surveyor, acting in conjunction with the Hydrographic Division of the United States Geological Survey. These reports have been compiled by Mr Robert E. Horton.

Rochester, April 1, 1904.

George W. Rafter.

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THE HYDROLOGY OF THE STATE OF NEW YORK

THE SOURCE OF THE GREATNESS OF NEW YORK

Introductory statements. It is proposed to give in this report some general statements in regard to the water resources of the State of New York, to be followed by a discussion in detail of the chief contributing causes which have made New York State great. As we proceed, we shall see not only in what manner the resources of the State have been developed, but also how restrictive legislation has prevented any such full development as has occurred in neighboring states where such restrictive legislation has never been enacted. A comprehensive commercial policy will be outlined, which, if followed, will lead to a relatively far greater development than has occurred in the past.

The preeminent position of New York is due almost entirely to her great natural water resources. Reaching from the ocean on the east to the Great Lakes on the west, she has gathered to herself the treasures of the foreign world as well as those of half the western continent. Her inland rivers, with their great water powers, have been in the past and will continue to be in the future a perpetual source of wealth. Taking into account the commercial supremacy guaranteed by the Erie canal, it may be said that the history of the State's progress during the nineteenth century was largely a history of the development of her water resources. It is the purpose of the writer in this report to relate briefly not only in what manner these resources have been employed, but to indicate the recent lines of development and the probable future of the State if her water is utilized to the fullest degree. It is proposed to describe in a general way the river systems, giving brief descriptions of several of the more important utilizations of water in New York, together with a discussion of some of the economic problems confronting the people of the State.

As regards the water power of New York, the Tenth Census of the United States (1880), Vols. XVI and XVII, gives in detail the statistics of the main water powers as they existed in 1882. Many of these show considerable increase at the present time, although the extensions are for the most part similar to those described in the census report, and hence present few additional features of interest. Several of the recent plants, however, are on quite different lines both as to their scope and as to the method of development adopted. It has therefore seemed more important to describe a number of the new plants, illustrating them by photographs, and to give the main facts of the great storage projects of the Black, Genesee, Hudson, Salmon, Schroon, Wallkill and other rivers, than to spend time on small and relatively unimportant powers which are already sufficiently described.

The peculiar relation of the State to water power development on the main rivers of New York is an interesting subject for discussion. Owing to the circumstances of the early settlement and the development of the canal system, the State has assumed ownership of the inland waters, or, at any rate, of all streams used as feeders to the canals. This assumption has worked injustice to riparian owners, and is at present a bar in the way of the full development of important streams by private enterprise.

Moreover, New York is preeminent in position by virtue of the fact that she is the only State resting on the ocean and at the same time grounded on the Great Lakes. The Hudson river is a navigable estuary for one hundred and fifty miles inland, and the depression of the Mohawk valley, together with the valley of Oswego river, extends, with slight elevation, from the northern end of this estuary west to Lake Ontario. It was inevitable, therefore, that from time immemorial the Mohawk valley should be the highway, along which passed the commerce between the east and the west. If the proposed deep waterway connecting the Great Lakes with the ocean is ever constructed, nature has from the beginning predestined by two possible routes, both of which pass through the State of New York—one by way of Oswego-Mohawk valleys to tidewater and the other by way of St Lawrence-

Champlain-Hudson valleys to tidewater. The former of these routes—that through the Mohawk valley—was the pathway from the east to the west when the white man first came. Here the Iroquois warriors journeyed back and forth, and here, where the Dutch patroons built with the fur trade the early beginnings of what is now a vast interstate commerce, is the great highway of today. At Rome, the highest point on the divide between the Mohawk river and the Great Lakes drainage, the surface of the ground is only 430 feet above tidewater. This is the lowest pass from the Adirondacks to Alabama; all other lines of communication rise to much higher altitudes than this. Hence, it was inevitable that New York State, by virtue of position alone, should become a great manufacturing State.

Let us see why the great waterpowers, indispensable to the development of manufacturing, happen to be located on the direct line of greatest commercial activity. The explanation is partly geologic and partly topographic, or, if we consider topography as an outcome of geology, then the explanation is all geologic.

Favorable natural conditions. New York State is great in water resources, not only by virtue of her position between the Atlantic ocean and the Great Lakes, but because topographic, geologic and climatic conditions have combined to make her the highway of commerce as well as the manufacturing center of the United States. Some of the contributing causes to this position may be found in her mountain systems, affording great water centers, from which large streams descend to the neighboring lowlands, affording large opportunities for the economic development of waterpower, as well as insuring an adequate supply of potable water to her towns and municipalities.

As regards waterpower, the other chief contributing causes are the possession, as part of her domain, of the Niagara and St Lawrence rivers, with their extensive waterpower development.

A study of the climatology of New York shows that in nearly every portion of the State the amount and distribution of the rainfall are such as to insure a large enough runoff of streams to furnish, even under natural conditions, considerable waterpower.

Artificial modifications. Natural conditions have been largely interfered with by the cutting off of forests and the consequent extensive development of the agricultural interests of the State. Under conditions now existing, the water yield of streams is very different from what it was originally. As a tentative proposition, it may be assumed that the general cutting off of forests in New York has decreased the annual runoff of streams issuing from the deforested areas to a depth of from four to six inches per annum.

The proof of this proposition is found in considering that in a number of places the runoff of streams is gradually decreasing, not only because of the decrease in forest area, due to clearing up of lands for agricultural purposes, but is even changing because of the varying character of the crops raised from year to year. The fact that such changes are taking place has been very strongly impressed upon the writer in a number of litigations in which he has been at different times employed where the question of damages for diverting water from streams, either for municipal or manufacturing purposes, was the leading issue. Invariably in such cases a large number of old residents have been sworn as witnesses for the plaintiff and have testified that formerly, say, thirty, forty or fifty years ago, as the case may be, the stream in question had a sufficient summer flow to operate a mill of a given capacity. In western New York, where several of these cases have occurred, there are mills from sixty to seventy years old, in which, up to the time of changing from the old-fashioned grinding process to the roller process, the machinery was substantially as it was made at the original erection.

Why waterpowers are less reliable now than formerly. However valuable water privileges at these mills may have been originally, it is nevertheless certain that now a number of them are practically worthless during several months of the summer and fall of the average year. In order to present a valid reason why the waterpower of streams in western New York may be less valuable now than forty or fifty years ago, there was prepared for use in a certain litigation an extended discussion of this question. The discussion in question applies particularly to catchment areas in Wyoming county, the runoff data being from gagings of Oatka creek for the years 1890-92.

Wyoming county is an elevated region of the same general character throughout. Formerly it was covered with heavy pine, hemlock, oak, beech, maple, ash and elm forests. At the present time the forest area is exceedingly small, and what there is left of it is so scattered and so open as to exercise almost no effect on stream flow. In order to illustrate the progressive changes which may take place in the water-yielding capacity of a given catchment area, the writer compiled from the census reports for each decennial period from 1850 to 1890, inclusive, the statistics as therein given for Wyoming county, the assumption being that whatever was true of Wyoming county must be substantially true of the Oatka creek catchment area of 27.5 square miles, situated in the central part of the county. The census data give the total area, total improved area for a portion of the period, tilled area and permanent meadows, total unimproved area, woodland and forest area, and the miscellaneous unimproved area. As illustrating the changes which have taken place in Wyoming county since 1850, the writer merely cites from the tabulations that, with a total area of 387,840 acres, the total improved area was 223,533 acres in 1850, and 356,880 acres in 1890. The total unimproved area was 164,307 acres in 1850 and only 30,960 acres in 1890, of which 26,960 was woodland and forest and 4000 miscellaneous unimproved area.

Again, the tables show that in 1850 there were 50,035 acres in clover seed and grass seed, wheat, rye, corn, oats, peas, beans, potatoes, barley and buckwheat, while in 1890 the same crops showed 71,915 acres. In 1850 the area in oats amounted to 18,132 acres, while in 1890 it amounted to 29,083 acres. Barley in 1850 covered 2409 acres, and in 1890, 14,164 acres. Again, the area in hay amounted in 1850 to 62,563 acres, and in 1890 to

80,446 acres. The total tons of hay in 1850 were 75,076; in 1890, 105,134 tons. Probably the statistics as pertinent as any to the case in hand are those relating to changes in live stock. For instance, in 1850 the total number of milch cows was 10,022, while in 1890 the total number was 22,919. The total number of horses, mules, milch cows, oxen and other cattle in 1850 was 40,812, while the total number of all these classes of stock in 1890 was 44,810. Considering the total of hoof cattle, we might say that the increase had not been so great, but when we consider the total of improved area in comparison with the unimproved area in 1850, and also in comparison with the amount of stock then and in 1890, we see at once that in 1850 the principal pasture area of the country must have been in forest, whereas the pasture in 1890 must have been, as in fact is well known was the case, largely in permanent meadows. Referring to Risler's results as to the amount of water required for crops, we learn at once the great increase in water demand for supporting crops from 1850 to 1890.

In a paper, *Recherches sur l'Evaporation du Sol et des Plantes,* Risler has given the results of experiments at his estate in Switzerland, carried out specially with reference to ascertaining the mean daily consumption of water by growing agricultural plants, as well as by vineyards and two kinds of forests.

The following matter relating to Risler's experiments is condensed from Ronna's *Les Irrigations:*

> By way of confirming the results of investigations as to the water consumed by growing plants, etc. carried out at the Agricultural Experiment Station of Rothamsted, England, Risler has shown the different methods employed by him in 1867 and 1868. By a continuation of these experiments in 1869-72, he has shown the mean daily consumption of water by lucerne, wheat, oats, clover, meadow grass, etc. One of his interesting conclusions is that winter wheat would have consumed daily from April to July, 1869, 0.10 inch of water per day for 101 days, or over 10 inches for the growing season. The experiments on water content of soil show that for the year 1869 the crops must have taken a small amount of water from the ground which, with the rainfall was sufficient to produce a satisfactory crop for the meteorological conditions prevailing that year.

For oats there was needed in 1870, according to Risler, a quantity of water 250 times the weight of dry material contained in the crop. In 1871 clover transpired 263 units of water to produce one unit of dry substance, and English ray-grass 545 units of water for one unit of hay containing 15 per cent of water. For this last the quantity of water corresponds to 0.276 inch in depth per day.

Risler observed, furthermore, that following rains or wettings transpiration of plants increases, gradually diminishing in proportion as dryness increases, other conditions remaining equal. When the water given off by the leaves is less than that taken up by the roots, growth is active, while under the contrary condition, plants wither.

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In a general way, the consumption of water by plants is more regular in clay soils than in sandy. Hellriegel states that in a sandy soil plants begin to suffer from drouth when the soil does not contain more than 2.5 per cent moisture. Risler finds that the approximate limit for clay soils is 10 per cent, although in clay soil, part of the water escapes absorption by the roots.

Taking as a basis the observations made on the crops raised at Caleves, Risler expresses the mean daily consumption of water as a depth on the cropped area as follows:

	Inches.
Meadow grass requires from	0.134 to 0.267
Oats require from	0.141 to 0.193
Indian corn requires from	0.110 to 0.157
Clover requires from	0.140 to
Wheat requires from	0.106 to 0.110
Rye requires from	0.091 to
Potatoes require from	0.038 to 0.055
Vineyards require from	0.035 to 0.031
Oak trees require from	0.038 to 0.035
Fir trees require from	0.020 to 0.043

Risler determined the consumption of water on a meadow of one hectare (2.47 acres) of very thickly turfed English ray-grass as 281 millimeters (11.06 inches), amounting to a daily depth of 0.267 inch. This consumption applies to a meadow well provided with water during the warmest season of the year. The experiments showed that on cloudy days evaporation was reduced to about one fourth of the mean, that is, to 0.069 inch per day.

In Switzerland the fields begin to grow green the latter part of March, and the hay harvest occurs in June; hence, the growth of the plant takes place in April and May. The point is brought out very forcibly by Risler's experiments, that hay crops depend more on the quantity of rain than on temperature; thus, in 1867, when the temperature of the two months was the lowest but the rainfall high, the meadows yielded abundantly, while in 1868, with a high temperature and medium rainfall, the crop was satisfactory because the soil had water in reserve, the drains continuing to flow until the end of May that year.

Taking into account the foregoing data, the writer prepared a table giving the per cent that each crop actually raised in 1850, was of the total area in the county assigned to forest area, fallow land, etc., each in its proper area. Similar data have been prepared for each census period to 1890, inclusive. From such tabulation it was learned that in 1850 the area in wheat, rye, oats, barley and buckwheat was 10 per cent of the whole; Indian corn, 2 per cent; potatoes, 0.7 of one per cent; long grass, 16 per cent; short grass, 20 per cent; fallow land, orchards, peas, beans and miscellaneous, 11 per cent; and forest, 40 per cent. Without giving the details of 1860, 1870 and 1880, we may pass to 1890, in which year the following percentages were found: Wheat, rye, oats, barley and buckwheat, 7.9 per cent; Indian corn, 0.7 of 1 per cent; potatoes, 1.6 per cent; long grass, 20.8 per cent; short grass, 33.5 per cent; fallow land, orchards, peas, beans, miscellaneous, 25 per cent; clover, 1.5 per cent, and forest, 9 per cent. It will be noticed that the forest area had changed from 40 per cent in 1850 to 9 per cent in 1890. Taking Risler's data as a basis, it was then easily computed that wheat, rye, oats, barley and buckwheat would require 9.2 inches of water on the actual area cropped to fully supply their demands; Indian corn would require 12.2 inches; potatoes, 4.3 inches; long grass, 19.3 inches; short grass, 15.4 inches; fallow land, peas, beans, orchards and miscellaneous, 12 inches; clover, 12.9 inches, and forest, 3.6 inches. Proceeding on this line it was ascertained that in 1850, the total depth of water over the entire area of Wyoming county, required to fully support vegetation as it existed in that year amounted to 10.17 inches; in 1860, it amounted to 11.15 inches; in 1870, to 11.89 inches; in 1880, to 13.24 inches, and in 1890, to 13.57 inches. Hence, the conclusion seemed to be safely drawn that in 1890, due to changes in forest area and in quality of crops grown, the amount of water required in Wyoming county to support vegetation during the growing season would amount to 3.4 inches more than in 1850. Why a mill stream in Wyoming county, which was ample for all demands in 1850, entirely failed in 1890 seemed, therefore, fully explained.

In order to determine whether such conclusion was in accord with the rainfall records of western New York, a large number of such were tabulated in periods, with December to May, inclusive, making the storage period; June to August, inclusive, the growing period, and September to November, inclusive, the replenishing period. From a tabulation of the rainfall records kept at Middlebury Academy, in Wyoming county, for certain years—seventeen in all—from 1826 to 1848, inclusive, the mean rainfall for the growing period was determined at 9.52 inches. In 1832 it was only 6.76 inches. The maximum at Middlebury Academy was 14.36 inches in the growing period of 1828. Tabulating more recent records it was found that at Arcade, in Wyoming county, from 1891 to 1896, the mean of the growing period was 13.61 inches, the minimum of 9.62 inches occurring in 1894. At Leroy, in the adjoining county of Genesee, the mean of the growing period from 1891 to 1895, inclusive, was 10.31 inches, the minimum being 6.61 inches in 1894. At Rochester the records show a mean of the growing period for the years 1871 to 1896, inclusive, of 8.29 inches, the minimum being only 5 inches in 1887. It appeared, therefore, that at the present time, with the catchment areas almost entirely deforested, streams must necessarily be very low during the summer season of nearly every year. Practical observation in western New York amply confirms this theoretical deduction.[1]

Variation in water yield. The runoff of Niagara river has been commonly assumed on the authority of the Lake Survey at about

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[1] Abstract from Stream Flow in Relation to Forests, by George W. Rafter, in An. Rept. of Fisheries, Game and Forest Commission for 1896. The portion relating to Risler's experiments is from paper on the Data of Stream Flow in Relation to Forests.

265,000 cubic feet per second. The recent studies indicate that the extreme low flow of a cycle of minimum years may not be more than 60 per cent to 70 per cent of this figure. From this point of view, the people of the State of New York have great interest in any project which would tend to decrease the low-water runoff of that stream. The figures obtained by the Deep Waterways Survey, substantiate this statement. Such interest is equally pronounced in the case of the St Lawrence river.

The measurements of discharge of a number of inland streams of New York indicate considerable variation in the water yield in different parts of the State. Genesee river, in 1895, gave, with a rainfall of 31 inches, a minimum flow for the year of only 6.67 inches. The catchment area of this stream is, as already stated, mostly deforested, whence it results that serious floods are frequent.

The lowest annual runoff thus far measured in the State of New York is that of the Hemlock lake catchment area, where, in 1880, the total runoff from an area of 48 square miles was only about 3.35 inches.

Oswego, Mohawk, and Hudson rivers and their tributaries in this State all have large pondage on natural lakes, which, with other conditions, tend to maintain the low-water flow. Croton river presents surface geologic conditions which tend to increase its low-water flow. Without going into detail, we may say that these streams will yield a minimum flow of about 0.2 of a cubic foot per second per square mile. Variations from this limit are given in the chapters specially discussing minimum flow.

As a typical flood stream of the State we have Chemung river, where serious floods, due to deforestation of a mountainous catchment area, have become so common as to necessitate the carrying out of extensive protection works at the large towns on that stream.

Value of water to industries. Water power is extensively sold at Oswego, Cohoes, and Niagara Falls, and to some extent at Rochester. It will also be extensively sold at Massena when the development there is completed.

The value of the internal waters of the State to some of the leading industries, such as the lumber industry and the woodpulp and paper industry, may be noted. On the Hudson river, from 1851 to 1897, inclusive, the total number of logs taken to market by water transportation was 23,313,585, these market logs furnishing 4,662,717,000 feet B. M. of lumber. The cost of driving logs from the headwaters of the Hudson to the Big Boom above Glens Falls is said to be from 50 to 75 cents per thousand feet B. M.

The wood-pulp and paper industry is developed in New York State to a point beyond that reached in any other State of the Union. On January 1, 1900, there were 191,117 net water horsepower in use in the State in the production of mechanical woodpulp, including from 30,000 to 35,000 consumed in operating paper mills.

One obstacle to the easy operation of water power in this State is the formation on many streams of frazil or anchor ice. A study of the formation of frazil and anchor ice, as made by the Montreal Harbor Commissioners, indicates that it may be possible to learn in the future how to remedy this difficulty.

The most of these interesting questions are discussed in detail in the following pages.

The relation of the mountains to the river valleys. Studying the hypsography of New York one can not fail to be struck with the fact that there are within the boundaries of this State six main elevated mountainous or semimountainous regions from which waters issue in all directions. In order then to understand the river systems of the State we need to briefly consider the mountains as appearing in Chautauqua, Cattaraugus, Allegany and Steuben counties and extending northward into Erie, Wyoming, Livingston, Ontario and Yates counties. The Genesee river and the lake system of western New York mostly lie in valleys between the spurs of these mountains. On the State line between New York and Pennsylvania the higher peaks of the Alleghenys rise to an altitude of over 2500 feet. North of the Allegheny river there is a well-defined plateau, varying in elevation from 1500 feet to 2000 feet, the northern extremity of which lies in the central part of Wyoming county. To the north of this there are three well-defined terraces gradually stepping down to the level of Lake Ontario, the first of which varies from 1000 to 1500 feet above tide; the second, from 500 to 1000 feet, and the third, between about 250 and 500 feet. Lake Ontario lies at a mean elevation of 247 feet above tidewater. It is by these several successive steps that the northern spurs of the New York plateau gradually run out and merge themselves almost imperceptibly into the flatlands about and in the vicinity of Lake Ontario and the St Lawrence river. The course of the streams of this region has thus been defined by the topography. With the exception of those trubutary to the Allegheny river, their course is generally to the north, to either Lake Erie, Niagara river or Lake Ontario.

Farther east we find a number of mountain or semimountain ranges which are a part of the great Appalachian system, and which extend across the State in a general course from southwest to northeast. The first of this series extends into New York from Pennsylvania and extends northeast through Broome, Delaware, Otsego, Schoharie, Montgomery and Herkimer counties to the Mohawk valley. This mountain system consists of broad, irregular hills, broken by deep ravines, with many of the slopes steep and precipitous. To the north of that river an elevated area of crystalline rocks forms the Adirondack mountain range, which extends to Lake Champlain. To the westward of this area the land is more level, gradually declining to the northwest until it finally terminates at the level of Lake Ontario and the St Lawrence river. The streams of these sections mostly flow west and northwest to the east end of Lake Ontario and to the St Lawrence river, while a short distance from the Mohawk they flow south to the Susquehanna river. The Chenango river is the typical stream of the section, tributary to the Susquehanna.

Still farther east and south of the Susquehanna valley a second series of mountains enters New York from Pennsylvania and extends northeast through Sullivan, Ulster and Greene counties, terminating in the Catskill mountains upon the Hudson. The highest peaks are about 4000 feet above tide. The Shawangunk mountain, a high and continuous ridge which extends through Sullivan and Orange counties and the south part of Ulster, is the extreme easterly range of this series. The Helderberg mountains are foothills extending north from the main range into Albany and Schoharie counties. The streams rising in the Catskill mountains flow in all directions—Schoharie creek north to the Mohawk; Rondout creek easterly to the Hudson, and the headwaters of Delaware river southwesterly to that stream.

The most easterly mountain range enters the State from New Jersey, and extending northeast through Rockland and Orange counties to the Hudson, appears on the east side of that river, forming the Highlands of Putnam and Dutchess counties. The northerly extension of this range passes into the Green mountains of western Massachusetts and Vermont. The highest peaks of this range in New York culminate in the Highlands upon the Hudson where there are points from 1000 to about 1700 feet above tide. The Wallkill river, the principal stream of this division, lies in a deep valley to the west of the main range and between it and the Shawangunk mountain.

We have referred to the main Adirondack mountain range as beginning near Little Falls on the Mohawk river and extending northeasterly to Lake Champlain. There are a number of other well-defined mountain ranges in the northeastern part of the State, all of which are included under the general term of Adirondack mountains, and which require notice in detail. The Adirondack range proper crosses Herkimer, Hamilton and Essex counties and terminates near Port Kent on Lake Champlain. It is about 100 miles in length and may be considered the backbone of the Adirondack mountain group, its ridge line dividing the waters of the St Lawrence from those of the Hudson river and Lake Champlain. Mount Marcy, rising to a hight of 5430 feet, is the principal peak of this range, while McIntyre, Haystack and Skylight, each over 5000 feet in hight, are also in this chain.

Next to the main Adirondack range to the eastward is the Bouquet range, beginning on the south in the vicinity of East

Canada creek and extending through the northwestern part of Hamilton county, and crossing the center of Essex county to Lake Champlain. The highest peak is Mount Dix, with an altitude of 4915 feet above sea level. Other prominent mountains of the Bouquet range are Giant, Noon Mark, Dial, Nippletop, McComb, Sable and Boreas mountains.

The third range, known as the Schroon, begins at the valley of the Mohawk, in the eastern part of Fulton county, and crossing through Warren and Essex counties ends near Westport, on Lake Champlain. The Schroon river flows along the eastern base of this range.

The fourth range is the Kayaderosseras, which begins in the lowlands north of Saratoga Springs and extends through Warren county to Crown Point. Mount Pharaoh, a high peak near Schroon lake, is the only important mountain of this range.

The fifth range, known as the Luzerne mountains, begins in the foothills near Saratoga, crosses the Hudson river a little above Glens Falls, and running northeasterly encircles Lake George on the west, ending at Ticonderoga on Lake Champlain. The peaks of this range around Lake George are about 2000 feet above tidewater.

According to Prof. Arnold Guyot, the main mass of the State of New York is a high triangular tract or tableland, elevated from 1500 to 2000 feet above the ocean, and may be considered the northeastern extremity of the western half of the Appalachian plateau in this latitude. The natural limits to the west and north are the depression now only partly filled by the waters of Lakes Erie and Ontario, and which continues in a northeastern course down the St Lawrence river to the ocean. The natural limit at the east is the long and deep valley of Lake Champlain and the Hudson river. In the south the tableland continues uninterrupted into Pennsylvania. The eastern edge is formed by a series of mountain chains, more or less isolated, in which are the highest summits in the State. These are the Highlands, crossed by the Hudson, the Shawangunk mountain and the Catskills on the western bank and the Adirondacks covering the territory between the St Lawrence and Champlain valleys. Beyond this eastern wall the true mountain chains cease. The surface of the western portion of the Appalachian plateau is deeply indented by valleys with their bottoms generally several hundred feet below the common level and separated by high ridges. The deep transverse cut forming the valley of the Mohawk river and Oneida lake and opening a channel from the low lake region to the Hudson river, thus dividing the main plateau into two distinct masses, is not the least remarkable feature. It was the possession of this mountain pass, with broad level valleys in either direction, which made New York State the original highway from the east to the west.

Rivers and lakes of Adirondack plateau. From the Adirondack plateau streams flow to the north, southeast and west. The principal streams flowing north, east and west to the St Lawrence system are Moose, Beaver, Oswegatchie, Grasse, Raquette, St Regis, Salmon, Saranac, Ausable, and Bouquet rivers. The southern streams, which all belong to the Hudson system, are Sacandaga, Indian, Cedar, Opalescent, Boreas, and Schroon rivers, and East Canada and West Canada creeks. All these streams head in lakes, of which the most important, tributary to the St Lawrence, are Placid, Saranac, St Regis, Loon, Rainbow, Osgood, Meacham, Massawepie, Cranberry, Tupper, Smiths, Albany, Red Horse Chain, Beaver, Brandreth, Bog River Chain, Big Moose, Fulton Chain, Woodhull, Bisby, Raquette, and Blue Mountain.

Following are the principal lakes of the Adirondack plateau tributary to the Hudson system: Pleasant, Piseco, Oxbow, Sacandaga, Elm, Morehouse, Honnedaga, West Canada, Wilmurt, Salmon, Spruce, Cedar, Lewey, Indian, Rock, Chain, Catlin, Rich, Harris, Newcomb, Thirteenth, Henderson, Sanford, Colden, Boreas, Elk, Paradox, Brant, Schroon, and Luzerne. There are a number of other lakes in New York, as Chautauqua, Conesus, Hemlock, Honeoye, the Finger Lakes, Onondaga, Oneida and others.

The great forest as a stream conservator. The great forest of northern New York occupies the central part of the Adirondack plateau, and deserves notice from its importance as a conservator of the streams issuing from that region. The outlines of the great forest are substantially as follows: Its eastern boundary coincides quite closely with a line drawn through Keene Valley and thence along the valleys of Schroon river and the upper Hudson; its southern boundary is for the main part identical with that of Hamilton county and the town of Wilmurt, in Herkimer county, although in some places the forest extends a short distance into Fulton county; its western boundary is the county line between Lewis and Herkimer counties; its northern boundary runs in an irregular line from a point near Harrisville, on the Lewis and St Lawrence county line, to the Upper Chateaugay lake, which is situated near the line between Franklin and Clinton counties. This territory contains about 3,590,000 acres, of which 3,280,000 acres are considered to be covered with dense forests. Within this region there are from 1300 to 1400 lakes and ponds, while from it the eighteen important streams just enumerated diverge in every direction. The general elevation of the Adirondack plateau is about 2000 feet above the level of the sea. Little discussion is needed, therefore, to show the great value of this elevated forest-covered plateau as a conservator of the natural waters of the State.

One important utilization of the waters of this State formerly was the carrying of logs to market through the various streams. By reason of the clearing off of the forests, that business has gradually declined until, except in the Adirondack plateau, it is now of little importance. It has been the policy of the State for a number of years to acquire, as far as possible, by tax title and purchase, bodies of land in the Adirondack forest for the purpose not only of conserving the forests in order to increase the yield of streams, but for the further purpose of creating a forest park worthy of the great Commonwealth of New York. In order to carry out this project the Forest-Preserve Board has been empowered to purchase lands within the forest, or, failing to agree on terms with the landowners, to take lands under condemnation proceedings.[1]

The Adirondack plateau is a rugged, rocky region, sparsely populated, and worthless for agriculture. Its chief value lies in a complete utilization of such natural resources as attach to its unparalleled water-yielding capacity. From this point of view it may easily become an important factor in the future development of New York. To insure this result, the water yield of every stream of the region needs to be conserved by reservoir systems.

DATA OF CLIMATE IN NEW YORK

Climate may be defined as the atmospheric conditions affecting life, health and comfort, and including temperature, moisture, prevailing winds, pressure, etc.

The climatic data of New York have been accumulating for over seventy-five years. In 1825 the Board of Regents organized a systematic service at over fifty schools and academies in the State. This is noteworthy as being the first important attempt made in this country towards the investigation of local climate. In 1854-59 the Smithsonian Institution began the distribution of meteorological instruments throughout the State and a large number of observations were taken, some of them by private parties, from 1826-1875. The work of the Board of Regents was discontinued in 1863, although weather records were maintained at the military posts at Sackett Harbor, Plattsburg and in New York harbor, as well as by independent observers. From 1871 to about 1874 stations were established by the United States Signal Service at Buffalo, Rochester, Oswego, Albany and New York city, and in 1895 at Binghamton. In 1903 a station was established at Syracuse.

The State Meteorological Bureau was organized in 1889, and for ten years, in consideration of the number of observations, the records are the most satisfactory thus far made. In 1899 this bureau passed under the control of the Department of Agriculture

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[1] The State holdings in the Adirondack region up to the year 1902 may be determined by reference to a Map of the Adirondack Forest and Adjoining Territory as issued by the Forest, Fish, and Game Commission in 1902.

of the United States, and has since been operated as a bureau of that department. Complete observations are taken at the six original stations established by the United States Signal Service, including barometer, temperature, dewpoint, relative humidity, vapor pressure, precipitation, wind, cloudiness and electrical phenomena. Generally, the Regents and the Smithsonian observations only included temperature and precipitation, although there were a few exceptions where barometer and wind were taken. The Meteorological Bureau also generally confines itself to temperature and precipitation, except that at the central office at Ithaca, and at a few other places, barometer and cloudiness are taken. The same statement applies to the work of the Meteorological Bureau as carried on under the direction of the United States Department of Agriculture.

The average annual temperature is generally taken as decreasing with altitude at the ratio of 1° F. to every 300 feet of elevation, the rate being somewhat below this average in winter and above it in summer. An approximate determination for the State indicates that the rates of decrease are 0.3° F. per hundred feet elevation for the winter, and 0.4° F. per hundred feet for the summer. For the mountains of northern New York a much smaller variation than 0.3° F. appears to hold for the winter months.

The intimate relation which exists between air circulation and precipitation in New York is one of the most interesting facts to be noted. Owing to lack of moisture in the continental interior, northwest winds in the spring, summer and fall are essentially dry. In winter their dryness proceeds from low temperature and consequent small vapor-carrying capacity. The winter precipitation is due almost entirely to storm areas passing either actually across or in the vicinity of this State and deriving their supply of vapor from the inflow of moist air which they induce, either from the Atlantic ocean or from the Gulf region.

The winter months—December, January, and February—have somewhat less precipitation than either of the other seasons, although in the vicinity of the Atlantic coast, on the southwestern highlands of the State, and in the region of the Great Lakes the winter precipitation is relatively large.

In the spring, rising temperature produces a modification and shifting of pressure systems, the winds decreasing in velocity and their direction being more variable than in winter. The frequent showers occurring in April and May appear to be due more than at any other time to the effect of an admixture of air having different temperatures.

In summer the Gulf of Mexico and the Atlantic ocean contribute large supplies of moisture to northward-moving air currents, and, although cyclonic depressions are less frequent than at any other season, the rainfall accompanying each storm is heavy, and in New York the maximum seasonal precipitation, amounting as an average for the whole State to 10.96 inches, occurs in this season.

As regards the fall months, the rainfall of September is usually light in the region east of the Great Lakes, while in October the maximum general rainfall occurs. As regards meteorological conditions, winter may be considered as beginning in November.

A study of the data shows that there are a number of contending forces which are distinctively operative in New York, and which by modifying one another tend to produce numerous irregularities of the rainfall. So irregular indeed is the precipitation that frequently places only a short distance apart show wide variation.

In a general way it may be said that the amounts of annual rainfall in different sections of New York are mainly determined by proximity to sources of vapor or to vapor-laden air currents, and by the character of the local topography. As regards the latter statement, a more definite form would be that under similar conditions the precipitation is in some degree proportionate to the altitude. This rule, while generally true, does not apply to the valley of the Hudson river, where the upper portion, including the Champlain valley, receives a somewhat deficient rainfall as compared with the State as a whole. To the west, the Adirondack plateau receives a marked increase of rainfall, while farther northwest there is a decrease in the valley of the St Lawrence. This is also true of the elevated region in the vicinity of Hemlock lake, which, although several hundred feet higher, has a rainfall considerably less than that at Rochester.

In the southeastern portion of the State the ocean winds find no obstruction along the coast, but, passing inland and meeting the abrupt ranges of the southeastern counties, give a copious rainfall as compared with that of the intervening regions.

Western New York, on account of the frequent southwesterly direction of the winds, receives an appreciable portion of its vapor supply from the Gulf of Mexico. The rainfall in central New York, although less than that of the southeastern and southwestern highlands, is generally abundant. The principal valleys of the Susquehanna system, and also the depression of the central lakes tributary to Oswego river, show a deficiency as compared with the average of the State.

A knowledge of the snowfall is important in a study of the water resources, because by reason of the snow lying on the ground continuously for several months it is a great source of loss in open regions subject to severe winds, the evaporative effect of the winds tending to carry away large quantities of moisture which would otherwise be available to maintain stream flow. Thus far the only data relating to depth of snow are those derived from the Reports of the State Meteorological Bureau. The following are a few figures so derived: In the winter of 1893-94 the total depth of snow at Humphrey, in the western plateau, was 136.5 inches; in 1890-91 the total depth at Cooperstown, in the eastern plateau, was 110 inches; in 1891-92 the total depth at Constableville, in the northern plateau, was 170.7 inches; in the winter of 1890-91, at Utica, in the Mohawk valley, the total depth was 165 inches, and in 1891-92, at the same place, 151.6 inches. The records show that at the places where these large snowfalls occurred the ground was continuously covered with snow for several months. If the winds were of high velocity at the same time the evaporation loss must have been very great.[1]

Division of the State into climatic areas. In 1891 the State Meteorological Bureau divided the State into ten subdivisions,

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[1] For extended discussion of climate of New York see a monograph by E. T. Tanner, in 8th Rep't New York Weather Bureau.

namely: Western plateau, Eastern plateau, Northern plateau, Atlantic coast, Hudson valley, Mohawk valley, Champlain valley, St. Lawrence valley, Great Lakes and Central Lakes.

The Western plateau includes the western portion of the central plateau extending across the southern part of the State from the Hudson valley to Lake Erie. This plateau extends from Lake Erie to the valley of Seneca lake and to the point due south of Seneca lake where the two main branches of the Susquehanna river unite.

The Eastern plateau includes the portion of the central plateau to east of the valley of Seneca lake and the point due south of Seneca lake where the two main branches of Susquehanna river unite. It is terminated to the east by the Hudson river valley.

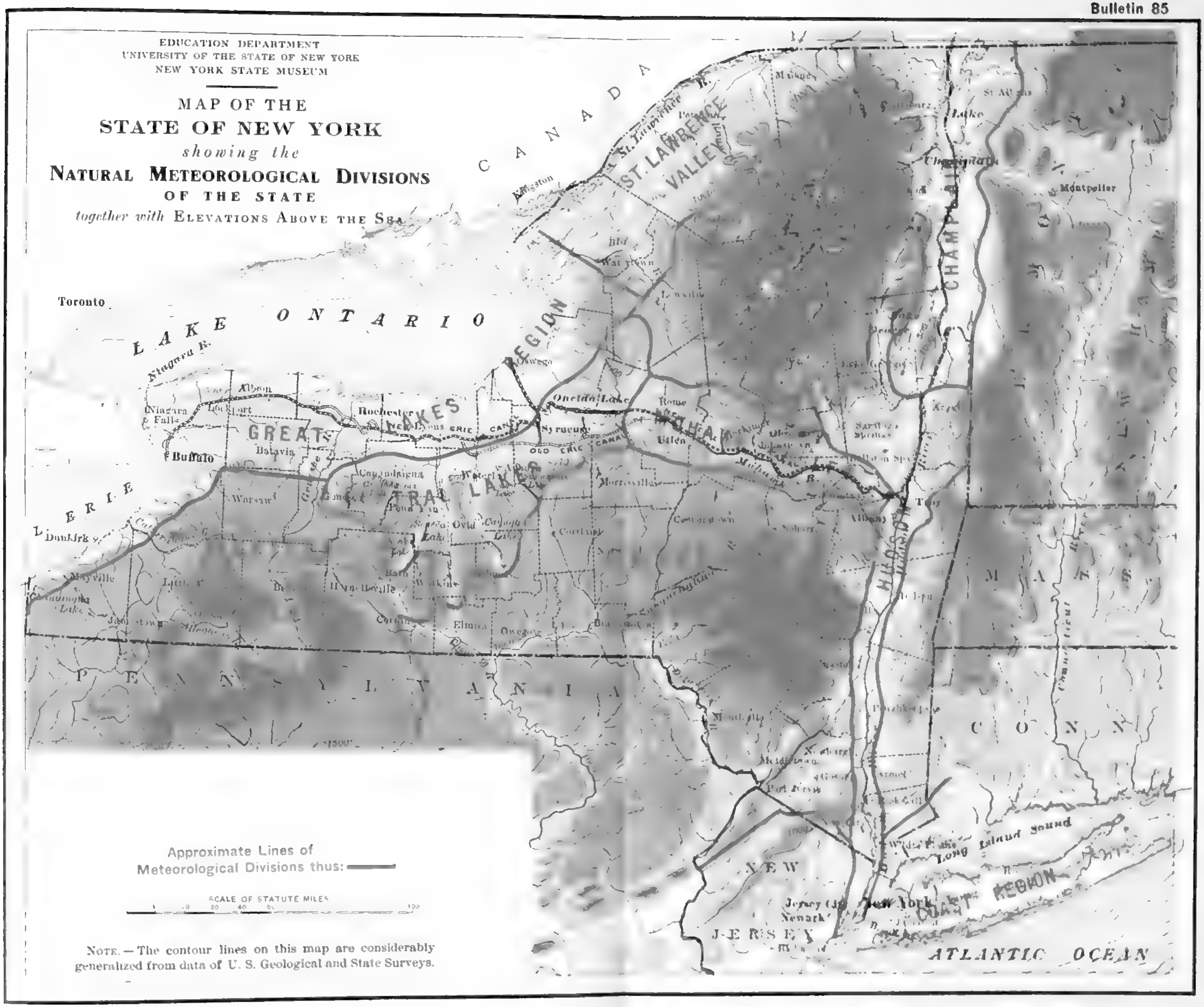
The Northern plateau includes the region north of the Mohawk valley, west of the Champlain valley and east and south of Lake Ontario and the St Lawrence valley.

The Atlantic coast region includes Long Island, New York city and its neighborhood, to the northern part of Westchester county. With the flat, sandy beaches and low ground surrounded by water, with hills never rising more than one hundred feet, this region is entirely open to the influence of sea winds. It has the highest temperature and precipitation in the State.

The Hudson valley is a narrow strip of land on both sides of the river, surrounded by hills and tablelands as far as the Highlands. Higher up, the valley widens into the extensive plains on the west side of the river. Although this region is nearly at sea level, its climate is generally much severer than the Atlantic coast region, owing to the cold northern winds flowing from Canada along the valley of Lake Champlain.

The Mohawk valley extends along the Mohawk river to beyond Rome. The rainfall is about two inches less than that of the northern plateau.

The Champlain valley includes the valleys of Lakes Champlain and George, only a few hundred feet above sea level for the whole distance. On the east, in Vermont and Massachusetts, mountains rise to over 3000 feet, while on the west, the Adirondack



EDUCATION DEPARTMENT
UNIVERSITY OF THE STATE OF NEW YORK
NEW YORK STATE MUSEUM

MAP OF THE
STATE OF NEW YORK
showing the
NATURAL METEOROLOGICAL DIVISIONS
OF THE STATE
together with ELEVATIONS ABOVE THE SEA

Approximate Lines of
Meteorological Divisions thus:

NOTE.—The contour lines on this map are considerably generalized from data of U. S. Geological and State Surveys.

mountains are over 5000 feet in hight. The temperature of this region is low, for the same reason as given in the description of the Hudson valley.

St Lawrence valley extends along the St Lawrence river from Lake Ontario to the north line of the State. It is a level region, gradually inclining upward to the northern plateau. In New York State it is from 40 to 50 miles in width, while in Canada it extends for a long distance to north and west of the St Lawrence river.

The region of the Great Lakes begins as a narrow strip in Chautauqua county, gradually widening and extending along the shore of Lake Ontario, from 20 to 40 miles in width, to Oneida lake. North of Oneida lake this region shrinks to a narrow belt, at Oswego, but widens again above this point towards the plains of the St Lawrence valley.

The region of the Central Lakes includes the valleys of Keuka, Seneca, Cayuga, Owasco and Oneida lakes. On account of its central location, it possesses climatic peculiarities differing considerably from the balance of the State.[1]

TABLE NO. 1. SHOWING NUMBER OF STATIONS OF WEATHER BUREAU AND APPROXIMATE ELEVATION ABOVE TIDEWATER, IN 1893 AND 1902.

	1893		1902	
	Number of stations	Approximate elevation	Number of stations	Approximate elevation
(1)	(2)	(3)	(4)	(5)
Western plateau	14	1,211	17	1,135
Eastern plateau	14	1,192	19	1,068
Northern plateau	7	1,328	12	1,318
Atlantic coast	4	82	5	175
Hudson valley	9	353	8	382
Mohawk valley	2	491	3	556
Champlain valley	2	233	6	286
St Lawrence valley	7	389	4	351
Great Lakes region	12	496	12	446
Central Lakes region	5	742	6	676
	76	....	92	....

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[1] This description of the climatic divisions of the State is abstracted from the 2d An. Rept. of the Commissioners of the State Meteorological Bureau and Weather Service, 1890.

These several regions have considerable difference in elevation, as exhibited by table No. 1, showing number of stations and approximate elevation above tidewater in 1893 and 1902. In 1893 the western plateau comprised fourteen stations, with an approximate elevation above tidewater of 1211 feet, while in 1902 the western plateau comprised seventeen stations, with an approximate elevation of 1135 feet. Owing to the fact that the observations are voluntarily made, considerable change in the stations has taken place between 1893 and 1902, many stations at which observations were kept in the former year having been discontinued and new stations at other places substituted. The showing, therefore, of table No. 1 is relative, and merely intended to give a general idea of the approximate elevations of the several divisions. In the case of the northern plateau there are no stations in the higher mountains, and hence that region is inadequately represented in table No. 1.

Description of the meteorological tables. Tables Nos. 2 to 8, inclusive, give a meteorological summary at Albany, Buffalo, Erie, Pa., New York city, Northfield, Vt., Oswego and Rochester, for the calendar years 1891–1901, inclusive. Column (11) in these tables gives the maximum precipitation in 24 hours for each year, and column (12) the month in which the maximum precipitation occurred. The utility of these columns in designing sewers and in considering effects of floods is obvious.

Tables Nos. 9 to 18, inclusive, give the mean temperature of the several climatic areas into which the State has been divided for the water years 1891–1901, inclusive. The mean temperature for the eleven years included in these tables varies from 42.2° per year in the northern plateau to 50.9° for the Atlantic coast region.

In tables Nos. 19 to 28, inclusive, we have the precipitation of the several climatic areas of the State for the water years 1891–1902, inclusive. The average precipitation varies from a minimum of 34.46 inches in the Central Lakes region to 46.71 inches in the Atlantic coast region, or a range of 12.25 inches.

TABLE No. 2—METEOROLOGICAL SUMMARY AT ALBANY FOR CALENDAR YEARS 1891–1901, INCLUSIVE.

(Elevation of weather bureau=85)

YEAR	Mean barometer, inches	Mean temperature, F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION			Average hourly velocity of wind, miles
			8 A.M., F°	8 P.M., F°	8 A.M., per cent	8 P.M., per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.97	49.4	40	42	80	74	0.287	0.203	41.68	1.92	August	7.1
1892	29.94	48.0	39	41	80	76	0.289	0.298	34.83	2.54	June	7.5
1893	29.94	47.0	38	40	80	74	0.281	0.297	35.39	2.62	August	8.0
1894	29.97	49.6	40	41	80	73	0.301	0.313	35.11	2.12	June	7.6
1895	29.95	48.5	39	40	80	72	0.292	0.300	29.80	1.75	November	7.8
1896	29.96	48.4	39	41	82	72	0.299	0.308	27.88	1.89	February	8.2
1897	29.96	48.8	40	40	81	72	0.291	0.304	40.79	3.12	July	7.9
1898	29.94	50.3	40	42	79	71	0.300	0.317	38.77	2.14	June	7.5
1899	29.95	49.0	38	41	77	72	0.286	0.315	28.92	2.87	September	7.6
1900	29.92	50.1	38	41	75	68	0.284	0.309	30.56	2.14	March	7.8
1901	29.88	48.5	38	41	79	72	0.288	0.317	40.53	2.90	August	7.7
Mean	29.94	48.9	39	41	79	72	0.291	0.298	34.84	......	....	7.7

TABLE NO. 3—METEOROLOGICAL SUMMARY AT BUFFALO FOR CALENDAR YEARS 1891–1901, INCLUSIVE.

(Elevation of weather bureau=690)

YEAR	Mean barometer, inches	Mean temperature, F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION			Average hourly velocity of wind, miles
			8 A.M., F°	8 P.M., F°	8 A.M., per cent	8 P.M., per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.28	47.9	38	38	72	68	0.251	0.256	30.74	1.41	July	11.3
1892	29.28	46.3	38	38	78	71	0.265	0.267	45.87	2.67	June	10.9
1893	29.25	45.8	38	38	77	72	0.276	0.283	38.64	4.25	August	11.8
1894	29.29	48.6	40	41	74	73	0.287	0.305	38.92	2.29	September	11.5
1895	29.28	46.4	37	38	72	69	0.265	0.273	32.02	1.60	January	11.4
1896	29.22	47.1	38	39	75	70	0.274	0.280	37.29	3.56	July	14.2
1897	29.20	48.0	38	39	73	69	0.265	0.277	37.72	2.10	July	14.9
1898	29.19	49.8	40	42	75	73	0.303	0.324	33.50	1.36	November	14.9
1899	29.19	48.3	39	40	75	72	0.291	0.309	29.39	1.44	May	13.9
1900	29.19	48.8	39	40	75	70	0.292	0.301	35.93	1.50	March	14.3
1901	29.15	47.6	38	39	76	72	0.282	0.295	35.49	1.94	December	14.3
Mean	29.23	47.7	38	39	75	71	0.277	0.288	35.96	......	....	13.0

TABLE NO. 4—METEOROLOGICAL SUMMARY AT ERIE, PA., FOR CALENDAR YEARS 1891–1901, INCLUSIVE.

(Elevation of weather bureau=714)

YEAR	Mean barometer, inches	Mean temperature, F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION			Average hourly velocity of wind, miles
			8 A.M., F°	8 P.M., F°	8 A.M., per cent	8 P.M., per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.27	49.3	40	41	76	73	0.273	0.287	30.24	1.57	February	11.4
1892	29.27	47.8	39	40	76	75	0.276	0.287	41.67	2.54	August	11.5
1893	29.24	47.4	38	39	75	73	0.274	0.283	39.99	4.71	May	11.9
1894	29.27	50.6	40	41	73	71	0.286	0.299	35.16	2.20	October	11.3
1895	29.27	47.4	38	37	74	72	0.280	0.289	35.55	1.95	December	10.8
1896	29.29	49.1	40	41	76	74	0.299	0.309	37.02	2.24	July	11.1
1897	29.28	48.6	40	41	78	76	0.287	0.305	34.34	1.99	August	11.4
1898	29.27	50.5	42	43	79	75	0.319	0.330	34.07	1.39	August	11.2
1899	29.28	49.1	39	42	76	76	0.289	0.324	28.36	1.56	May	10.9
1900	29.26	49.9	42	42	79	74	0.319	0.323	32.62	2.74	June	11.2
1901	29.22	48.2	40	42	82	79	0.307	0.325	31.67	1.89	August	10.9
Mean	29.26	48.9	40	41	78	74	0.292	0.306	34.61	......	....	11.2

TABLE NO. 5—METEOROLOGICAL SUMMARY AT NEW YORK FOR CALENDAR YEARS 1891–1901, INCLUSIVE.

(Elevation of weather bureau=314)

YEAR	Mean barometer, inches	Mean temperature, F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION			Average hourly velocity of wind, miles
			8 A.M., F°	8 P.M., F°	8 A.M., per cent	8 P.M., per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.87	53.8	43	45	77	73	0.310	0.338	41.44	3.20	August	11.5
1892	29.85	51.9	40	42	73	70	0.290	0.315	38.90	3.62	November	10.8
1893	29.84	51.3	40	42	73	69	0.295	0.316	53.01	3.83	August	10.9
1894	29.87	53.7	42	44	76	70	0.320	0.334	44.17	4.86	September	10.3
1895	29.72	51.4	41	43	76	71	0.315	0.331	35.73	2.78	October	12.7
1896	29.72	51.2	42	43	80	74	0.327	0.344	37.99	2.59	June	14.3
1897	29.72	51.6	41	42	78	71	0.308	0.318	44.27	2.56	July	13.2
1898	29.72	52.9	43	44	78	72	0.330	0.340	45.12	2.84	February	12.5
1899	29.72	52.6	42	44	76	73	0.319	0.343	42.06	2.50	July	13.8
1900	29.69	54.3	42	44	73	67	0.330	0.340	41.78	2.53	November	14.7
1901	29.65	52.3	41	42	73	67	0.318	0.330	47.06	2.93	March	14.6
Mean	29.76	52.5	42	43	76	71	0.315	0.332	42.87	......	....	12.7

TABLE No. 6—METEOROLOGICAL SUMMARY AT NORTHFIELD, VT., FOR CALENDAR YEARS 1891–1901, INCLUSIVE.

(Elevation of weather bureau=871)

YEAR	Mean barometer, inches	Mean temperature F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION.			Average hourly velocity of wind, miles
			8 A. M., F°	8 P. M., F°	8 A. M., per cent	8 P. M., per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.09	42.6	34	37	78	76	0.235	0.253	31.11	2.00	January	9.1
1892	29.06	41.2	33	36	77	77	0.237	0.251	32.67	1.60	August	8.5
1893	29.06	39.6	31	34	78	77	0.232	0.250	30.36	1.56	August	9.0
1894	29.09	42.6	34	37	79	77	0.254	0.273	28.92	2.11	August	8.9
1895	29.07	41.6	32	34	75	74	0.232	0.253	35.20	2.15	April	8.6
1896	29.09	40.8	32	35	79	76	0.239	0.260	33.82	2.32	July	8.8
1897	29.09	41.4	33	36	81	77	0.244	0.261	39.14	2.12	July	8.4
1898	29.08	42.9	34	37	80	78	0.252	0.275	30.52	2.22	August	8.6
1899	29.08	41.4	33	35	79	76	0.237	0.258	27.36	1.68	September	8.8
1900	29.05	41.6	33	35	79	76	0.243	0.262	34.11	2.20	March	8.8
1901	29.02	41.6	33	36	81	77	0.253	0.272	31.42	2.10	July	8.8
Mean	29.07	41.6	33	36	79	76	0.242	0.261	32.24	......	....	8.7

TABLE NO. 7—METEOROLOGICAL SUMMARY AT OSWEGO FOR THE CALENDAR YEARS 1891–1901, INCLUSIVE.

(Elevation of weather bureau=335)

YEAR	Mean barometer, inches	Mean temperature F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION			Average hourly velocity of wind, miles
			8 A. M., F°	8 P. M., F°	8 A. M. per cent	8 P. M. per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.66	46.6	38	38	78	72	0.258	0.259	31.44	1.57	March	11.2
1892	29.66	45.0	37	38	78	74	0.260	0.260	34.81	2.56	June	11.2
1893	29.63	44.3	36	36	77	73	0.263	0.260	34.78	3.76	August	11.6
1894	29.66	47.3	38	40	76	73	0.275	0.283	36.44	1.80	December	11.3
1895	29.64	45.4	36	38	76	72	0.265	0.271	32.48	1.49	December	10.9
1896	29.66	45.9	38	38	78	73	0.273	0.277	38.32	3.30	July	11.2
1897	29.66	46.4	38	39	78	73	0.267	0.275	36.61	1.40	November	11.3
1898	29.64	48.4	39	41	77	72	0.288	0.302	40.44	2.04	September	11.0
1899	29.66	46.8	37	38	76	71	0.264	0.277	34.65	1.40	September	10.6
1900	29.64	47.0	38	39	79	74	0.285	0.292	37.17	1.91	March	11.0
1901	29.60	46.0	38	39	80	75	0.280	0.288	45.09	2.06	December	10.9
Mean	29.65	46.3	38	39	78	73	0.271	0.277	36.57	......	....	11.1

TABLE NO. 8—METEOROLOGICAL SUMMARY AT ROCHESTER FOR CALENDAR YEARS, 1891–1901, INCLUSIVE.

(Elevation of weather bureau=510)

YEAR	Mean barometer, inches.	Mean temperature, F°	DEWPOINT		RELATIVE HUMIDITY		VAPOR PRESSURE		PRECIPITATION			Average hourly velocity of wind, miles
			8 A.M., F°	8 P.M., F°	8 A.M., per cent	8 P.M., per cent	8 A. M., inches	8 P. M., inches	Total, inches	Max. in 24 hours, inches	Month	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1891	29.48	48.7	39	40	74	71	0.266	0.275	33.64	1.52	October	8.5
1892	29.47	47.1	38	39	76	74	0.264	0.277	35.02	2.10	July	8.4
1893	29.46	46.5	37	39	77	77	0.270	0.288	35.50	4.19	August	8.0
1894	29.49	49.5	39	40	76	71	0.284	0.289	35.11	1.72	December...	8.2
1895	29.46	47.4	36	37	71	69	0.259	0.267	30.42	1.86	August	8.2
1896	29.48	47.7	38	39	74	71	0.273	0.283	36.84	2.11	July	8.1
1897	29.46	48.0	38	38	74	70	0.266	0.270	30.12	3.57	July	8.1
1898	29.45	49.9	39	40	74	72	0.287	0.302	37.50	2.53	August	7.9
1899	29.46	48.5	37	38	72	67	0.264	0.269	26.76	1.42	June........	7.8
1900	29.44	49.2	38	39	74	70	0.280	0.289	38.12	2.98	March	8.2
1901	29.41	47.1	38	40	78	75	0.286	0.294	37.20	2.20	December...	8.6
Mean	29.46	48.1	38	39	75	72	0.273	0.282	34.10	......	....	8.2

TABLE NO. 9—MEAN TEMPERATURE OF WESTERN PLATEAU FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH (1)	1891 (2)	1892 (3)	1893 (4)	1894 (5)	1895 (6)	1896 (7)	1897 (8)	1898 (9)	1899 (10)	1900 (11)	1901 (12)	Mean (13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	22.8	34.9	24.0	27.0	30.2	31.1	27.5	29.7	26.9	28.1	27.8	......
January	26.1	21.0	16.0	29.2	20.2	23.2	21.9	26.5	22.8	26.5	25.3	......
February	29.0	26.9	21.7	21.9	16.1	24.4	26.6	26.9	20.2	22.6	16.1	......
March	29.9	26.1	30.4	38.6	27.4	24.2	34.3	40.7	31.3	24.4	31.3	......
April	45.7	42.1	42.5	43.6	45.2	49.5	44.8	41.5	47.9	45.3	44.4	......
May	52.8	50.0	54.4	55.6	58.6	62.6	54.1	56.8	57.5	56.8	55.2	......
Mean of storage period	34.4	33.5	31.5	36.0	32.9	35.8	34.9	37.0	34.4	33.9	33.4	34.3
June	65.2	67.2	67 6	66.1	68.8	64.7	60.5	66.1	67.4	66.4	66.5	......
July	63.9	68.1	68.7	69.6	65.6	69.6	71.2	71.8	70.0	70.4	73.0	......
August	65.4	67.1	66.7	65.0	67.3	67.5	64.2	69.0	69.2	72.3	68.7	......
Mean of growing period	64.8	67.5	67.3	66.9	67.2	67.3	65.3	69.0	68.9	69.7	69.4	67.6
September	62.5	59.0	57.2	63.1	63.0	58.6	60.1	63.5	58.2	64.5	61.5	......
October	46.6	47.2	49.8	51.0	43.1	44.8	51.3	51.0	52.6	57.0	49.5	......
November	36.5	35.0	36.6	33.9	38.9	42.3	38.5	37.4	38.7	40.0	33.2	......
Mean of replenishing period	48.5	47.1	51.2	49.3	48.3	48.6	50.0	50.6	49.8	53.8	48.1	48.8
Yearly mean	45.5	45.4	45.5	47.1	45.4	46.9	46.3	48.4	46.9	47.9	46.0	46.5

TABLE No. 10—MEAN TEMPERATURE OF EASTERN PLATEAU FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	20.0	34.5	23.3	26.6	27.9	30.1	25.9	28.5	26.1	28.2	25.4	.....
January	25.0	21.2	15.3	27.3	19.9	19.8	22.8	24.5	21.2	25.1	23.1	.....
February	27.7	25.4	20.8	20.5	16.8	23.4	25.0	26.1	19.9	22.9	15.9	.....
March	30.2	25.9	29.2	37.3	27.1	24.5	33.2	39.5	29.7	25.5	30.9	.....
April	45.2	42.3	41.9	44.1	44.4	48.6	45.1	41.3	46.2	44.6	44.8	.....
May	53.0	53.8	54.7	56.6	58.1	61.1	55.0	55.4	57.2	55.6	55.6	.....
Mean of storage period	33.4	33.9	30.9	35.4	32.4	34.6	34.5	35.9	33.4	33.7	34.3	33.9
June	63.8	67.2	67.3	66.5	69.2	63.9	60.5	66.0	66.7	66.4	66.3	.....
July	63.8	67.9	67.7	70.1	65.9	69.7	71.0	71.1	69.6	70.8	73.0	.....
August	65.9	67.2	67.1	64.6	67.3	67.9	65.0	69.1	68.4	71.0	68.1	.....
Mean of growing period	64.5	67.4	67.4	67.1	67.5	67.2	65.5	68.7	68.2	69.4	69.1	67.5
September	62.4	58.0	56.0	63.2	62.2	58.9	59.3	62.2	58.3	63.7	60.3	.....
October	45.7	46.5	49.6	50.1	42.6	45.4	50.3	50.1	51.7	54.8	48.9	.....
November	35.6	34.8	35.7	33.9	39.3	42.4	37.4	36.5	37.4	39.7	31.3	.....
Mean of replenishing period	47.9	46.4	47.1	49.1	48.0	48.9	49.0	49.6	49.1	52.7	47.2	48.6
Yearly mean	44.8	45.4	44.1	46.7	45.1	46.3	45.8	47.5	46.0	47.3	46.2	45.9

TABLE No. 11—MEAN TEMPERATURE OF NORTHERN PLATEAU FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	11.3	30.0	19.4	20.6	23.7	26.0	19.3	22.4	21.8	23.7	20.1	......
January	19.5	16.1	10.0	22.0	16.5	14.7	17.7	16.8	16.1	18.1	16.3	......
February	21.9	19.8	16.0	14.6	12.8	18.1	20.1	22.9	16.8	17.4	10.7	......
March	25.6	20.3	25.3	33.5	21.9	19.9	28.0	35.8	24.8	19.7	26.3	......
April	41.0	37.5	37.8	42.9	41.0	43.3	41.4	38.9	42.8	41.2	43.7	......
May	50.1	49.4	51.8	54.4	56.9	58.1	52.1	52.9	54.2	51.7	53.6	......
Mean of storage period	28.2	28.9	26.7	31.3	28.8	30.0	29.8	31.6	29.4	28.6	28.5	29.2
June	61.3	63.5	65.5	64.2	66.8	61.6	58.1	63.0	63.9	63.5	64.2	......
July	61.7	64.9	64.6	67.0	63.8	67.7	69.2	68.8	66.7	66.8	69.3	......
August	63.6	63.5	64.5	61.8	64.0	65.8	61.9	66.3	66.0	66.8	66.0	......
Mean of growing period	62.2	64.0	64.9	64.3	64.9	65.0	63.1	66.0	65.5	65.7	66.5	64.7
September	60.7	55.4	52.2	60.5	58.5	55.8	56.3	59.8	56.2	59.7	57.8	......
October	45.6	43.4	48.2	48.0	40.2	42.7	47.7	47.7	49.5	52.0	46.3	......
November	31.5	31.0	33.0	29.9	35.3	37.5	32.7	33.2	34.5	35.1	28.2	......
Mean of replenishing period	45.9	43.6	44.5	46.1	44.7	45.3	45.6	46.9	46.7	48.9	44.1	45.7
Yearly mean	41.2	41.2	40.7	43.3	41.8	42.6	42.0	44.0	42.8	43.0	41.9	42.2

TABLE No. 12—MEAN TEMPERATURE OF ATLANTIC COAST REGION FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH (1)	1891 (2)	1892 (3)	1893 (4)	1894 (5)	1895 (6)	1896 (7)	1897 (8)	1898 (9)	1899 (10)	1900 (11)	1901 (12)	Mean (13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	30.3	40.8	30.4	34.7	34.4	36.5	30.4	34.9	32.4	35.7	34.1	......
January	33.1	29.9	22.0	33.1	28.3	27.2	28.6	31.5	29.4	31.6	30.6	......
February	35.6	31.9	29.0	28.2	23.6	30.5	31.1	31.6	25.6	30.0	24.4	......
March	36.6	34.4	34.8	42.2	35.5	32.4	38.6	43.1	36.1	34.3	36.8	......
April	50.7	49.8	46.2	47.5	47.1	49.4	48.5	46.5	47.5	48.9	46.9	......
May	58 4	57.7	57.2	59.8	59.9	62.8	58.7	56.9	59.0	58.5	56.4	......
Mean of storage period	40.8	40.8	36.6	40.9	38.1	38.1	39.3	40.8	38.3	38.2	38.2	39.1
June	68.2	70.0	67.8	69.3	69.7	66.1	65.2	68.1	70.2	69.1	68.4	......
July	69.9	72.2	73.2	74.4	70.2	73.0	72.6	73.0	72.1	74.2	75.1	......
August	72.7	72.4	72.0	70.2	73.0	72.3	70.0	73.0	71.1	74.6	72.6	......
Mean of growing period	70.3	71.5	71.0	71.3	71.0	70.5	69.3	71.4	71.1	72.6	72.0	71.1
September	68.6	63.2	62.0	67.5	68.0	63.9	64.1	67.2	63.2	68.5	65.5	......
October	53.4	53.5	56.3	55.2	49.6	51.4	55.0	55.2	55.9	58.4	53.7	......
November	42.7	40.9	43.0	40.2	44.6	47.2	43 5	41.6	43.3	47.1	38.0	......
Mean of replenishing period	54.9	52.9	53.8	54.3	54.1	54.2	54.2	54.7	54.1	58.0	52.4	54.3
Yearly mean	51.7	51.6	49.5	51.9	50.3	50.2	50.5	51.9	50.5	51.8	50.2	50.9

TABLE NO. 13—MEAN TEMPERATURE OF HUDSON VALLEY FOR THE WATER YEARS 1891–1901, INCLUSIVE.

MONTH (1)	1891 (2)	1892 (3)	1893 (4)	1894 (5)	1895 (6)	1896 (7)	1897 (8)	1898 (9)	1899 (10)	1900 (11)	1901 (12)	Mean (13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	23.3	37.4	26.4	27.8	28.5	32.0	25.3	30.3	28.5	32.4	27.4	......
January	26.2	24.4	17.1	27.0	21.3	21.1	25.1	24.3	24.1	26.4	24.2	......
February	29.8	27.2	23.7	21.6	17.1	26.2	26.2	26.8	22.4	25.4	17.7	......
March	33.2	29.7	31.6	38.4	29.9	28.1	35.2	41.9	32.3	29.4	32.6	......
April	48.3	46.3	44.6	46.9	46.1	49.9	48.3	44.9	48.3	47.5	48.2	......
May	56.4	56.5	57.8	59.0	59.3	63.3	59.0	57.3	59.7	58.1	57.6	......
Mean of storage period	36.2	36.9	33.5	36.8	33.7	36.8	36.5	37.6	35.9	36.5	34.6	35.9
June	66.5	70.2	68.9	68.9	71.0	65.7	64.3	68.8	70.3	69.2	69.1	......
July	66.9	71.2	70.5	73.4	68.2	72.7	73.6	73.7	72.1	74.1	74.7	......
August	70.5	70.0	70.5	67.8	70.7	71.4	68.6	71.8	70.8	73.3	71.4	......
Mean of growing period	68.0	70.5	70.0	70.0	70.0	69.9	68.8	71.4	71.1	72.2	71.7	70.3
September	66.0	60.7	58.5	65.6	65.3	61.1	61.1	65.9	61.0	66.1	63.2	......
October	49.3	49.9	51.8	51.8	45.6	48.5	51.7	53.4	52.9	56.6	51.0	......
November	38.5	38.3	38.3	35.6	41.3	43.4	38.9	38.5	39.5	41.6	34.6	......
Mean of replenishing period	51.3	49.6	49.5	51.0	50.7	51.0	50.6	52.6	51.1	54.8	49.6	51.1
Yearly mean	47.9	48.4	46.6	48.7	47.0	48.6	48.1	49.8	48.5	50.0	47.6	48.3

TABLE 14—MEAN TEMPERATURE OF MOHAWK VALLEY FOR THE WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	18.3	33.8	22.5	23.6	26.9	29.2	23.2	26.5	27.0	28.3	23.8	......
January	23.8	19.6	14.2	25.4	20.2	20.6	20.2	21.6	20.0	22.8	20.1	......
February	27.3	24.6	18.0	*17.1	17.6	20.4	22.9	24.0	20.4	21.4	14.6	......
March	29.1	26.8	28.2	*34.7	25.0	24.2	30.4	38.4	28.5	23.4	29.2	......
April	46.7	43.8	42.4	46.3	48.2	48.5	44.9	43.1	45.7	44.6	45.1	......
May	53.2	54.8	57.2	57.2	58.5	60.4	56.0	56.7	56.9	55.3	57.0	......
Mean of storage period	33.1	33.9	30.4	34.1	32.7	33.9	32.9	35.1	33.1	32.6	31.6	33.0
June	65.2	69.8	68.8	65.2	68.4	65.2	61.1	67.6	68.1	66.8	67.3	......
July	64.7	70.0	67.7	70.0	65.8	70.2	72.3	72.6	70.1	70.4	73.7	......
August	67.5	68.8	68.4	64.3	66.6	67.8	65.9	69.7	69.6	70.4	69.0	......
Mean of growing period	65.8	69.5	68.3	66.5	66.9	67.7	66.4	70.0	69.3	69.2	70.0	68.1
September	64.4	59.4	56.7	62.1	61.4	58.9	59.2	63.1	59.8	63.7	66.7	......
October	47.8	48.0	51.2	50.9	43.0	45.2	49.0	50.2	51.2	54.8	48.2	......
November	37.1	34.8	37.0	34.8	38.4	39.1	35.2	37.0	36.8	38.3	31.2	......
Mean of replenishing period	49.8	47.4	48.3	49.3	47.6	47.7	47.8	50.1	49.3	52.3	48.7	48.9
Yearly mean	45.6	46.2	44.4	46.0	45.0	45.8	45.0	47.5	46.2	46.7	45.5	45.8

* Record not given—that of Brookfield used

TABLE NO. 15—MEAN TEMPERATURE OF CHAMPLAIN VALLEY FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	14.0	34.0	20.8	21.2	24.6	26.4	21.8	25.2	25.4	28.6	24.4	......
January	19.9	19.6	11.0	18.2	18.6	16.1	19.7	17.5	18.3	21.2	19.8	......
February	24.0	20.8	16.0	15.4	16.2	18.4	20.5	24.4	19.0	20.7	14.9	......
March	29.7	25.4	25.8	35.6	27.0	23.2	30.1	37.4	28.0	23.7	28.4	......
April	44.0	43.8	37.6	44.0	44.8	45.2	44.0	43.3	44.8	44.6	47.2	......
May	53.0	53.8	53.4	57.4	59.5	58.8	55.4	56.3	55.5	54.5	56.5	......
Mean of storage period	30.8	32.9	27.4	32.0	32.0	31.4	31.9	34.0	31.8	32.2	31.9	31.7
June	64.8	67.4	66.3	67.5	70.5	64.4	61.7	66.4	66.0	66.8	67.4	......
July	66.2	68.8	68.0	70.6	67.2	69.5	71.6	72.1	70.3	70.9	72.5	......
August	67.1	66.6	65.4	65.0	66.2	68.0	65.7	69.8	68.8	70.0	69.3	......
Mean of growing period	66.0	67.6	66.8	71.0	68.0	67.3	66.3	69.4	68.4	69.2	69.7	68.2
September	63.1	58.6	54.6	62.5	60.6	58.0	58.6	62.7	59.1	63.0	61.7	......
October	46.9	46.4	49.0	50.2	42.9	44.6	49.8	51.3	50.8	54.6	50.1	......
November	36.6	35.2	35.2	32.6	36.2	40.1	35.1	35.6	36.8	38.8	32.5	......
Mean of replenishing period	52.2	50.1	49.6	48.4	46.6	47.6	54.3	49.9	52.6	52.1	48.1	50.1
Yearly mean	44.9	45.9	42.8	45.9	45.4	44.4	46.2	46.8	46.2	46.5	45.4	45.5

TABLE No. 16—MEAN TEMPERATURE OF ST. LAWRENCE VALLEY FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	13.1	33.0	20.2	18.4	26.5	26.9	21.8	24.2	25.2	27.3	22.0	......
January	19.2	17.4	9.7	22.3	17.7	13.4	19.2	17.6	19.1	20.4	17.3	......
February	23.7	19.3	15.6	16.6	14.7	16.5	20.0	24.5	17.4	19.9	13.1	......
March	28.1	21.7	27.5	36.2	22.6	21.4	29.7	39.3	27.2	21.5	27.3	......
April	37.2	40.4	39.4	45.3	42.6	45.8	43.3	42.8	46.3	44.9	45.4	......
May	53.1	52.6	54.4	55.9	58.6	59.3	54.8	57.2	56.0	53.8	56.3	......
Mean of storage period	29.1	30.7	27.8	32.4	30.5	30.6	31.5	34.3	31.9	31.3	30.2	30.9
June	65.3	65.5	68.9	66.4	69.6	63.9	60.8	66.9	65.9	65.6	66.8	......
July	64.6	67.5	67.5	70.4	67.2	68.9	72.8	72.3	69.0	69.7	71.4	......
August	66.5	66.9	67.3	65.0	66.6	68.0	64.9	69.4	70.2	70.5	68.9	......
Mean of growing period	65.8	66.6	67.9	67.3	67.8	66.9	66.2	69.5	68.4	68.6	69.0	67.6
September	61.9	59.3	55.0	63.5	61.4	58.0	58.7	62.8	58.1	62.4	60.9	......
October	45.7	47.2	50.6	50.0	42.6	44.6	49.3	50.1	51.2	54.5	49.6	......
November	35.9	33.6	36.7	32.8	36.4	39.6	34.8	36.4	37.1	36.4	31.1	......
Mean of replenishing period	47.8	46.7	47.4	48.8	46.8	47.4	47.6	49.8	48.8	51.1	47.2	48.1
Yearly mean	42.9	43.7	42.7	45.2	43.9	43.9	44.2	47.0	45.2	45.6	44.2	44.4

TABLE NO. 17—MEAN TEMPERATURE OF GREAT LAKES REGION FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	24.4	36.3	26.5	27.3	31.9	32.1	28.9	29.9	28.5	30.4	29.7	......
January	27.0	22.8	17.1	29.4	22.4	23.4	23.9	27.4	24.9	27.3	25.7	......
February	30.2	28.8	22.0	22.4	18.1	24.9	26.6	27.4	21.2	23.4	17.6	......
March	30.9	28.2	31.1	39.0	27.2	25.4	34.3	41.4	31.1	25.4	31.5	......
April	45.7	39.5	42.3	45.2	44.4	49.0	45.1	42.9	47.2	45.5	44.8	......
May	53.0	53.6	54.4	55.8	58.5	61.2	54.7	56.6	56.8	57.0	55.1	......
Mean of storage period	35.2	34.9	32.2	36.5	33.8	36.0	35.6	37.6	35.0	34.8	34.1	35.1
June	65.6	67.3	68.5	67.2	69.0	65.4	62.1	67.0	67.6	66.4	66.8	......
July	66.0	70.2	70.4	71.2	67.6	71.0	73.3	72.8	70.7	70.7	74.5	......
August	67.9	69.3	68.4	66.4	68.6	69.7	66.4	70.8	69.9	73.1	70.1	......
Mean of growing period	66.5	68.9	69.1	68.3	68.4	68.7	67.3	70.2	69.4	70.1	70.5	68.8
September	64.8	61.9	59.2	64.8	64.4	59.9	62.3	65.2	60.1	65.5	62.8	......
October	49.7	50.1	52.0	52.6	45.1	47.1	53.2	52.6	54.4	58.7	51.5	......
November	39.0	37.3	38.9	35.9	39.8	43.1	39.9	39.1	41.2	41.0	35.6	......
Mean of replenishing period	51.2	49.8	50.0	51.1	49.8	50.0	51.8	52.3	51.9	55.1	50.0	51.2
Yearly mean	47.0	47.1	45.9	48.1	46.4	47.7	47.6	49.4	47.8	48.7	47.1	47.5

TABLE No. 18—MEAN TEMPERATURE OF CENTRAL LAKES REGION FOR WATER YEARS 1891–1901, INCLUSIVE.

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°	F°
December	23.2	36.9	26.5	28.0	31.6	32.8	27.9	30.3	28.5	29.9	28.6	......
January	28.5	23.0	17.4	30.0	21.7	22.9	24.2	26.9	24.0	26.9	25.6	......
February	30.1	28.0	22.3	21.4	18.4	24.9	27.2	28.3	22.2	24.5	18.1	......
March	32.2	27.8	31.2	39.5	28.1	25.1	35.0	42.1	31.8	25.0	31.8	......
April	47.8	43.2	43.3	44.8	44.8	50.7	46.3	43.1	49.1	46.3	46.2	......
May	54.5	55.6	56.0	56.8	59.9	62.7	55.8	57.2	58.6	57.8	56.9	......
Mean of storage period	36.1	35.8	32.8	36.8	34.1	36.5	36.1	38.0	35.7	35.1	34.5	35.6
June	66.2	68.9	69.4	67.8	70.2	66.0	62.0	68.4	68.7	68.8	68.6	......
July	66.2	70.8	71.0	71.9	67.2	71.4	73.2	74.0	71.4	72.8	75.6	......
August	67.7	69.0	69.7	67.0	69.5	70.2	66.9	71.2	71.4	73.4	70.3	......
Mean of growing period	66.7	69.6	70.0	68.9	69.0	69.2	67.4	71.2	70.5	71.7	71.5	69.6
September	64.2	61.0	59.4	65.4	65.2	60.9	62.7	66.2	60.2	66.2	62.9	......
October	49.0	49.8	51.9	52.7	45.6	46.8	53.4	53.3	54.4	58.4	51.3	......
November	39.4	36.7	39.2	35.8	40.6	44.3	39.6	39.5	39.4	40.8	34.1	......
Mean of replenishing period	50.9	52.5	50.2	58.0	50.5	50.6	51.9	53.0	51.3	55.1	49.4	52.1
Yearly mean	47.4	48.4	46.4	50.9	46.9	48.2	47.9	50.0	48.3	49.2	47.5	48.3

TABLE No. 19—PRECIPITATION OF WESTERN PLATEAU FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	3.19	3.73	1.27	3.62	2.54	3.39	1.38	3.01	2.53	3.94	1.76	4.41	......
January	2.36	3.49	2.28	3.40	3.31	2.31	2.31	3.79	1.82	3.02	2.07	2.36	......
February	4.12	3.10	4.02	2.98	1.47	4.14	1.55	2.12	1.72	3.16	1.82	2.01	......
March	2.91	2.96	2.74	1.66	1.53	3.52	2.93	2.80	2.53	3.63	2.55	2.06	......
April	1.87	1.12	3.95	5.48	1.82	1.36	2.50	2.73	1.32	1.53	5.49	2.88	......
May	1.17	5.72	6.40	8.65	2.31	2.79	3.31	3.65	3.17	2.23	4.71	2.68	......
Storage period	15.62	20.12	20.66	25.79	12.98	17.51	13.98	18.10	13.09	17.51	18.40	16.40	17.51
June	3.13	5.48	3.04	2.95	3.90	3.48	2.64	4.12	1.79	2.13	2.82	5.29	......
July	4.36	3.95	3.11	2.70	2.44	5.64	5.10	2.68	3.08	4.09	3.73	8.57	......
August	4.69	4.53	5.22	1.53	4.17	2.48	2.47	5.74	1.73	2.84	5.37	2.31	......
Growing period	12.18	13.96	11.37	7.18	10.51	11.60	10.21	12.54	6.60	9.06	11.92	16.17	11.11
September	1.74	1.81	3.47	5.33	1.73	4.59	1.95	2.37	3.56	1.84	3.26	3.25	......
October	2.60	2.15	3.04	2.78	1.35	3.49	0.89	4.86	2.37	4.07	1.30	2.75	......
November	2.78	3.68	2.17	1.62	3.19	2.19	3.92	3.06	2.03	5.34	3.06	1.33	......
Replenishing period	7.12	7.64	8.68	9.73	6.27	10.27	6.76	10.29	7.96	11.25	7.62	7.33	8.41
Yearly total	34.92	41.72	40.71	42.70	29.76	39.38	30.95	40.93	27.65	37.82	37.94	39.90	37.03

TABLE NO. 20—PRECIPITATION OF EASTERN PLATEAU FOR WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH (1)	1891 (2)	1892 (3)	1893 (4)	1894 (5)	1895 (6)	1896 (7)	1897 (8)	1898 (9)	1899 (10)	1900 (11)	1901 (12)	1902 (13)	Mean (14)
December	3.89	4.25	1.18	3.08	2.97	3.59	1.32	3.86	2.46	2.81	2.53	5.66	......
January	5.22	4.69	2.25	2.56	2.75	1.54	1.70	3.87	2.01	2.68	1.75	1.84	......
February	4.19	1.60	4.58	2.73	1.66	4.83	1.76	2.88	2.67	4.16	1.30	3.69	......
March	3.25	3.59	2.72	1.61	1.74	4.88	2.83	2.38	4.54	3.85	3.61	3.79	......
April	2.10	1.13	3.40	3.09	3.12	1.17	2.77	3.43	1.54	1.89	5.64	2.89	......
May	2.76	6.94	6.40	5.98	2.69	2.71	4.63	4.79	2.98	2.09	5.77	2.55	......
Storage period	21.41	22.20	20.53	19.05	14.93	18.72	15.01	21.21	16.20	17.48	20.60	20.42	18.98
June	3.12	4.64	2.67	3.08	2.38	3.72	3.66	3.12	3.33	3.13	2.91	5.60	......
July	4.54	5.72	4.02	2.70	2.85	5.41	6.07	3.76	4.59	4.43	4.61	7.47	......
August	5.10	6.63	6.08	1.63	4.91	2.42	3.13	7.98	2.60	3.07	5.70	3.13	......
Growing period	12.76	16.99	12.77	7.41	10.14	11.55	12.86	14.86	10.52	10.63	13.22	16.20	12.49
September	1.75	2.27	3.73	5.02	2.14	4.44	3.16	3.01	4.25	2.20	3.44	5.19	......
October	3.38	1.46	2.41	4.98	2.04	3.08	0.79	5.58	1.86	2.95	2.01	4.32	......
November	2.99	3.81	1.75	2.21	3.62	3.10	4.29	3.97	2.43	4.37	2.77	1.13	......
Replenishing period	8.12	7.54	7.89	12.21	7.80	10.62	8.24	12.56	8.54	9.52	8.22	10.64	9.33
Yearly total	42.29	46.73	41.19	38.67	32.87	40.89	36.11	48.63	35.26	37.63	42.04	47.26	40.80

TABLE No. 21—PRECIPITATION OF NORTHERN PLATEAU FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	3.01	4.41	2.11	5.75	3.01	4.18	1.84	4.59	4.17	4.82	3.21	4.17	......
January	4.82	5.99	2.16	3.48	2.96	2.25	2.93	5.46	3.40	3.92	2.28	1.98	......
February	4.91	3.15	4.43	2.87	1.58	6.36	1.99	3.29	2.38	3.93	1.34	3.55	......
March	3.70	3.59	1.97	2.26	2.14	5.56	4.88	2.09	4.79	5.07	3.25	4.32	......
April	2.46	1.62	3.52	1.81	3.11	1.19	3.72	3.28	1.64	1.01	3.45	4.32	......
May	1.79	6.19	5.64	5.20	2.99	2.63	4.41	4.09	3.10	2.38	4.94	3.22	......
Storage period	20.69	24.95	19.83	21.37	15.79	22.17	19.77	22.80	19.48	21.13	18.47	21.56	20.67
June	3.42	5.38	3.20	4.40	2.61	2.87	4.97	3.78	2.10	3.12	4.75	5.16	......
July	6.06	4.90	3.34	2.89	3.13	4.80	7.36	3.28	3.77	4.11	5.25	6.10	......
August	4.01	8.84	6.83	1.44	4.63	2.58	3.47	6.46	1.53	4.88	5.09	3.56	......
Growing period	13.49	19.12	13.37	8.73	10.37	10.25	15.80	13.52	7.40	12.11	15.09	14.82	12.84
September	1.96	3.41	3.90	4.00	3.42	4.93	2.25	3.67	3.37	2.92	3.72	2.79	......
October	2.90	2.16	1.96	5.10	2.14	2.85	1.70	4.89	2.95	2.30	2.69	5.29	......
November	3.92	4.23	3.12	2.77	4.95	5.01	6.99	3.63	2.59	6.95	2.61	2.18	......
Replenishing period	8.78	9.80	8.98	11.87	10.51	12.79	10.94	12.19	8.91	12.17	9.02	10.26	10.52
Yearly total	42.96	53.87	42.18	41.97	36.67	45.21	46.51	48.51	35.79	45.41	42.58	46.64	44.03

TABLE No. 22—PRECIPITATION OF ATLANTIC COAST REGION FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	4.47	3.78	1.63	3.68	4.56	2.38	1.71	5.20	3.00	2.17	2.49	7.58	......
January	6.67	4.80	3.26	3.32	5.55	1.54	3.68	4.65	4.45	4.16	2.46	2.19	......
February	4.69	1.78	7.34	5.05	1.07	6.63	2.87	3.89	5.21	6.43	0.77	5.80	......
March	3.35	3.90	4.88	1.82	2.85	5.55	3.18	3.46	7.37	4.24	6.02	5.36	......
April	2.53	2.58	5.01	2.97	3.79	1.12	3.31	4.36	2.04	1.77	8.35	3.89	......
May	2.58	4.53	5.33	4.98	2.45	2.48	6.25	8.29	2.01	4.52	6.79	1.84	......
Storage period	24.29	21.37	27.45	21.82	20.27	19.70	21.00	29.85	24.08	23.29	26.88	26.66	23.89
June	1.36	2.61	1.48	1.48	2.85	5.37	3.00	1.07	3.02	2.27	1.06	5.65	......
July	4.57	3.35	1.70	2.36	4.56	4.68	11.13	6.35	5.52	4.47	5.60	3.43	......
August.	4.54	4.67	7.02	1.58	3.83	2.85	3.53	5.64	1.64	4.23	7.31	1.88	......
Growing period	10.47	10.63	10.20	5.42	11.24	12.90	17.66	13.06	10.18	10.97	13.97	10.96	11.47
September	2.54	1.95	2.25	7.14	1.55	4.48	1.90	1.53	5.80	3.23	3.77	6.73	......
October	3.75	0.78	4.54	6.64	3.44	2.40	1.48	6.82	2.48	3.91	2.47	6.38	......
November	2.40	8.57	3.34	4.98	4.27	3.29	4.77	6.48	2.00	4.93	1.75	1.46	......
Replenishing period	8.69	11.30	10.13	18.76	9.26	10.17	8.15	14.83	10.28	12.07	7.99	14.57	11.35
Yearly total	43.45	43.30	47.78	46.00	40.77	42.77	46.81	57.74	44.54	46.33	48.84	52.19	46.71

TABLE NO. 23—PRECIPITATION OF HUDSON VALLEY FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	3.61	3.92	1.02	3.55	3.74	3.64	1.81	5.16	2.04	2.08	2.21	6.00	......
January	7.90	5.50	3.24	2.77	3.21	1.07	2.61	4.40	2.69	2.76	1.91	1.95	......
February	4.53	1.40	7.07	3.17	1.26	5.95	2.60	3.63	3.80	3.96	0.70	3.60	......
March	3.32	3.23	3.47	1.31	1.64	6.14	3.02	2.14	6.00	4.38	5.26	4.58	......
April	2.91	0.82	3.35	2.24	4.32	1.34	3.10	3.34	1.40	1.35	6.16	2.95	......
May	1.77	5.78	6.89	5.03	2.18	2.52	4.88	6.02	2.09	3.89	5.88	2.61	.....
Storage period	24.04	20.65	25.04	18.07	16.35	20.66	18.02	24.69	18.02	18.22	22.12	21.69	20.63
June	2.75	3.68	2.24	1.97	2.56	3.52	3.92	2.60	3.55	2.68	2.52	4.96	......
July	5.06	4.85	3.01	2.36	3.82	4.38	10.35	3.00	4.71	3.24	5.54	6.54	......
August	4.58	6.28	6.18	1.53	2.93	3.97	4.66	8.54	1.49	3.34	6.24	2.94	......
Growing period	12.39	14.81	11.43	5.86	9.31	11.87	18.93	14.14	9.75	9.26	14.30	14.44	12.21
September	1.70	2.40	3.62	4.70	1.72	5.52	2.01	2.75	6.77	1.77	3.67	5.12	......
October	2.13	0.84	3.00	5.44	3.98	2.63	1.11	4.93	1.34	2.63	2.33	4.26	......
November	2.87	5.46	2.00	2.84	4.38	3.13	5.73	5.02	2.10	4.18	1.86	1.02	......
Replenishing period	6.70	8.70	8.62	12.98	10.08	11.28	8.85	12.70	10.21	8.58	7.86	10.40	9.75
Yearly total	43.13	44.16	45.09	36.91	35.74	43.81	45.80	51.53	37.98	36.06	44.28	46.53	42.59

TABLE No. 24—PRECIPITATION OF MOHAWK VALLEY FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	4.83	6.27	1.98	5.43	2.75	4.15	1.86	4.49	2.51	3.03	2.85	4.00	......
January	4.68	5.30	1.96	3.77	1.89	2.17	1.48	4.55	2.02	3.61	2.36	0.91	......
February	5.67	3.07	7.42	*4.05	2.88	7.59	1.48	2.33	2.11	3.62	0.75	3.22	......
March	3.76	6.00	3.16	*2.65	0.89	4.74	3.74	2.38	5.22	4.38	2.74	3.89	......
April	1.53	1.92	3.72	2.39	2.55	1.25	2.92	3.49	1.37	1.75	4.06	2.58	......
May	1.53	6.56	7.16	5.01	2.61	2.85	4.18	3.80	3.56	1.63	5.61	3.44	......
Storage period	22.00	29.12	25.40	23.30	13.57	22.75	15.66	21.04	16.73	18.02	18.37	18.04	20.33
June	2.60	5.66	2.07	5.98	2.05	1.51	5.03	3.74	3.66	3.93	3.74	5.61	......
July	3.79	5.31	4.14	2.01	3.35	6.04	5.19	3.93	3.73	4.78	4.30	7.21	......
August	3.32	7.50	6.62	2.40	3.49	1.92	2.87	7.12	2.24	4.08	2.86	2.79	......
Growing period	9.71	18.47	12.83	10.39	8.89	9.47	13.09	14.79	9.63	12.79	10.90	15.61	12.21
September	1.46	3.53	3.54	6.07	2.51	4.57	2.00	3.26	4.40	1.76	3.80	3.83	......
October	3.49	2.59	2.56	4.65	2.01	1.90	0.84	4.75	2.00	2.36	2.04	4.05	.....
November	4.42	3.99	2.10	1.78	4.32	3.86	4.53	3.79	2.55	5.31	2.86	1.67	......
Replenishing period	9.37	10.11	8.20	12.50	8.84	10.33	7.37	11.70	8.95	9.43	8.70	9.55	9.59
Yearly total	41.08	57.70	46.43	46.19	31.30	42.55	36.12	47.53	35.31	40.24	37.97	43.20	42.13

*Not given in Record — the record for Brookfield, Madison Co., used.

TABLE NO. 25—PRECIPITATION OF CHAMPLAIN VALLEY FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	2.19	2.73	1.22	3.92	3.16	3.06	1.07	3.88	1.72	3.01	2.10	4.87	......
January	2.10	5.04	1.53	2.04	2.30	1.56	2.51	5.68	2.62	3.97	1.79	1.42	......
February	1.30	2.20	3.52	1.52	1.08	5.81	1.92	5.30	2.24	4.36	0.68	2.46	......
March	2.28	1.93	1.29	1.76	1.40	6.52	3.52	1.17	5.00	4.80	3.29	4.96	......
April	2.38	0.85	2.11	1.14	4.44	1.02	3.38	2.46	1.35	0.80	4.14	2.76	......
May	1.86	5.07	3.26	4.03	1.74	1.69	3.91	3.63	2.09	1.80	4.47	3.09	......
Storage period	12.11	17.82	12.93	14.41	14.12	19.66	16.31	22.12	15.02	18.74	16.47	19.56	16.61
June	1.66	6.50	2.42	3.39	3.36	2.90	5.00	3.27	1.69	3.83	3.17	4.11	......
July	4.24	5.21	3.34	2.12	2.50	4.76	8.28	2.56	3.26	2.69	4.48	5.93	......
August	3.40	7.18	5.76	1.66	4.74	4.38	4.43	6.06	2.29	5.12	4.08	3.11	......
Growing period	9.30	18.89	11.52	7.17	10.60	12.04	18.71	11.89	7.44	11.64	11.73	13.15	12.01
September	0.98	2.20	3.00	3.25	2.52	3.83	1.41	3.05	7.31	1.54	3.07	3.95	......
October	2.04	1.46	0.85	3.81	0.81	2.66	1.46	4.26	2.02	1.69	1.55	3.87	......
November	1.73	2.94	1.28	3.04	4.90	4.31	6.53	3.31	2.06	5.93	1.48	1.21	......
Replenishing period	4.75	6.60	5.13	10.10	8.23	10.80	9.40	10.62	11.39	9.16	6.10	9.03	8.44
Yearly total	26.16	43.51	29.58	31.68	32.95	42.50	44.42	44.63	33.85	39.54	34.30	41.74	37.06

TABLE No. 26—PRECIPITATION OF ST. LAWRENCE VALLEY FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	2.08	2.64	1.63	4.49	3.83	4.46	1.10	3.00	2.52	4.90	1.66	3.97	......
January	3.12	3.62	2.11	3.36	3.36	1.49	2.00	4.20	1.96	3.30	1.83	2.07	......
February	3.12	2.02	2.49	1.93	1.93	4.82	1.73	2.46	1.74	3.43	1.30	2.22	......
March	3.70	2.52	1.06	2.39	1.73	3.84	3.48	1.51	4.54	3.57	4.20	3.71	......
April	2.52	1.35	3.04	1.20	2.18	1.41	2.64	1.37	1.67	0.94	4.34	2.63	......
May	1.24	4.51	5.68	3.78	2.44	1.96	3.45	3.05	2.67	2.99	5.49	3.10	......
Storage period	15.78	16.66	16.01	17.15	15.47	17.98	14.40	15.59	15.10	19.13	18.82	17.70	16.64
June	2.34	6.82	2.86	3.31	1.91	3.22	2.28	2.69	1.64	3.83	4.00	4.63	......
July	5.54	5.10	3.05	2.96	3.14	3.85	5.16	1.96	2.46	2.83	3.43	2.92	......
August	4.97	8.94	8.42	0.72	4.89	3.70	2.21	4.42	0.68	2.85	5.13	2.22	......
Growing period	12.85	20.86	14.33	6.99	9.94	10.77	9.65	9.07	4.78	9.51	12.56	9.77	10.92
September	1.91	3.26	2.47	3.95	3.25	4.94	1.33	4.20	3.40	3.62	4.01	1.32	......
October	3.16	1.79	1.17	4.42	0.78	1.33	0.80	3.88	2.74	2.66	2.63	2.70	......
November	2.33	4.31	2.08	2.27	4.31	2.96	4.16	1.92	2.49	6.05	3.42	1.41	.....
Replenishing period	7.40	9.36	5.72	10.64	8.34	9.23	6.29	10.00	8.63	12.33	10.06	5.43	8.62
Yearly total	36.03	46.88	36.06	34.78	33.75	37.98	30.34	34.66	28.51	40.97	41.44	32.90	36.18

TABLE No. 27—PRECIPITATION OF THE GREAT LAKES REGION FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
December	2.26	3.65	2.27	3.89	2.95	4.51	1.72	3.36	2.60	4.20	2.46	4.65	......
January	2.53	3.37	2.26	2.83	3.63	2.70	3.09	3.89	1.74	3.31	2.61	2.87	......
February	3.44	2.69	4.33	3.05	2.06	4.64	1.65	1.96	1.76	3.68	2.41	2.40	......
March	3.24	2.45	2.27	1.86	1.39	4.00	3.31	1.82	3.19	3.64	2.75	2.34	......
April	1.69	1.18	3.63	2.50	1.73	0.89	2.37	1.89	1.44	1.31	4.87	2.47	......
May	1.07	5.37	5.48	6.63	2.64	2.36	2.50	3.07	3.40	1.64	3.70	2.99	......
Storage period	14.23	18.71	20.24	20.76	14.40	19.10	14.64	15.99	14.13	17.78	18.80	17.72	17.21
June	1.38	6.98	2.68	3.35	1.73	2.27	2.77	2.39	1.42	1.74	3.55	4.73	......
July	3.48	3.94	2.90	2.66	2.06	4.91	6.09	1.86	2.89	4.50	3.17	6.74	......
August	3.19	5.17	5.46	0.97	3.03	2.71	2.24	4.19	1.35	2.25	3.40	2.26	......
Growing period	8.05	16.09	11.04	6.98	6.82	9.89	11.10	8.44	5.66	8.49	10.12	13.73	9.70
September	1.74	2.27	2.55	4.85	2.65	4.20	0.83	3.66	4.51	2.69	3.51	2.99	......
October	2.26	2.04	2.55	3.96	1.81	1.71	0.87	4.33	2.72	3.29	2.01	2.92	......
November	2.54	3.34	2.47	2.30	3.45	3.13	4.98	3.19	1.65	5.95	3.50	1.50	......
Replenishing period	6.54	7.65	7.57	11.11	7.91	9.04	6.68	11.18	8.88	11.93	9.02	7.41	8.74
Yearly total	28.82	42.45	38.85	38.85	29.13	38.03	32.42	35.61	28.67	38.20	37.94	38.86	35.65

TABLE NO. 28—PRECIPITATION OF THE CENTRAL LAKES REGION FOR THE WATER YEARS 1891–1902, INCLUSIVE.

(In inches)

MONTH (1)	1891 (2)	1892 (3)	1893 (4)	1894 (5)	1895 (6)	1896 (7)	1897 (8)	1898 (9)	1899 (10)	1900 (11)	1901 (12)	1902 (13)	Mean (14)
December	2.42	3.62	0.82	1.76	2.66	3.51	1.12	2.43	2.24	3.40	2.35	4.62	......
January	2.25	2.94	1.17	2.17	2.00	1.86	1.70	2.92	1.26	2.79	2.06	1.65	......
February	2.76	2.00	2.12	2.48	0.74	4.41	1.16	1.78	1.25	3.40	2.04	1.99	......
March	3.31	2.86	1.63	1.00	0.95	4.50	3.23	1.84	2.51	4.14	2.66	2.72	......
April	2.04	0.91	3.27	4.70	1.41	1.49	2.57	2.86	1.28	1.20	5.12	1.91	......
May	0.57	5.00	5.45	6.50	3.50	3.15	3.55	3.89	3.17	1.33	5.28	3.10	......
Storage period	13.35	17.33	14.46	18.61	11.26	18.92	13.33	15.72	11.71	16.26	19.51	15.99	15.54
June	3.84	4.38	2.02	3.46	3.27	3.04	3.21	3.16	2.34	1.44	4.78	5.75	......
July	3.86	3.29	1.79	2.96	3.09	4.58	3.95	2.34	3.34	4.51	2.92	7.60	......
August	3.83	5.19	3.97	1.66	3.68	2.74	1.82	5.24	2.66	2.50	5.00	2.84	......
Growing period	11.53	12.86	7.78	8.08	10.04	10.36	8.98	10.74	8.34	8.45	12.70	16.19	10.50
September	1.28	1.26	3.27	5.29	1.81	4.55	3.23	3.48	2.71	1.07	2.38	2.10	......
October	4.05	1.59	1.65	4.63	1.07	3.61	1.01	5.65	2.41	3.68	1.55	3.71	......
November	1.69	2.81	1.01	1.72	3.13	2.32	3.71	3.36	2.66	6.68	3.27	1.62	......
Replenishing period	7.02	5.66	5.93	11.64	6.01	10.48	7.95	12.49	7.78	11.43	7.20	7.43	8.42
Yearly total	31.90	35.85	28.17	38.33	27.31	39.76	30.26	38.95	27.83	36.14	39.41	39.61	34.46

Division of the year into storage, growing and replenishing periods. In reference to taking as a water year, the period extending from December–November, inclusive, instead of from January–December, inclusive, it may be stated that such or a similar division has been customary with advanced hydrologists for many years, although in the United States the advantages of this division have not thus far generally appeared obvious to writers on this subject. In England a water year beginning with September and ending with August is quite common. The same thing has been done by the Philadelphia Water Department in tabulating the data of Neshaminy, Perkiomen, Tohichon and Wissahickon creeks and Schuylkill river. However, no hard and fast rule can be laid down for the beginning and ending of these periods. In some years the storage period will end soon after May 1, while in other years it may be extended into the first or second week in June. After some consideration a division of the storage period from December–May, inclusive, has been taken as, on the whole, best representing average conditions.

The storage period is the period when evaporation is lowest and the largest amount of water may be stored. On reference to table No. 67, runoff data of Croton river for the water years 1877–1899, inclusive, it appears that the mean runoff for the storage period is 16.83 inches; the mean evaporation, 6.85 inches; and the mean rainfall, 23.68 inches. The mean runoff, therefore, is 71 per cent. of the mean rainfall. In the growing period on Croton river the mean runoff is 2.57 inches, with 13.58 inches mean rainfall, or the runoff is 19 per cent. of the rainfall. In the replenishing period the mean runoff is 3.42 inches and the mean rainfall 12.08 inches, or the runoff is 27 per cent. of the rainfall. It is obvious, therefore, that it is only during the months of the storage period that any large amount of water can be stored. A similar condition is shown by tables Nos. 43 and 61.

During the storage period, vegetation is inactive and evaporation takes place chiefly through wind action. It seems clear, therefore, that a forest-protected area will show less evaporation during the months of the storage period than will an area which is fully exposed to the sweep of the winds. In proof of this it may be cited that the Hudson area shows, on an average, only 4.6 inches evaporation during the storage period, while the Genesee area, during the same period, shows 8.9 inches. The Croton area shows 6.85 inches evaporation for the same period. It is probable that, due to greater elevation, winds are more searching on the Genesee area than on the Croton area, although the forestation is not very different. It is also probable that owing to proximity to the ocean the humidity is greater on the Croton area than on the Genesee, but since there are no observations this latter point can not be stated except as an inference. At Erie, Buffalo, Rochester and Oswego the conditions are somewhat the same as at New York and the humidity shown by tables Nos. 3, 4, 7 and 8 is not very different. We need humidity observations for the upper Genesee in order to settle the relation.

In the growing period vegetation is active and large demands are made upon ground water to supply its requirements. During this period, as an average, 2.57 inches of water runs off from the Croton area, although in 1880 only 0.68 inch ran off. As a broad proposition, ground water tends to become lower and lower throughout the growing period.

In the replenishing period the average runoff from the Croton area is 3.42 inches, from an average rainfall of 12.08 inches. During this period, broadly, ground water is rising and conditions tend to restore themselves to that at the beginning of the storage period. The varying conditions on the Genesee and Hudson rivers during these periods may be seen by reference to the tables relating to those streams.

One great advantage of dividing records into these periods is as follows: Since evaporation and plant absorption are light during the months of the storage period, it follows to a great degree that the amount of water which can be stored is exhibited by the rainfall of the storage months. Realizing this fact, it has been the writer's habit for several years, in storage projects, to first tabulate rainfall in the manner indicated. Such procedure has the advantage that it leads one away from the contemplation of mere detail. There is a positive disadvantage in considering the monthly quantities, for which there is no compensation. The division into the three periods exhibits the more important characteristics without overburdening the mind. It is believed that a considerable advance on ordinary practice has been made by proceeding in the manner stated.

THE RELATION OF RAINFALL TO RUNOFF

The runoff of a stream is influenced by many complex conditions—as, for instance, amount of rainfall and its intensity, nature of soil, slope of surface and area and configuration of catchment basin. It is also influenced by geologic structure, forests, wind, force of vapor pressure and other elements. Data are still lacking for a really satisfactory discussion of the question, although they have accumulated so rapidly during the last few years that many conservative conclusions can be drawn which may be accepted as substantially true.

As a result of many years' study of the problem indicated by the heading of this chapter the writer has come to the conclusion that no general formula is likely to be found expressing accurately the relation of rainfall to the runoff of streams, for streams vary widely in their behavior, and when they do agree the agreement is usually accidental. As a general proposition we may say that every stream is a law unto itself.

The final formula of runoff for a given stream, therefore, will differ in some particulars from that for every other, except that there may be accidental resemblances as regards slope, shape of catchment area, surface geology or some other peculiarity. It is, however, true that an empirical formula may be made for certain classes of streams which will give approximately the runoff for a series of years.

Rainfall

Cause of rainfall. The cause of rainfall has been discussed by Mr Velschow in the transactions of the American Society of Civil Engineers.[1] This paper may be referred to for a very good discussion of the subject.

The subject is also very ably discussed by Alfred J. Henry in one of the Weather Bureau Reports.[2] Mr Henry remarks that the theories of rainfall given in books of twenty or thirty years ago are not now wholly accepted. Still there is one simple principle upon which no disagreement exists—that in order to produce rain the temperature of the air must be suddenly cooled below the dewpoint. When the air is thus cooled a portion of the vapor is changed to the liquid and the particles thus formed may float away with the wind or they may increase in size and fall to the ground by virtue of gravity. Whether the condensation results simply in cloud, or whether rain falls, depends on the magnitude of the temperature changes taking place in the air mass.

The precise manner in which air is cooled to produce rain, whether by contact or by mixing, is not clearly apprehended. Cooling by expansion, as air ascends, is one of the most effective causes of rainfall. The ascensional movement is brought about in several ways, probably the most important of which is circulation of air in cyclonic storms, by a radial inflow from all sides and an ascensional movement in the center. A very large percentage of the rain of the United States is precipitated in connection with the passage of storms of this class.[3]

Mr Henry discusses the precipitation of the United States under the following topics: (1) The statistics used and their accuracy; (2) geographic distribution and annual allowance; (3) monthly distribution by districts and types; (4) the precipitation of the crop-growing season; (5) secular variations; (6) details of the

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[1] The Cause of Rain and the Structure of the Atmosphere, by Franz A. Velschow: Trans. Am. Soc. Civil Eng., Vol. XXXIII, 1890, p. 303.

[2] Rainfall of the United States, by Alfred J. Henry, chief of division: Ann. Rept. Weather Bureau, 1896-97, p. 317.

[3] Abstracted from Mr Henry's paper.

precipitation by geographic districts, and (7) excessive precipitation.

The chapter on "Excessive precipitation" is probably, from an engineering point of view, the most important. Mr Henry states that in 1888 attention was first directed to the importance of statistics of excessive rainfall. At the present time the Monthly Weather Review publishes a table of maximum rainfalls in five and ten minute and one hour periods, etc.

Table No. VIII of Mr Henry's paper gives details of excessive rainfall at Washington, Savannah, and St Louis, and table No. IX gives maximum intensity of rainfall for periods of five, ten, and sixty minutes at the Weather Bureau stations equipped with self-registering gages, compiled from all available records. Inasmuch as this paper may be readily referred to further detail is omitted.

Measurement of rainfall. The subject, "How close may rainfall be measured?" has been fully discussed by Prof. Cleveland Abbe.[1] Professor Abbe states that the influence of altitude was first brought to the attention of the learned world by Heberden who, in 1769, in a memoir in the Transactions of the Royal Society of London, stated that a gage on Westminster Abbey, over 150 feet above the ground, caught less than half as much as a gage at the ground.

Profs. Alexander D. Bache and Joseph Henry, and Mr Desmond FitzGerald have studied the question extensively in this country. Mr FitzGerald's results may be found in the Journal of the Association of Engineering Societies for August, 1884.[2]

Mr FitzGerald kept two gages, one at a hight of 2 feet 6 inches above the level of the ground, and the second at a distance of 150 feet from the first, and at an elevation of 20 feet 4 inches above the lower gage. Both gages were 14.85 inches in diameter.

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[1] Determination of the True Amount of Precipitation and its Bearing on Theories of Forest Influences, by Cleveland Abbe: Appendix I of Bulletin No. 7, Forest Influences; Forestry Division, United States Department of Agriculture.

[2] Does the Wind Cause the Diminished Amount of Rain Collected in Elevated Rain Gages? By Desmond FitzGerald: Jour. Assoc. Engineering Societies, Vol. III, No. 10 (August, 1884).

These gages were located at Chestnut Hill reservoir, in the city of Boston, but the observations for wind velocity were taken from the Signal Service observations, 5 miles distant. With only five exceptions during the five-year period, the upper gage delivered materially less water than the ground gage, the average difference being 10.6 per cent for the whole period. But snowfalls and mixtures of snow and rain are not included in the table of data given in the paper.

The results recorded by Professor Abbe are somewhat more extensive than those presented by Mr FitzGerald, though Mr FitzGerald states in his paper that he has prepared a series of experiments with nine gages and a self-recording anemometer, from which in the course of time some more definite results may be reached. So far as the writer knows, this second series of observations has not been published.

In order to show how the catch of rainfall diminishes with hight of the gage, Professor Abbe gives in his table No. IV the results of observations at different places. These range from 90 per cent of a gage at the ground to 47 per cent. In tables Nos. I, II, and III, Professor Abbe also gives the result of various gages, which gave 52 to 7 per cent less of rainfall, and from 80 to 16 per cent less of snowfall, than gages at the ground. Professor Abbe remarks that these tables show conclusively the large influence of wind on the catch of rain, but show nothing of its influence on the catch of snow. As an observational method of obtaining the true rainfall from gage readings, Professor Abbe suggests the following as offering a fair approximation:

> If the present gage has been standing in an open field at a few feet elevation, place two or more similar gages near it, and similarly located as far as obstacles are concerned, except only that one of these is to be decidedly lower than the old one and the other decidedly higher. From a comparison of the simultaneous records of any two gages and their altitudes, we should for each separate rainfall, rather than for the monthly and annual sums, deduce the normal rainfall by the solution of two or more equations of the form:
>
> Observed catch of gage $=(1-x$ altitude$)\times($desired catch of normal pit gage$)$. (1)

Where x is the unknown special coefficient of deficiency due to wind at that altitude—that is to say, having two gage catches, c_1 and c_2 for the two altitudes, H_1 and H_2—we obtain the true rainfall (R) by the formulas:

$$c_1=(1-x\sqrt{H})\ R;\ \text{and} \tag{2}$$

$$c_2=(1-x\sqrt{H_2})\ R. \tag{3}$$

whence,

$$R=\frac{c_1\sqrt{H_2}-c_2\sqrt{H_1}}{\sqrt{H_2}-\sqrt{H}}=c_1+\frac{1}{\sqrt{\frac{H_2}{H_1}}-1}(c_1-c=c_1+n(c_1-c_2). \tag{4}$$

If c_1 and H_1 relate to the lower gage, we shall generally have $c_1 > c_2$ and $H_1 < H_2$, and the coefficient n will be a positive fraction, for value of which, for such combinations as may easily occur in practice, a table is given in the paper.

It is evident then, without special discussion, that nearly all rainfall measurements thus far made in the United States are only approximations, and that while they remain in this state to carry them out to more than one decimal place is an unnecessary refinement.

Determination of minimum rainfall. The writer has spent considerable time in an attempt to determine about what the minimum rainfall at any particular station may be expected to be; or, rather, he has endeavored to ascertain the relation between the minimum rainfall and the maximum. In the course of this quest he has examined practically all the records in the State of New York, as well as many records in New Jersey, Pennsylvania, Michigan, Illinois, Nebraska, Colorado, and Wyoming, as well as in Canada. As a general rule, to which there are some exceptions, the minimum rainfall may be placed at about one-half of the maximum. That is, if the maximum rainfall at a given station is about 50 inches, the minimum will be in the vicinity of 20 to 25 inches. In some cases the minimum will be not more than one-third of the maximum, or even somewhat less than one-third; occasionally, not more than one-quarter. It is not intended, however, to lay this down as an absolutely universal rule, but rather, for the present, as a somewhat imperfect guide. As a further rough guide it remains to point out that in case a given record does not conform substantially to the foregoing it may be assumed that either the minimum or the maximum, as the case may be, is still to occur. Near the seacoast, where the supply of moisture in the air is more nearly constant, there is less variation than in the interior, and the rule that the maximum is double the minimum is more generally true. This proposition is also generally true as regards English meteorology.

Is rainfall increasing? This question has been discussed by Prof. Mark W. Harrington,[1] who, however, reached no very definite conclusion, although he is disposed to answer it in the negative. The method of discussion followed was to reduce the annual rainfalls to a series of means of each five years. These means were entered on a succession of maps, five years apart in time, and on these maps were drawn the line of 40 inches of annual rainfall. The question to be determined is, as we draw this line for each five-year mean, does it change its position in any regular and systematic way?

An examination of the detail shows that while these lines are subject to limited fluctuations, there are no uniform or systematic fluctuations. The line of equal rainfall for 1861–1865 occupied nearly the same position as the line for 1886–1890. The variations are sometimes extensive, but without systematic progress. Professor Harrington therefore concludes that with the data at hand there is not sufficient evidence of systematic fluctuation of the rainfall.

Relation of rainfall to altitude. This matter has been referred to in a discussion of Mr Noble's paper, Gagings of Cedar River, Washington,[2] where the statement has been made that in the State of New York the rainfall records show both increase and diminution of precipitation with increase of altitude. The Hudson river catchment area shows a higher precipitation at the mouth of the river than it does at its source in the Adirondack

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[1] Rainfall and Snow of the United States, Compiled to the End of 1891; with Annual, Seasonal, Monthly, and other Charts, by Mark W. Harrington: Bulletin C, Weather Bureau, U. S. Dept. of Agriculture.

[2] Trans, Am. Soc. Civil Eng., Vol. XLI, pp. 1-26.

mountains, while the Genesee river shows the opposite, namely, higher precipitation at its source than at its mouth.

According to a table of average monthly, annual and seasonal precipitation in Mr Turner's monograph on the climate of New York State[1] it appears that the coast region, which includes Block Island, East Hampton, Setauket, Fort Columbus, New York city, Mount Pleasant, Tarrytown, White Plains, Croton dam, and North Salem, has an average annual precipitation of 44.93 inches. With the exception of Block Island, these stations are all in New York and not far from the coast, and they range in elevation above tidewater from 16 feet at East Hampton to 361 feet at North Salem. The average elevation of the coast region is 132 feet. The records vary in length from 7 years to 49 years, with a total of 195 years. Five of the stations are in Westchester county.

As given by Mr Turner, the northern plateau includes Constableville, Lowville, Fairfield, Johnstown, Pottersville, Elizabethtown, Keene Valley and Dannemora, in the counties of Lewis, Herkimer, Warren, Essex, and Clinton. According to the table the average annual precipitation at these places is 38.97 inches. The elevation of the stations above tide ranges from 600 feet at Elizabethtown to 1356 feet at Dannemora, with an average elevation of 973 feet. The records vary in length from 4 to 22 years, with a total of 73 years.

Again, the western plateau, which includes stations in Cattaraugus, Wyoming, Allegany, Steuben, Livingston and Chemung counties, has an average elevation above tide of 1307 feet, ranging from 1950 feet to 525 feet, and has an average annual precipitation of 35.58 inches, while the Hudson valley, which includes stations in Putnam, Orange, Dutchess, Ulster, Columbia, Albany, Rensselaer and Washington counties, has an average elevation of 230 feet above tide, with an average annual precipitation of 38.46 inches. The records range from 9 years to 65 years, with a total of 277 years.

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[1] The Climate of New York State, by E. T. Turner, C. E., late Meteorologist of the New York Weather Bureau: Fifth Ann. Rept. New York Weather Bureau, 1893. Reprinted in Eighth Ann. Rept. of the Bureau, 1896.

The Great Lakes region, with an average elevation of 494 feet, has an average annual precipitation of 35.17 inches, while the Central Lakes region, with an average elevation of 690 feet, has an average annual precipitation of 43.41 inches.

Mr Turner's table is based on a calendar year, from January to December, inclusive. Further data may be obtained from this excellent table.

In table No. 24 of the Upper Hudson Storage Surveys Report for 1896 there is given the mean precipitation of the Upper Hudson catchment area. The stations therein included are: Albany, 1825-1895, 71 years; Glens Falls, 1879-1895, 17 years; Keene Valley, 1879-1895, 17 years; western Massachusetts, 1887-1895, 9 years; northern plateau, 1889-1895, 6½ years; Lowville Academy, 1827-1848, 22 years; Johnstown Academy, 1828-1845, 18 years; Cambridge Academy, 1827-1839, 13 years; Fairfield Academy, 1828-1849, 22 years; Granville Academy, 1835-1849, 15 years. Assuming the northern plateau as a unit, the total number of years is 199½, and the mean of all is 37.4 inches. A reference to the rainfall map in the report of the United States Board of Engineers on Deep Waterways will show that this is necessarily an approximation, because of great lack of stations in the interior of this region.

As regards the catchment area of the Upper Genesee river, there is a very decided increase in rainfall as one goes toward the source. For the years 1889-1896, inclusive, the rainfall in the upper area of this stream was 42.19 inches, while at Rochester for the same years it was 35.64 inches. This statement is specially interesting, because there seems to be a well-marked line dividing the smaller rainfalls of the lower area from the higher rainfalls of the upper. At Hemlock lake, Avon, and Mount Morris the rainfalls are all low, the average at Hemlock lake from 1876-1895, inclusive, being 27.56 inches. In 1880 it was 21.99 inches; in 1879, 22.16 inches, and in 1881 only 24.36 inches. We have here three years of exceedingly low rainfall, in which the runoff must have also been very low. In 1895 the rainfall at Hemlock lake was only 18.58 inches. The average precipitation at Avon and Mount Morris from 1891 to 1896, inclusive, was 30.12

inches. In 1895 it was only 25.05 inches. The following are stations at which it was much higher for the years 1891 to 1895, inclusive; Leroy, 45.25 inches, and Arcade, 41.60 inches.

The statements of precipitation in the Genesee river catchment area are all based on a water year, December to November, inclusive.

The following are from Russell's Meteorology,[1] illustrating Atlantic coast rainfalls, and are the averages derived from observations extending from 1870 to 1888. The rainfalls are stated to be fairly representative for large districts of country around the places.

At Jacksonville the Weather Bureau office is at an elevation above tide of 43 feet, while the average annual rainfall is 57.1 inches. At Norfolk the elevation of the Weather Bureau is 57 feet above tide, and the average rainfall is 51.7 inches. At Boston the Weather Bureau office is 125 feet above tide, and the average rainfall is 46.8 inches.

The following illustrate the change as one goes north through the Mississippi valley: At New Orleans the Weather Bureau office is 54 feet above tide, the average rainfall 62.6 inches; at St Louis, Weather Bureau office 567 feet above tide, average rainfall 37.8 inches; at St Paul, Weather Bureau office 850 feet above tide, average rainfall 28.9 inches.

The following illustrate the Rocky mountain region: At Fort Grant, Ariz., elevation of Weather Bureau 4833 feet, average rainfall 15.8 inches; at Denver, elevation of Weather Bureau 5300 feet, average rainfall 14.7 inches; at Fort Benton, Mont., elevation 2565 feet, average rainfall 13.2 inches.

The following illustrate the Pacific coast region: At Portland, elevation of Weather Bureau office is 157 feet, average rainfall 50.3 inches; San Francisco, elevation 153 feet, average rainfall 23 inches; San Diego, elevation 69 feet, average rainfall 10.2 inches.

These figures abundantly support the proposition that in the United States the rule of increased precipitation with higher

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[1] Meteorology, by Thomas Russell, U. S. Asst. Engineer.

altitude is by no means universal. The writer can not say positively, because he has not examined the vast number of records with reference to this point, but he thinks it quite possible that the reverse is more nearly true. That is, owing to distance from the ocean, prevailing direction of wind, and other causes, it is probable that for the entire country precipitation decreases with higher altitude rather than increases.

The decision of this question will depend to some extent upon steepness of ascent. Thus on Mount Washington, which is projected into the air far above the surrounding mountains, the rainfall is about 83 inches. In other cases, where the ascent is gradual, no increase is apparent. The same is also frequently true of sharp ascents. On Longs Peak, in Colorado (elevation 14,271 feet,) the rainfall in 1899 was 16.7 inches.

Moreover, the writer has mostly avoided comparatively small differences in rainfall—those not exceeding 2 to 2.5 inches. In such cases the difference is too small to be any certain guide. Specially is this true in the case of the northern plateau, where there is still a great lack of stations. The differences between high altitudes and low should be as much as 5 or 6 inches. Again, whether the excess rainfall occurs in the winter or summer months must be taken into account. If it occurs in the summer, even 3 inches of rainfall may not make more than 0.1 or 0.2 inch in the stream. Rainfall and runoff observations are not yet, nor are they likely to ever be, definite enough to take into account an annual difference of much less than about 1 to 1.5 inches. Again, the writer has ceased to be excessively particular about the total of the annual rainfall. Assuming some considerable length of record, small errors have relatively slight effect. This matter is referred to here because nearly all rainfall records—at any rate in the United States—have more or less error in them, and while it is desirable to have records as reliable as possible, a few errors do not affect a record very seriously. It is nevertheless very desirable to know the history of the record in order to insure the degree of confidence to be placed in it.

Increase of runoff with increase of rainfall. In making allowance for difference in rainfall, it should be remembered (1) that in many catchment areas the annual runoff is in nearly constant relation to the precipitation; and (2) that such relation will be more marked when the excess rainfall above a certain minimum annual depth is taken into account. This subject will not be pursued at length any farther than to point out that in the Genesee catchment an average of 10.5 inches runs off in the storage period; 1.7 inches in the growing period, and 2.0 inches in the replenishing period. In the Hudson catchment, an average of 16.10 inches runs off in the storage period; 3.45 inches in the growing period, and 3.72 inches in the replenishing. In the Croton catchment, an average of 16.83 inches runs off in the storage period; 2.57 inches in the growing period, and 3.42 inches in the replenishing. These figures, it may be again stated, are the means—the maximum and minimum runoffs can be determined by examining the tables.

Broadly, the proposition is that a given increase in rainfall above the amounts required to produce the foregoing figures will be followed by something like a similar increase in runoff. Such increase, however, is not very definite, although the broad statement is true that it bears a relation to the rainfall.

The following will illustrate the essential truth of this proposition:

	Inches	
	Rainfall	Runoff
Genesee river.		
Yearly average	40.3	14.20
1895 (minimum year)	31.0	6.67
Difference	9.3	7.53
1894 (maximum year)	47.79	19.38
Yearly average	40.30	14.20
Difference	7.49	5.18

Comparing the maximum year with the minimum, we have:

1894	47.79	19.38
1895	31.00	6.67
Difference	16.79	12.71

	Inches	
	Rainfall	Runoff
Comparing the storage periods, we have:		
Average of storage period	19.40	10.50
Storage period of 1895 (minimum)	13.20	5.63
Difference	6.20	4.87
Storage period of 1894 (maximum)	27.71	15.73
Average of storage period	19.40	10.50
Difference	8.31	5.23
Comparing any two years, we have:		
1892	41.69	15.42
1896	40.68	12.80
Difference	1.01	2.62
Comparing storage periods:		
Storage period of 1892	19.84	9.38
Storage period of 1896	17.84	9.25
Difference	2.00	0.13
Comparing growing periods:		
Growing period of 1892	15.30	4.90
Growing period of 1896	10.28	0.83
Difference	5.02	4.07
Comparing replenishing period:		
Replenishing period of 1896	12.56	2.72
Replenishing period of 1892	6.55	1.14
Difference	6.01	1.58
Hudson river.		
Yearly average	44.21	23.27
1895 (minimum year)	36.67	17.46
Difference	7.54	5.81
1892 (maximum year)	53.87	33.08
Yearly average	44.21	23.27
Difference	9.66	9.81
Comparing the maximum year with the minimum, we have:		
1892	53.87	33.08
1895	36.67	17.46
Difference	17.20	15.62

	Inches	
	Rainfall	Runoff
Comparing the storage periods, we have:		
Average of storage period	20.62	16.10
Storage period of 1895 (minimum)	15.79	11.68
Difference	4.83	4.42
Storage period of 1892 (maximum)	24.95	22.50
Average of storage period	20.62	16.10
Difference	4.33	6.40
Comparing any two years, we have:		
1898	48.28	27.12
1891	42.96	20.56
Difference	5.32	6.56
Storage period of 1898	22.80	16.81
Storage period of 1891	20.69	16.59
Difference	2.11	0.22
Growing period of 1898	13.52	3.24
Growing period of 1891	13.49	2.07
Difference	0.03	1.17
Replenishing period of 1898	12.19	5.27
Replenishing period of 1891	8.78	1.90
Difference	3.41	3.37
Croton river.		
Average of storage period	23.68	16.83
Storage period of 1897	20.55	14.64
Difference	3.13	2.19
Storage period of 1898	28.81	20.08
Average of storage period	23.68	16.83
Difference	5.13	3.25
Comparing any two storage periods, we have:		
Storage period of 1896	24.84	18.01
Storage period of 1895	19.55	14.78
Difference	5.29	3.23
Storage period of 1888	30.33	21.74
Storage period of 1883	19.03	11.37
Difference	11.30	10.37

By observing the relation indicated in the foregoing tabulations, together with hight of ground water, one may approximately compute the rainfall from the runoff. In the same way the runoff may be approximately computed from the rainfall.

Map of average rainfall in the State of New York. On plate XCVIII of the Report of the United States Board of Engineers on Deep Waterways, the writer has given the average rainfall at a large number of stations throughout the State of New York. When this map was prepared considerable time was expended in drawing lines of equal rainfall upon it, but so many discrepancies appeared that it was finally concluded, for the present, that it should be allowed to stand without such lines. The only way these contours could be drawn with any satisfaction was to omit stations which conflicted too much therewith. This, the writer did not feel justified in doing. The observations are not extensive enough to enable one to draw these lines.

Length of time required to make good a series of rainfall records. This question is partially answered in the writer's second report on the Upper Hudson Storage Surveys, for 1896, by a short analysis of a paper by Alexander R. Binnie, Member of the Institution of Civil Engineers.[1]

One of the important problems worked out by Mr Binnie is an answer to this question: What is the least number of years the continuous record of which, when a mean fall has been determined, will not be materially affected, as far as the value of the mean is concerned, even if the record be extended by a greater number of years of observation? Mr Binnie says:

> Collaterally, inquiry must also be made if the period necessary to determine the true mean fall is in any way affected by the amount of the mean fall of rain; or if any approximate rule can be applied to all countries, and to differing amounts of mean annual rainfall at different stations.
>
> To approach the subject without bias, some good records of long periods must be carefully examined, and it must be found, not how near the averages of the shorter periods into which they

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[1] On Mean or Average Rainfall and the Fluctuations to Which it is Subject, by Alexander R. Binnie, M. Inst. C. E.: Proc. Inst. C. E., Vol. CIX (1892), pp. 89-172.

can be divided, approach the mean, but rather what are the extreme divergencies from the mean of such shorter periods. By this method, any approach to a general law will soon be detected, if the extreme divergencies are found gradually to decrease, as the subordinate periods into which the record has been divided increase in length.

Also, What is the probable accuracy of any record the length of which is less than that necessary to give an average which will not be materially altered when the record is extended?

Space will not be taken to show Mr Binnie's views in detail, for which reference may be made to the abstract in the second Hudson report, or, for the complete views, to the paper in the Proceedings of the Institution of Civil Engineers, but assuming that the observations are properly made it is stated that "dependence can be placed on any good record of thirty-five years' duration to give a mean rainfall correct within 2 per cent of the truth."

Further, it can be stated that for records from twenty years to thirty-five years in length, the error may be expected to vary from 3.25 per cent down to 2 per cent, and that for the shorter periods of five, ten, and fifteen years, the probable extreme deviation from the mean would be 15 per cent and 4.75 per cent, respectively.

A twenty years' record, therefore, may be expected to show an error of 3.24 per cent. This is about as close as rainfall records in this country will agree, as comparatively few are much beyond twenty years in length.

In his paper on Rainfall of the United States, Mr Henry has examined this question, using long records at New Bedford, St Louis, Philadelphia, Cincinnati, and other places. The rainfall has been measured at New Bedford for 83 consecutive years, and at St Louis for 60 years. For a 10-year period Mr Henry found the following variations from the normal: At New Bedford + 16 per cent and — 11 per cent; at Cincinnati, + 20 per cent and — 17 per cent; at St Louis, + 17 per cent and — 13 per cent; at Fort Leavenworth, + 16 per cent and — 18 per cent; and at San

Francisco, + 9 per cent and — 10 per cent. For a 25 year period, it was found that the extreme variation was 10 per cent, both at St Louis and New Bedford. Mr Henry reached the conclusion that at least 35 to 40 years' observations are required to obtain a result that will not depart more than ± 5 per cent from the true normal. The average variation of a 35 year period was found to be ± 5 per cent, and for a total 40 year period ± 3 per cent.

This preliminary study indicates slightly more range than was found by Mr Binnie, although it may be remembered that the observations of the latter are far more extensive than Mr Henry's.

Again, since the runoff is a function of the rainfall, it follows that it must be affected in some degree in a similar manner. As to just the relation, so far as known, very few computations have been made. Indeed, very few runoff tabulations are extant which are long enough to settle this question. It is clearly, therefore, very difficult to solve definitely so abstruse a problem as that of the extent to which forests affect rainfall. All solutions are necessarily tentative in their character and will be for some time to come.

Minimum precipitation in New York. Let us now examine as to what the records of precipitation in New York indicate in regard to the probabilities of extreme low-water periods. The following records of minimum precipitation are herewith included: At Albany the water years 1895 and 1896 represented a period of very low precipitation. The following are the totals of the several periods:

	1895	1896
Storage	12.58	14.79
Growing	8.88	8.31
Replenishing	8.93	6.64
Total	30.39	29.74

The total precipitation of the previous year, 1894, was 34.45 inches. It is probable that for the water year 1896 streams in the vicinity of Albany did not run to exceed 9 inches on the catchment area.

At Auburn the years 1836, 1837 and 1838 cover a period of very low precipitation, as shown by the following:

	1836	1837	1838
Storage	19.41	10.37	7.50
Growing	6.39	11.35	8.14
Replenishing	6.56	6.78	6.05
Total	32.36	28.50	21.69

Taking into account the sequence of the foregoing record at Auburn, it is probable that in the water year 1838 the runoff of streams in that vicinity did not exceed 3 to 4 inches on the catchment area.

In view of its relations to the runoff of the Upper Hudson catchment area, we may refer to the record at Burlington, Vt., for the years 1893-1896, inclusive. We have the following from the Burlington record:

	1893	1894	1895	1896
Storage	8.63	10.35	10.70	9.70
Growing	13.78	4.51	10.08	11.05
Replenishing	5.25	8.34	8.19	8.55
Total	27.36	23.20	28.97	29.30

Taking into account the low precipitation of 1894, it is probable that in 1895 and 1896 streams in the vicinity of Burlington did not run to exceed 5 to 6 inches on the catchment area.

At Cazenovia the two lowest consecutive years are 1834 and 1835, when the total rainfalls were 34.29 inches in 1834 and 32.82 inches in 1835. Inasmuch as streams in that vicinity fall in the same category as the Genesee river, if we assume similar conditions of forestation, the runoff was probably about 8 inches on the catchment area.

At Cooperstown the mean precipitation for the period from 1854 to 1898, inclusive, is 39.07 inches. The three consecutive minimum years occurred from 1879 to 1881, inclusive. The following are the precipitations for those years:

	1879	1880	1881
Storage	14.91	18.57	12.33
Growing	8.44	10.05	7.38
Replenishing	6.38	8.61	9.56
Total	29.73	37.23	29.27

In 1881 the runoff of streams in the vicinity of Cooperstown probably did not exceed 7 inches. The Cooperstown record is considered one of the best long records in the State.

At Geneva the mean precipitation for twenty-five years, between 1850 and 1893, inclusive, is 30.86. In the period from 1883-1888, inclusive, the precipitation at Geneva was continuously below the mean, as indicated by the following:

	1883	1884	1885	1886	1887	1888
Storage	9.38	10.43	5.61	10.02	6.70	10.48
Growing	10.57	5.78	12.15	10.19	11.41	8.89
Replenishing	5.76	5.85	6.35	7.18	4.07	8.22
Total	25.71	22.06	24.11	27.39	22.18	27.59

For the years 1887 and 1888, it is probable that streams in the vicinity of Geneva did not flow to much exceed 2 to 4 inches on the catchment area.

At Glens Falls the mean precipitation for the years 1879 to 1898, inclusive, is 37.76 inches. The following is the record for the minimum years, 1880-1884, inclusive:

	1880	1881	1882	1883	1884
Storage	14.73	14.83	15.35	13.07	15.97
Growing	4.61	5.15	9.37	5.01	7.31
Replenishing	10.38	8.08	6.49	10.11	6.37
Total	29.72	28.06	31.21	28.19	29.65

A study of runoff records shows that the precipitation of the storage period largely controls the runoff for the year; hence, in a year like 1883, when the precipitation of the storage period was only 13.07 inches, specially when such a year has been preceded by years like 1880-1882, inclusive, the runoff will certainly be very low. Probably in 1883 it did not exceed, in the vicinity of Glens Falls, 6 inches. In 1884 the precipitation of the storage period was 2.90 inches greater than in the preceding year, but this small additional precipitation was probably mostly without effect on the streams because of low ground-water. It appears, therefore, entirely safe to assume that the runoff of streams in the vicinity of Glens Falls must have been quite as low in 1884 as in the previous year 1883.

At Gouverneur the total precipitation of the year 1838 was 20.93 inches; of 1839, 18.87 inches, and of 1842, 17.06 inches. Assuming forestry conditions at that time in the vicinity of Gouverneur substantially as they now exist on the Hudson river catchment area, the runoff of the streams may have been 3 inches, or from deforested areas probably 2 inches.

At Ithaca the two lowest years of precipitation are 1884 and 1895, in both of which the total happens to be 26.98 inches. In 1846 the total of the storage period was 9.67 inches, the total for the year being 30.07 inches. It is probable that the extreme minimum runoff in the vicinity of Ithaca does not exceed 5 inches.

At Keene Valley the lowest precipitation recorded occurred in 1881, the total for that year being 28.20 inches. The precipitation of the storage period was 13.15 inches. The totals of the previous years, 1879 and 1880, were 32.15 and 33.32 inches, respectively. The runoff for 1881 probably did not exceed 8.9 inches.

At Lowville the period of lowest precipitation was for the years 1843-1846, inclusive. The following are the figures for those years:

	1843	1844	1845	1846
Storage	7.06	11.53	12.90	9.76
Growing	12.12	7.64	8.30	5.78
Replenishing	8.30	7.34	9.60	11.63
Total	27.48	26.51	30.80	27.17

A marked peculiarity of this Lowville period is the low precipitation of the storage period for all the years included. Taking this into account, it is probable that for the years 1845 and 1846 the runoff in the vicinity of Lowville was very low. In 1845 it may have reached 8 inches, but for 1846 it is doubtful if it exceeded 5 or 6 inches. These conclusions, it must be understood, are based on present conditions of forestation. In case there were much larger forest areas in that vicinity at that time, the runoffs may have been somewhat larger.

At Mexico the total precipitation for the year 1840 was 20.21 inches, the storage period of that year being 9.73 inches. The runoff probably did not exceed 2 inches.

At Mount Morris the total precipitation of the year 1891 was 23.69 inches, that of the storage period being 10.24 inches. In 1895 the total was 25.05 inches, the storage period giving 11.95 inches. From the writer's personal knowledge of the subject he has no hesitation in saying that in 1895 streams in the vicinity of Mount Morris did not run to exceed a total of about 3 to 4 inches.

The year 1895 was generally a year of low precipitation throughout the whole State. Thus, at Newark Valley the total was 28.40 inches; at New Lisbon, the total was 29.93; at North Hammond, the total was 29.80, and so on. An extended analysis of the precipitation records shows that for a large portion of the State of New York the runoff of 1895 did not exceed 6 to 12 inches on the catchment areas. At some places the runoffs were less than 6 inches. At Onondaga Hollow the year of minimum precipitation occurred in 1841, having been preceded by several years of rather low rainfall. Streams in that vicinity probably do not exceed 6 inches runoff in years of minimum precipitation.

At Oswego the precipitation sank to 26.15 inches in 1855 and to 23.46 in 1887; in 1889 it was 30.39 inches. In 1887 the total for the storage period was 10.55 inches. It is doubtful if the runoff at Oswego exceeded about 2 to 4 inches for that year.

At Oxford we have the following record for the years 1832-1834, inclusive:

	1832	1833	1834
Storage	13.72	14.65	9.62
Growing	8.71	9.61	11.75
Replenishing	5.64	10.69	6.99
Total	28.07	34.95	28.36

The low precipitation of the storage period of the water year 1834 indicates runoffs in the vicinity of Oxford for that year of perhaps 5 inches.

At Palermo, where there is a continuous record from 1854-1898, inclusive, there are several years in which the precipitation is given considerably below 30 inches, as for instance in 1871, 27.81 inches; in 1875, 28.11 inches; in 1881, 26.37 inches; in 1882, 28.86 inches, and in 1895, 25.97 inches. The precipitation of the storage period of 1895 was only 10.15 inches. It is probable that for that year streams in the vicinity of Palermo did not exceed a runoff of 2 inches.

At Penn Yan there is a continuous record from 1829-1867, inclusive, the mean of the whole period being 27.93 inches. There are several periods of from three to six years when the rainfall was less than the average. So marked is this that it seems safe to assume that streams in the vicinity of Penn Yan do not ordinarily run more than from 4 to 6 inches on the catchment area. In 1854 the total precipitation was 19.66 inches. There are several years in which the total precipitation at Penn Yan for the storage period has not exceeded from 8 to 9 inches.

At Pierpont Manor the totals for the years 1852-1854 are as follows: 1852, 30.93 inches; 1853, 27.57 inches, and for 1854, 28.89 inches. In 1862 the total precipitation was 28.15 inches.

At Plattsburg the total precipitation in 1858 was 29.11 inches and in 1859, 22.78 inches. In 1893 it was 25.69 inches, with a total of only 9.92 inches in the storage period. For 1895 the total was 29.75 inches. It is evident that the minimum runoff of streams in the vicinity of Plattsburg does not exceed 6 inches.

At Pompey the totals for the years 1836-1838 are as follows: For 1836, 24.22 inches; 1837, 28.37 inches, and for 1838, 24.82 inches.

At Port Ontario the total precipitation for 1855 was 26.15 inches; for 1871, 29.76 inches, and for 1872, 28.81 inches.

At Potsdam we have the following record for the years 1837-1839, inclusive:

	1837	1838	1839
Storage	10.70	10.19	7.75
Growing	7.91	9.57	10.20
Replenishing	9.63	7.44	4.67
Total	28.24	27.20	22.62

In 1895 the total precipitation at Potsdam was 31.83 inches.

At Poughkeepsie the total for the year 1895 was 31.53 inches.

At Rochester there is a continuous record from 1834-1898, inclusive. The mean precipitation for this whole period is 33.61 inches. For the period 1834-1840, inclusive, the total for each water year is considerably under the mean, as follows: In 1834, 20.37 inches; 1835, 28.67 inches; 1836, 26.83 inches; 1837, 29.57 inches; 1838, 27.02 inches; 1839, 29.97 inches, and in 1840, 28.64 inches. In 1854 the total was 28.06 inches; in 1882, it was 26.74 inches; in 1885, 28.68 inches, and in 1887, only 20.61 inches. In 1888 the total rose to 27.34 inches, but the precipitation of the storage period was only 9.65 inches. It is probable that the runoff of streams in 1888 in the vicinity of Rochester did not exceed 3 to 4 inches. In 1895 the total at Rochester was 30.15 inches.

At Rome the year of minimum precipitation for the period 1890-1898, inclusive, was 1895, in which year the total of the storage period was 13.57 inches, and the total for the year 31.30 inches.

At Romulus the total for the storage period of 1895 was 10.87 inches, and the total for the year 27.76 inches.

At Rutland the period 1854-1856, inclusive, covered the years of lowest precipitation. The mean at that place from 1846-1861, inclusive, is 36.54 inches, but the total for 1854 was only 29.50 inches; for 1855, 32.07 inches, and for 1856, 28.83 inches. In 1856 the runoff of streams in the vicinity of Rutland could not have exceeded 5 inches.

At Sacket Harbor the mean 1864-1898, with four years omitted, is 32.50 inches. The period 1870-1876, inclusive, was far below the mean, the totals being as follows: 1870, 25.16 inches; 1871, 26.62 inches; 1872, 30.75 inches; 1873, 28.79 inches; 1874, 27.58 inches; 1875, 22.30 inches, and 1876, 25.42 inches. In 1875 the total precipitation of the storage period was 8.63 inches. The total runoff of that year in the vicinity of Sacket Harbor could not have much exceeded 2 inches.

The years 1879-1888 were also low years at Sacket Harbor. The following gives the record for 1886-1888, inclusive:

	1886	1887	1888
Storage	14.64	11.10	4.24
Growing	7.38	4.10	5.92
Replenishing	8.82	7.96	14.59
Total	30.84	23.16	24.75

These three years were preceded by several years in which the precipitation ranged from 22.50 inches to 28.87 inches, the year 1885 having shown a total of 26.83 inches. For the year 1895 the total at Sacket Harbor was 29.39 inches.

At South Canisteo the total for the year 1895 was 30.72 inches.

At Utica the mean of thirty-six years, included between 1826 and 1892, is 42.39 inches. The lowest year of this period was 1836, with a total of 31.75 inches.

At Watertown the mean of the period 1862-1898, inclusive, is 33.53 inches. There have been several short periods in which the precipitation has been far below the mean, as for instance 1874-1876, inclusive; 1879-1882, inclusive, and in the years 1887 and 1888. In 1875 the runoff of the storage period was 9.82 inches, the total for the year being 21.16 inches. The preceding remarks as to occasional very low runoff apply with force to conditions in the vicinity of Watertown. The minimum runoffs of the locality may be safely placed at from 4 to 6 inches.

At Waverly the total precipitation of the year 1895 was 25.10 inches.

At Williamstown, Mass., in the catchment area of Hoosic river, a tributary to the Hudson, there is a precipitation record covering certain years from 1855-1898, inclusive. The mean of the period is 39.41 inches. The year of minimum precipitation occurred in 1883, with a total of 29.55 inches for the year and 11.24 inches for the storage period.

The foregoing data of precipitation in the State are cited for the purpose of establishing the proposition that at times the runoffs of New York streams are very low, though undoubtedly the saving grace of the whole matter is that apparently the cycles of low precipitation do not affect the whole State at the same time. Indeed, it is only occasionally that catchment areas as large as the Upper Hudson, Black, Mohawk, Oswego, Allegheny, Susquehanna and Genesee rivers will be all subject to drought in the same year. A balancing of conditions is thus to some extent brought about. Nevertheless, while the preceding statement is fairly deducible from the data, it is the writer's opinion that if we had complete records it would be easily shown that the precipitation of nearly the entire State has in some year been on an average less than 30 inches, and that consequently the streams of the State, as a whole, did not average in such a year a runoff of more than about 7 to 10 inches. For individual catchment areas, like the Upper Genesee, where the total is 1070 square miles, or for the Oneida lake area, with a total above Brewerton of 1265 square miles, it is quite possible, and indeed probable, that the minimums affecting the whole area may sink somewhat lower. Probably 25 inches precipitation is not an unreasonable figure. If such a minimum should occur for the Oneida lake area, the runoff for the water year would not exceed 5 inches.[1]

Runoff

The laws of stream flow. A general statement of these laws from Mr Vermeule is as follows:

> The waters of the earth are taken up by the process which we call evaporation and formed into clouds, to be again precipitated to earth in the form of rain or snow. Of the water which falls upon the basin of a stream, a portion is evaporated directly by the sun; another large portion is taken up by plant growth and mostly transpired in vapor; still another portion, large in winter but very small in summer, finds its way over the surface directly

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[1] The foregoing in regard to minimum precipitation records in New York State has been abstracted from the writer's report on Special Water Supply Investigation, Appendix 16 of the Report of the Board of Engineers on Deep Waterways Between the Great Lakes and Atlantic Tidewaters. Executive Document No. 149 of the House of Representatives, 56th Congress, 2d Session.

into the stream, forming surface or flood flows; finally, another part sinks into the ground, to replenish the great reservoir from which plants are fed and stream flows maintained during the periods of slight rainfall, for the rainfall is frequently, for months together, much less than the combined demands of evaporation, plant growth, and stream flow. These demands are inexorable, and it is the ground storage which is called upon to supply them when rain fails to do so.

All of these ways of disposing of the rain which falls upon the earth may be classed as either evaporation or stream flow. Evaporation we take to include direct evaporation from the surface of the earth, or from water surfaces, and also the water taken up by vegetation, most of which is transpired as vapor, but a portion of which is taken permanently into the organisms of the plants. Stream flow includes the water which passes directly over the surface to the stream, and also that which is temporarily absorbed by the earth to be slowly discharged into the streams. A portion, usually extremely small, passes downward into the earth and appears neither as evaporation nor as stream flow. It is usually too small to be considered, and we may for our purposes assume that all of the rain which falls upon a given watershed and does not go off as stream flow is evaporated, using the latter word in the broadened sense which we have above described.

Probably one very important effect of forests is that upon the ground-water flow of streams. The stream with a catchment area wholly or largely in forests will show, without exception, a much better ground flow than one with the area denuded of forests. Neshaminy and Tohickon creeks may be cited as streams with the smallest amount of forest and the lowest curve of ground-water flow. Possibly this is not entirely due to forests, but it may be assumed that they bear some relation to the result.[1]

Units of measurement. Clemens Herschel, member American Society Civil Engineers, in his paper on Measuring Water[2] has defined the essential elements of this question in the following terms:

For most purposes the unit of volume, when using English measures, has been agreed upon in favor of the cubic foot, and

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[1] Examples of ground-water curves for the chief streams therein considered may be found in Mr. Vermeule's Report on the Flow of Streams, etc., in Final Rept. State Geologist of New Jersey, Vol. III. Trenton, 1894.

[2] Measuring Water, by Clemens Herschel; An address to the students of Rensselaer Polytechnic Institute, Troy, N. Y.

the nations of the earth being fortunately agreed upon their measures of time, have settled upon one second of time as the unit to use in measuring water. Nevertheless, the million United States gallons in twenty-four hours has become a standard for city water supply practice in the United States, and an acre in area covered an inch or a foot deep in a month or in a year is used in irrigation practice. But I would warn all engineers to be very slow to add to the number of such standards of measure for flowing water, and to abstain from and frown down such absurd standards as cubic yards per day, or tons weight of water per day, or even cubic feet per minute (instead of second), and other incongruities. . . As exercises in the art of arithmetic for children such computations may have value, but in the work of civil engineers they become a stumbling block to an advance of knowledge, and while unduly magnifying the unessentials, they indicate a deplorable lack of appreciation of the essentials of the art of the civil engineer.

Cubic measures do well enough for the contents of vessels, or as we may express it, for dealing with the science of hydrostatics. But so soon as the water to be measured is in motion, or so soon as the science of hydraulics has been entered upon, we must get clearly in our minds the idea of rates of flow, or of a procession of such cubic volumes passing a given point in a certain unit of time, as of a flow of so many cubic feet per second.

Very little can be added to what Mr Herschel has here said. It is a clear exposition of the whole subject. Such units as cubic feet per day and cubic miles have clearly no place in a modern paper on hydrology.

The unit of inches on the catchment area may, however, be pointed out as an exception to the foregoing general rule. This unit is exceedingly convenient because it admits of expressing rainfall and runoff in the same unit and without reference to the area. It brings out a number of relations not otherwise easily shown, as will be exhibited in discussing the tables accompanying this report.

Characteristics of the minimum runoff. Since the rainfall varies so widely, the runoff, which is a function of the rainfall, will also vary widely. On the Hudson river the maximum runoff of 33.08 inches, with a rainfall of 53.87 inches, occurred in 1892. The minimum, with a runoff of 17.46 inches and a rainfall of 36.37 inches, occurred in 1895. On the Genesee river the observed maximum rainfall of 47.79 inches, with a runoff of 19.38 inches, occurred in 1894.[1] The minimum rainfall of 31 inches, with a minimum runoff of 6.67 inches, occurred in 1895. These figures of rainfall indicate that either the extreme maximum or the extreme minimum rainfall has not yet occurred on the catchment area of this stream.

On the Muskingum river the maximum rainfall thus far observed is 56.97 inches, with a maximum runoff of 26.84 inches, which occurred in 1890. The observed minimum rainfall of 29.84 inches, with the corresponding minimum runoff of 4.9 inches, occurred in 1895. It is also doubtful if either the extreme maximum or the extreme minimum rainfall has been yet observed on the catchment area of this stream. As to whether the rainfall will go lower there is no certain way of determining. Moreover, 4.9 inches seems a very low runoff—and the runoff is not likely to be less than this figure. However, the runoff in any year depends very largely on the rainfall of the months from December to May, inclusive. There may possibly be, therefore, a lower annual runoff than 4.9 inches, even though the total rainfall should exceed 29.84 inches. The rainfall for December to May, inclusive, was 13.04 inches. The runoff for that period was 4.04 inches.

Division of streams into classes. The foregoing statements indicate that, as regards runoff, streams of the eastern part of the United States may be divided into classes. In the first class will fall streams where the maximum rainfall is from 50 to 60 inches, with corresponding runoff somewhat more than one half of the rainfall. The minimum runoff will be about one half the rainfall, or a little less. These statements, it may be again repeated, are general ones, to which there are exceptions.

Another class of streams, of which the Genesee and Muskingum rivers are typical, are those with maximum rainfall on their

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[1] In the combined Genesee river and Oatka creek record the maximum runoff of 21.22 inches occurred in 1890, when the rainfall is placed at 47.54 inches. This, however, is less reliable than the rainfall and runoff of 1894, which latter is accordingly given the preference.

catchments of 40 to 50 inches and with a corresponding runoff somewhat less than one half of the rainfall. The minimum runoff for these streams is from one fourth to one sixth of the corresponding rainfall, or from about 16 per cent to 25 per cent.

A further class, the far western streams, may be mentioned, in which the runoff is only a very small percentage of the rainfall, in some cases not more than 4 per cent to 5 per cent, or at times even less. Probably comprehensive study would further subdivide these streams, but the intention at present is to merely call attention to some of the more marked peculiarities as a basis for final detailed study.

If one takes the streams of the far west, as for instance Loup river, in Nebraska, with a catchment area of 13,542 square miles, where the rainfall in 1894, observed at 24 stations, was on an average only 12.84 inches and the runoff of the stream did not much exceed 1 inch, he will find entirely different conditions from those above stated. In many cases streams in that locality run much less than 1 inch. The South Platte, at Denver, Colo., in 1896, with a rainfall of 11.84 inches, ran 0.62 inch. The catchment area at this place is 3840 square miles. At Orchard, Colo., the South Platte, in 1898, with a rainfall of about 17 inches, ran 0.9 inch. The catchment area at this place is 12,260 square miles. The Republican river, at Junction, Nebr., with a rainfall of about 26 to 28 inches, in 1898, ran 0.39 inch. The catchment here is 25,837 square miles in extent.

The foregoing statements indicate the essential truth of the proposition that, broadly, each stream is a law unto itself. Any formula, for either maximum, average, or mean runoff, which does not take this into account is incomplete.

Estimation of runoff from rainfall diagrams. Can runoff of streams be estimated from diagrams of monthly rainfall? The writer has spent considerable time on this problem without arriving at any very satisfactory conclusion. For some months such a diagram may be made to fit quite closely, while for others, differences of as much as 2 or 3 inches appear. The conclusion of the writer is, therefore, that such diagrams are at the best crude approximations. Such study is, however, very fascinating, and it is not surprising that different hydrologists have attempted at various times its solution. Two lines of work may be mentioned. One is, by a combination of a large number of streams and their rainfall, to attempt to produce a universal formula. This, however, as has been already shown, leads to what is, in effect, a hodgepodge. Averages so applied " bring out class likenesses, to the exclusion of individual features."

The other method is to plat rainfall and runoff appearing monthly in inches, as abscissas and ordinates, respectively, and in this way to preserve the individual peculiarities of each stream. In some respects the most satisfactory way is to plat the rainfall and runoff of the storage, growing, and replenishing periods, thus grouping similar characteristics.

Storage in lakes. The runoff of a stream is very materially influenced by the number of lakes within its catchment area. If there are many, flood flows may be expected to be much smaller than they otherwise would be. Oswego river, as a marked stream with large lake pondage, may be discussed in this connection. The total catchment area of this stream is 5002 square miles. It issues from a region with a mean annual rainfall of from 30 to 40 inches and with heavy snowfalls, frequently melting suddenly at the end of winter. Nevertheless, the ordinary flood-flows do not exceed 4 cubic feet per second per square mile, and even extreme flood flows are only 6 to 7 cubic feet per second per square mile. As to why this is so is an interesting question which may be answered by considering the large temporary storage on the surfaces of the lakes, marshes and flat valleys in the Oswego area. In order to show this, the writer has prepared the following tabulations, in which appear the names of the several lakes, with their approximate catchment areas, areas of water surface, areas of flats and marsh, and total area of water surface, flats and marsh.

(1) *Seneca basin*

Name of Lake or River.	Catchment area, sq. mi.	Area of water surface, sq. mi.	Area of flats and marsh, sq. mi.	Total area of water surface, flats and marsh, sq. mi.
Canandaigua	175.0	18.6	8.0	26.6
Keuka	187.0	20.3	3.0?	23.3
Seneca	707.0	66.0	4.0?	70.0
Cayuga	1,593.0	66.8	2.0	68.8
Owasco	208.0	12.4	5.5	17.9
Skaneateles	73.0	12.8	0.5	13.3
Otisco	34.0	3.0	0.5	3.5
Cross	(1)	4.3	(2)	4.3
Onondaga	233.0	4.0	0.5	4.5
Seneca river	233.0	3.5	(2)	3.5
Montezuma marsh	......	....	45.0	45.0
Miscellaneous small ponds	......	3.5	....	3.5
Miscellaneous flat valleys	......	....	20.0	20.0
Total	3,433.0	215.2	89.0	304.2

(2) *Oneida basin*

Name of Lake or River.	Catchment area, sq. mi.	Area of water surface, sq. mi.	Area of flats and marsh, sq. mi.	Total area of water surface, flats and marsh, sq. mi.
Cazenovia	9.0	2.8	0.3	3.1
Oneida	1,265.0	80.0	120.0	200.0
Miscellaneous small ponds	......	5.9	....	5.9
Miscellaneous flat valleys	......	....	6.0	6.0
Oneida river	128.0	0.9	2.1	3.0
Total	4,835.0	304.8	217.4	522.2

(3) *Oswego basin*

Name of Lake or River.	Catchment area, sq. mi.	Area of water surface, sq. mi.	Area of flats and marsh, sq. mi.	Total area of water surface, flats and marsh, sq. mi.
Miscellaneous small ponds	......	2.5	....	2.5
Oswego river	167.0	2.0	3.3	5.3
Total	5,002.0	309.3	220.7	530.0

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(1) Enlargement of Seneca river. (2) Area of flats and marsh included in Montezuma marsh.

The foregoing tabulation is mostly self-explanatory, and attention is merely directed to the footings, from which it is learned that the total area of water surface is approximately 310 square miles; the total area of flats and marsh, 221 square miles, and the total of water surface flats and marsh, 530 square miles.

Dividing the total area of water surface, flats and marsh by 5002, the area of catchment basin, it appears that the total area of water surface, flats and marsh is 10.6 per cent of the whole catchment. We do not often have flood runoffs in New York exceeding 3 or 4 inches in depth over the catchment area, but 4 inches in depth over the Oswego area would be only 37.7 inches on the pondage area of 530 square miles.

Several of the large lakes of this basin fluctuate considerably between high and low water. From tabulations given in the Report of the Superintendent of Public Works it is shown that the fluctuation of Skaneateles lake, which is drawn upon as a canal reservoir, is as much as 5 feet, and of Otisco lake, about 4.5 feet. According to figures given in the Eleventh Annual Report of the State Board of Health of New York it appears that the maximum fluctuation of Cayuga lake for a long series of years has been 7.56 feet, although this large fluctuation may be possibly partly due to work done by the State in cutting out the channel of Seneca river for the purpose of draining the Montezuma marsh. Ordinarily the fluctuation of Cayuga lake does not exceed between 2 and 3 feet. From March 4, 1887, to December 2 of that year, the lake fell 2.93 feet, and from March, 1889, to December of that year, the fluctuation was 2.3 feet. The figures are not at hand giving the fluctuation of Canandaigua, Keuka, Seneca and the other large lakes of this catchment, but it may be certainly assumed that they do not vary greatly from the preceding figures of Skaneateles, Otisco and Cayuga lakes. By way of illustrating how these great natural reservoirs tend to prevent floods, it may be mentioned that the configuration of Cayuga outlet with relation to Clyde river is such that frequently, when there are heavy rainfalls in the catchment area of Clyde river, Cayuga lake being at the same time at a low level, the entire flood flow of Clyde river is discharged into Cayuga lake without affecting Seneca river below the mouth of Clyde river at all. It is undoubtedly due to this fact that fall floods on Oswego river are almost entirely unknown.

The evaporation of the Oswego river catchment area is exceedingly large—about 28 inches—whence it results that the runoff from a mean annual rainfall of from 36 to 37 inches does not exceed about 9 or 10 inches.[1]

Computation of annual runoff. No general rule can be formulated for computing annual runoff. The formulas of Mr Vermeule are excellent formulas of the purely empirical class, applying fairly well to many streams in the northeastern part of the United States, but they do not apply at all to streams of the middle west and far west. Nor do they apply to some streams in the northeastern section. Nevertheless, they take into account the ground water, and are the most useful formulas thus far devised. It may be mentioned that Mr Vermeule specially disclaims any intention of working out any formulas applying outside of the State of New Jersey. His general formula is in the nature of a suggestion.

Discrepancies in computation of runoff. In computing the runoff of various streams small discrepancies will continually appear, and when such do not exceed 1 to 2 inches they are outside the limit of discussion. The question does not admit of such minuteness as to permit the discussion of small differences, although a difference of 2 inches on several thousand square miles would be much less serious than on the usual municipal catchment area of from 20 to 100 square miles. The size of the catchment area should, therefore, in this particular be taken into account.

Moreover, the runoff of streams has thus far been almost universally over-estimated. Only a few were really down to the actual fact. Probably in no department of professional work are there more things to be taken into account than here.

Actual gagings preferable to general studies. While on the general subject of the computation of runoff the writer may repeat

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[1] The preceding chapter has been abstracted from the writer's report on Special Water Supply Investigation to the Board of Engineers on Deep Waterways.

what he has said in his report to the United States Board of Engineers on Deep Waterways, viz:

> The data for estimating the water supply of a large canal, specially when on a large scale, should be based, when such data are available, upon actual gagings of streams, rather than on general considerations derived from study of the rainfall alone. An examination of a large number of estimates of canal water supplies, based on the usual method, shows that rainfall data alone are in close cases inadequate for solving a water-supply problem of the magnitude of the one now under consideration. When, however, actual gagings of the streams, extending over a sufficient number of years, are available, there is no reason why a water-supply problem on a large scale may not be worked out with the precision of a proposition in mathematics.

What is here said in regard to water supplies for canals is equally true as regards all other water supplies, either municipal or for water power, etc. Farther on in the same chapter it is stated:

> It is not intended to say, however, that rainfall data are not of use in a hydrologic discussion. When, as in the present case, in addition to stream gagings an extended series of such data are available, the argument is made doubly good and the demonstration strengthened.

When records of gagings are available the computation becomes very simple. It is merely a matter of simple addition and subtraction.

The complete data required in order to compute the safe possible yield of a stream are as follows:

1) The catchment area.

2) The rainfall of the minimum year, as well as for a series of years.

3) A ground-water diagram of the stream or, lacking such, a diagram for a neighboring stream lying in the same or a similar geologic formation, and, so far as possible, with similar conditions of forestation.

4) The available storage capacity of the stream.

5) The loss by water surface evaporation from the reservoirs, together with an estimate of the loss by percolation.

The data required for ordinary computations may be frequently limited to the totals of the storage, growing, and replenishing periods, although when ground water is to be taken into account the monthly data should be given.

Formulas for runoff. At the risk of being considered somewhat elementary the writer will give the more important of the formulas for runoff, expressed in terms of inches on the catchment area:

$$I_m = \frac{n \times Q \times 86400 \times 12}{A \times 640 \times 43560} \qquad (5)$$

Whence we deduce,

$$I_m = \frac{n \times Q \times C_1}{A} \qquad (6)$$

Also,

$$I_y = \frac{Q \times C_2}{A} \qquad (7)$$

and

$$D = \frac{Q}{A} \qquad (8)$$

To change gallons per day into inches per month we have:

$$I_m = n \times G \times C_3 \qquad (9)$$

Also,

$$G = \frac{I_m}{n \times C_3} \qquad (10)$$

In the reports of the United States Geological Survey the discharge of streams is sometimes given in acre-feet per month. To reduce such to inches per month, we have, when total acre-feet are given:

$$I_m = \frac{B \times C_4}{A} \qquad (11)$$

In these formulas,

A=area of catchment in square miles.

B=total acre-feet per month.

D=cubic feet per second per square mile.

G=gallons per day.

I_m=inches in depth per month on the catchment area.

I_y =inches in depth per year on the catchment area.

n=number of days per month.

Q=cubic feet per second flowing from the catchment area, as determined by gagings.

C_1= constant $=\left(\frac{86400\times 12}{640\times 43560}\right)$.

C_2= constant $=\left(\frac{86400\times 12\times 365}{640\times 43560}\right)$.

C_3= constant $=\left(\frac{12}{7.48\times 640\times 43560}\right)$.

C_4= constant $=\left(\frac{12}{640}\right)$.

The constants, C_1, C_2, C_3, and C_4, are left in form for logarithmic computation. For a given case, catchment area is constant, and A, in the final logarithmic form, will be combined with these.

It is sometimes convenient to have a formula for converting discharge in cubic feet per second into inches draining from an area in 24 hours and *vice versa*. The following formulas answer to these conditions. In these formulas,

Q=discharge in cubic feet per second.

d=discharge over catchment, in depths in inches in 24 hours.

A=catchment area in square miles.

$$d=\frac{Q}{26.89\ A} \qquad (12)$$

$$\text{and } Q=26.89\ A\times d. \qquad (13)$$

This formula is convenient for use in considering floods.[1]

Maximum discharge formulas. A considerable number of such have been worked out, but the authors have taken into account so few of the controlling conditions, that they are, at the best, mostly only crude guides, and the writer long ago gave up their use, except in cases where only the roughest approximation was required. Two exceptions may, however, from the peculiar form of the coefficient, be briefly noted, viz:

$$\text{Dickens's formula, } D=C\sqrt{M^3}\text{; and} \qquad (14)$$

$$\text{Ryves's formula, } D=C\sqrt{M^2}. \qquad (15)$$

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[1] Irrigation Manual, by Lieut. Gen. J. Mullins (published for Madras Government), 1890.

In these formulas, D=discharge in cubic feet per second; C=a coefficient, depending for its value upon rainfall, soil, topographical slope, elevation, size of the stream, shape of the catchment, etc. and M=area of the catchment in square miles.

Coefficient table for representative areas. In Mullins's Irrigation Manual there are given tables for the value of the coefficients of these two formulas, together with the corresponding depth in inches, drained off from the given areas, and the discharges in cubic feet per second. These two formulas are cited because they take into account the principle of the sliding coefficient, as does the Kutter formula, a principle which, all things considered, is the most useful thus far devised. It is true that maximum discharge formulas have been devised taking into account average slope, depth, and intensity of rainfall, area of the mountainous part of the catchment and area of the flat part of the same in square miles, and length of stream from source to point of discharge. These formulas, however, also involve from one to two coefficients and become complicated in use without, it is believed, any special gain over the simpler expressions cited. The formulas of Dickens and Ryves, which comprise within the coefficient C everything included in the more complicated formulas, were the forerunners of formulas of this class.

Cooley's formulas. In an able paper[1] Mr George W. Cooley, C. E., gives the following formulas for runoff:

For a catchment without lakes,

$$F = 0.844\ LRC. \qquad (16)$$

For a catchment with large lakes as receiving reservoirs,

$$F = \left(R + \frac{LRC}{W} - E\right) \times 0.844\ W. \qquad (17)$$

In which, F = flow in cubic feet per second.
R = precipitation in feet.
L = land surface of catchment in square miles.
W = water surface of reservoirs in square miles.
E = evaporation in feet.
C = coefficient of available rainfall.

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[1] Hydrology of the Lake Minnetonka Watershed, by George W. Cooley, C. E.; Monthly Weather Review, January, 1899.

The constant 0.844 is equal to the number of feet in a square mile divided by the seconds in a year.

In these formulas the sliding coefficient is also recognized. The results, however, are based on averages, although it seems clear enough that, in either power or water supply works, what is wanted is the minimum runoff for a year or a series of years. For instance, the minimum rainfall at Lake Minnetonka in 1889 was only 18.36 inches, while the maximum in 1892 was 37.90 inches, or a little more than double the minimum. It is evident enough to any person who has gaged streams extensively that the runoff in 1889 must have been very much less than in 1892. In the absence of statements as to the amount of runoff in 1889, the writer can only estimate it, but he doubts if it were over 10 per cent to 12 per cent of the rainfall. Probably about 2 inches is not far from the mark. What is wanted, therefore, is a concise statement, not only in this case but in every other, of the runoff of the year or series of years of minimum rainfall.

Danger of using averages. The writer has dwelt upon the foregoing point somewhat because only a few of the more advanced students of hydrology have thus far fully appreciated its importance. A very large proportion of all the papers and reports prepared in the last ten years have proceeded on the supposition that safe deductions could be made from an average runoff. It is needless to say that all such are, without exception, erroneous. What is wanted is a clear statement of the minimum, together with the longest period which such minimum may be expected to occupy. A study of the meteorological records of the State of New York shows that the minimum period may be expected frequently to extend over three years. In the writer's report to the United States Board of Engineers on Deep Waterways, in the chapter on the Meteorology of New York and the relation of precipitation to runoff, a large number of specific cases are cited, but space will not be taken here to discuss them. This proposition is true for other regions than the State of New York.

Danger of using percentages. A much greater danger arises from the use of percentage of rainfall appearing in runoff. In many reports and papers it is assumed that averages of a series of percentages can be safely taken. The following illustration, with five cases drawn from observation, may be taken to show that this is erroneous:

RUNOFF, PER CENT OF RAINFALL

Case	Rainfall	Runoff	Per cent
	Inches	*Inches*	
1.	44.3	20.1	45.37
2.	62.5	35.0	56.00
3.	16.2	1.2	7.41
4.	24.3	2.5	10.29
5.	40.4	13.1	32.42
	187.7	71.9	5)151.49
			30.29

$$\frac{\text{Runoff}}{\text{Rainfall}}=\frac{71.9}{187.7}=38.31$$

Difference= 8.02

Runoff coefficient misleading. As a corollary to the preceding proposition, it follows that the ratio between annual rainfall and runoff, known as the "runoff coefficient or factor," is essentially misleading. A realization of this fact has led the writer, in his report to the United States Board of Engineers on Deep Waterways, to practically expurgate this statement, or anything approximating to it, from his report. The expressions, "average runoff" and "percentage of the rainfall," do not appear.

Relation between total runoff and runoff of storage period. Attention may also be again directed to the fact that the total runoff of a stream in any given year depends very largely on the runoff of what may be termed the "storage period." Usually about 0.55 to 0.75 of the total rainfall of this period appears as runoff in the stream, while for the summer, or growing period, not more than about 0.1 of the rainfall appears. This great difference is due to greater evaporation, as well as to the absorption of water by plants during this period. The total amount for the year which will appear as runoff in the stream will depend, therefore, very largely on whether or not the rainfall of the storage period—December to May, inclusive—is large or small. If the winter rainfall is relatively large, the runoff will also be relatively large, even though the total rainfall for the year is small. This fact must be taken into account in estimating the value of streams. Whether any given stream is low during the summer months or has then a well-sustained flow will depend very largely on the rainfall of the month of May. When the May rainfall is heavy enough to produce full ground water, the flow is likely to be well sustained, even though the rainfall is comparatively low during the summer months following. If, on the contrary, the May rainfall is so low as to leave a deficiency in ground water for that month, the flow will be low during the summer, even though the rainfall is large.

The foregoing explains why for certain years the runoff of a stream may be relatively small, even with rainfall considerably above the average.

To more particularly illustrate this, assume a stream with, say, 6 inches of ground-water flow and further assume that on any convenient date the ground water is practically depleted. Under these circumstances, the 6 inches of ground water must fill up before any very large flow can occur. On the other hand, we may consider the sequence of the rainfall such as to leave full ground water, whence it results that there will be a much larger runoff, even though rainfall and other conditions are the same.

What is wanted in a stream, therefore, is as large a ground flow as possible, with small evaporation. That there are very great differences in streams in this respect may be easily seen by examining a series of tables of stream flow. It may be remarked that these two conditions are obtained only on a forested area, for proof of which see Bulletin No. 7, Department of Agriculture, Forest Influences.

Effect of low ground water. Moreover, when rainfall is below the mean for several months, the ground water may be expected to become continuously lower. This is a subject about which comparatively little is known, although the data are very important in estimating the permanency of a stream. Aside from Mr Vermeule's, the most satisfactory discussion which the writer has seen is that of Mr W. S. Auchincloss.[1] This paper, while too long to be abstracted, is nevertheless very interesting, because the author recognizes the limitations of averages. On page 10, after giving a table of the average rise of his sublake, he states:

> Since the table was built up from averages, we must not expect it to emphasize special variations, for the grouping of averages resembles the grouping of pictures in composite photography. The combination invariably brings out class likenesses to the exclusion of individual features. Thus the table loses sight of an extraordinary year like 1889—full of plus quantities—also seasons of drought, like 1894 and 1895. It, however, clearly shows that influx has a tendency to prevail between February and July, inclusive, and efflux to hold the mastery during the remaining months of the year.

Though this paper does not fully recognize the wide variation occurring in different localities, this is probably not due to oversight, but merely to the fact that the author was discussing a specific case. The observations recorded were made at Bryn Mawr, Pa. The paper is valuable and well worth the attention of students of hydrology.

Vermeule's formulas. These formulas are somewhat different from those previously considered. Mr Vermeule claims to have discovered a relation between evaporation and mean annual temperature. For the relation between annual evaporation and annual precipitation on Sudbury, Croton and Passaic rivers he gives the following:

$$E = 15.50 + 0.16\ R, \qquad (18)$$

In which E = the annual evaporation and R = the annual rainfall.

In the original publication of this formula, in the Report of the Geological Survey of New Jersey,[2] Mr Vermeule allowed for other catchment areas an increase or decrease of 5 per cent from values

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[1] On Waters within the Earth and Laws of Rainflow, by W. S. Auchincloss, C. E. Philadelphia, 1897.

[2] Report on Water Supply, Water Power, the Flow of Streams, and Attendant Phenomena, by C. C. Vermeule: Final Report State Geologist of New Jersey, Vol. III. Trenton, 1894.

given for evaporation on the Sudbury, Croton and Passaic rivers. The following is his general formula for all streams:

$$E = (15.50 + 0.16\ R)\ (0.05\ T - 1.48) \tag{19}$$

This, however, he states is merely a suggestion. His purpose is to deduce laws which hold for the State of New Jersey alone.

In these formulas the evaporation is taken to include all the various losses of water to which a catchment area is subject, including direct evaporation as well as water absorbed and transpired by plant growth, etc. Hence,

$$F\ (\text{runoff}) = R - E. \tag{20}$$

Mr Vermeule gives the following formulas for the Sudbury, Croton and Passaic rivers:

$$\text{December–May, } E = 4.20 + 0.12\ R; \tag{21}$$

$$\text{June–November, } E = 11.30 + 0.20\ R. \tag{22}$$

These formulas take into account the fact that evaporation is low in the winter months and high during the summer.

Mr Vermeule also gives the following formula for computing monthly evaporation from the monthly rainfall for Sudbury, Croton and Passaic catchment areas:

[e=monthly evaporation; r=monthly rainfall.]

December	$e = 0.42 + 0.10\ r$	
January	$e = 0.27 + 0.10\ r$	
February	$e = 0.30 + 0.10\ r$	
March	$e = 0.48 + 0.10\ r$	
April	$e = 0.87 + 0.10\ r$	
May	$e = 1.87 + 0.20\ r$	
June	$e = 2.50 + 0.25\ r$	(23)
July	$e = 3.00 + 0.30\ r$	
August	$e = 2.62 + 0.25\ r$	
September	$e = 1.63 + 0.20\ r$	
October	$e = 0.88 + 0.12\ r$	
November	$e = 0.66 + 0.10\ r$	
Year	$e = 15.50 + 0.16\ r$	

To obtain the monthly evaporation for other streams the results obtained are multiplied by the following:

$$(0.05\ T - 1.48)$$

In which T=mean annual temperature.

At this point Mr Vermeule was confronted by the difficulty of ground storage. In regard to the effect of this it may be mentioned that, with rainfall above the average continuously for several years, ground water may be expected to stand above its average hight, yielding to streams the maximum flow possible to ground water. On the other hand, when the rainfall is below the average for a number of years ground-water flow will be lower, becoming less and less as the rainfall approaches the minimum. It is very important that this fact be taken into account, because without it one is certain to fall into error. The formulas for average depletion may be given as follows:

$$d_2 = d_1 + e + f - r\,; \tag{24}$$

$$d = \frac{f}{2} + d_1 - \frac{\mathrm{r} - \mathrm{e}}{2}. \tag{25}$$

In which d_1 and d_2=depletion at end of previous month and for the month under consideration; d=average depletion; e and r=monthly evaporation and monthly rainfall, respectively, and f=computed monthly flow.

The foregoing does not fully express the use of these formulas, but as all that is wanted at this time is an illustration of methods, this brief account may be deemed sufficient.

Mr Vermeule gives a diagram showing ground flow for the several different streams mentioned for a given depletion, which is to be used in conjunction with the foregoing formulas. In his opinion the diagrams present advantages over a ground-flow formula with varying constants and coefficients for different streams, being more readily compared and insuring greater accuracy. Later, in his Report on Forests,[1] Mr Vermeule modifies his formula, as follows:

$$\mathrm{E} = (11 + 0.29\ \mathrm{R})\ \mathrm{M}. \tag{26}$$

In which E=evaporation, R=rainfall, and M is a factor depending upon the mean temperature of the atmosphere. The writer understands Mr Vermeule to say that this is also an expression for annual evaporation.

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[1] Report on Forests, by C. C. Vermeule: Ann. Rept. State Geologist New Jersey for year 1899. Trenton, 1900.

Values of M for given mean annual temperatures are as follows:

40°, 0.77; 41°, 0.79; 42°, 0.82; 43°, 0.85; 44°, 0.88; 45°, 0.91; 46°, 0.94; 47°, 0.97; 48°, 1; 49°, 1.03; 50°, 1.07; 51°, 1.10; 52°, 1.14; 53°, 1.18; 54°, 1.22; 55°, 1.26; 56°, 1.30; 57°, 1.34; 58°, 1.39; 59°, 1.43; 60°, 1.47; 61°, 1.51.

In a table on page 149 of the Report on Forests Mr Vermeule compares observed annual evaporation with computed annual evaporation. The following are some of the differences which appear:

On the Genesee river the observed annual evaporation is 27.2 inches; computed annual evaporation, 20.6 inches; the observed annual evaporation, therefore, is 6.6 inches, or 32 per cent, greater than the estimated annual evaporation. On the Musconetcong river the observed, as compared with the computed evaporation, is 13 per cent less; on the Pequest it is 17 per cent less; on the Paulinskill it is 14 per cent less; on the Tohickon, 32 per cent less; on the Neshaminy, 16 per cent less; on the Perkiomen, 17 per cent less; on the Desplaines, 21 per cent greater; on the Kansas, 15 per cent greater; on the Upper Hudson, 10 per cent greater; on Hemlock lake, 18 per cent less; on the Potomac, 17 per cent less; on the Savannah, 13 per cent less. For the rest of the streams cited in the table the agreement is closer than this.

The observed annual evaporation is 32 per cent greater than the computed annual evaporation on the Genesee river and 32 per cent less on Tohickon creek—a range of 64 per cent. Somewhat similar differences are found on other streams where the gagings are approximately right. As to the gagings referred to in the Report on Forests, the writer will show farther on in this paper that gagings of the Genesee and Hudson rivers are, on the whole, probably the best thus far made in the United States. Tohickon, Neshaminy and Perkiomen creeks have been gaged by Francis weirs, and are, with the exception of Tohickon, considered approximately right. The difficulty here is probably in the flood flows. The writer understands that Mr Vermeule used the Francis formula for a sharp-crested weir. The gagings of Sudbury, Cochituate and Mystic rivers have been deduced, it is believed, by Mr Francis's formula for the Merrimac dam. As to the Desplaines river, a discharge curve determined by current meter has, it is believed, been applied.[1] The English streams cited, Lea, Wandle, Thames, etc. have probably been gaged by a sharp-crested weir, and the others mostly by the current meter and a rating table.

Russell's formulas. Mr Thomas Russell[2] gives the following formulas for the runoff of the Ohio, Upper Mississippi, and Upper and Middle Missouri valleys, in terms of the annual rainfall. For the Ohio river the formula is as follows:

$$O=0.600+0.95\ R-0.90\ R\ (0.975\ e-0.421\ e^2+0.626\ e^3). \quad (27)$$

For the Upper Mississippi it is:

$$O=0.50+0.93\ R-0.88\ R\ (1.131\ e-0.383\ e^2). \quad (28)$$

For the Upper and Middle Missouri it is:

$$O=0.12+0.98\ R-0.93\ R\ (0.91\ e-0.220\ e^2+0.009\ e^3). \quad (29)$$

In these formulas R is the rainfall for the month in cubic miles; e is the quantity of water required to saturate the air at any time, equal to the difference between what the air contains and the amount if it was saturated; and O is the outflow or runoff.

These formulas are interesting in the present connection, because they recognize the fact that every stream must have its own formula. The variation in runoff on the Ohio, Mississippi and Missouri rivers will be observed on inspection of the formulas. Like all formulas of this class they are subject to considerable variation. In the month of October, 1881, the computed outflow of the Missouri river was 4.9 cubic miles and the observed flow was 1.6 cubic miles, a difference of 3.3 cubic miles.

Relation between catchment area and maximum, minimum and mean runoff. It is quite common for hydrologists to assume that there is a relation between catchment area and maximum, minimum and mean runoff, the general proposition being that mean

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[1] Data Pertaining to Rainfall and Stream Flow, by Thomas T. Johnston: Jour. Western Soc. Engrs., Vol. I, No. 3, June, 1896.

[2] Rainfall and River Outflow in the Mississippi Valley, by Thomas Russell: Ann. Rept. Chief Signal Officer for the year 1889, Part I, Appendix 14.

annual runoff varies inversely as the size of the catchment, and that maximum runoff, or flood flow, varies directly as the size of the catchment.

In order to gain some idea as to the applicability of this proposition, the résumé of discharge data, in the Twentieth Annual Report of the United States Geological Survey, pages 46–64, has been examined. This table includes about 225 streams in various portions of the United States, with records ranging from 18 to 20 years in length to 1 year. A few of the best-known streams—as, for instance, the Croton and Sudbury—are not given in detail, although the large number included in this table, it is believed, is sufficient to settle definitely this question. Only a very few of the results will be referred to here.

In the first place, it appears certain that with equal rainfall there is no very definite relation between size of catchment area and mean annual runoff. For instance, the Kennebec, at Waterville, Me., with a catchment area of 4410 square miles, has a mean annual runoff for 6 years of 22.4 inches. The Cobbosseecontee, at Gardner, Me., with a catchment area of 230 square miles, has a mean annual runoff for 6 years of 18.5 inches. The Androscoggin, at Rumford Falls, Me., with a catchment area of 2220 square miles, has for 6 years a mean annual runoff of 24.2 inches. The Presumpscot, at Sebago Lake, Me., with a catchment of 470 square miles, has a mean annual runoff for 11 years of 21 inches. The Merrimac, at Lawrence, Mass., with a catchment area of 4553 square miles, has a mean annual runoff for 9 years of 21.3 inches. Aside from the Androscoggin river these five streams support the proposition that the runoff varies in some degree directly as the catchment area instead of inversely.

As to the maximum runoff, or flood flow, there is apparently some slight relation, although even this is less definite than has usually been assumed.

As to the minimum runoff, there is apparently no relation, extremely small flows happening on large streams as well as on the smallest. There is, however, much more definitely a relation between the runoff and the rainfall, runoff increasing as rainfall increases, and conversely.

As regards the division of streams into classes in proportion to size of catchment area, it appears, therefore, that aside from floods one is not, on present information, justified in such classification, and even in cases of floods it is quite probable that there are other considerations of such importance as to render a classification of this character inexpedient.

Since there is no very definite relation between size of catchment and runoff there is no reason why comparison may not be made of streams having such large difference in size of catchment. For some streams, as for instance, Pequannock river, where the slopes are very steep, the runoff is somewhat higher than it would be with other conditions the same, but with flatter slopes. But generally the degree of forestation and other elements exercise so much more important an influence that a comparison, without regard to size of catchment area, may be legitimately made. Nevertheless, this proposition is possibly debatable, and for the present the conclusions drawn are tentative merely.

The extreme low-water period. In the discussion of the streams the writer has given the low water of the minimum year, but this does not usually include the extreme low-water period, which is in almost every case much more than one year. Space will not be taken to show the extreme low-water periods of all the streams. It is considered that illustrations from Muskingum and Genesee rivers are sufficient.

On the Muskingum river three low-water periods have occurred during the time covered by the gagings. The first was from December, 1887, to November, 1889, inclusive, a period of twenty-four months, during which the total runoff was 18.55 inches, or if we assume a reservoir on said stream of 20 square miles water surface, the total net runoff becomes 18.15 inches. The computations of evaporation, etc. for such a reservoir, neglecting variation in water surface, are as follows. Assume an annual evaporation of 40 inches and with distribution for the several months as per column (1) in the following tabulation. Since the water surface area is 20 square miles, it becomes 20/5828 of the whole, or 1/292. Hence water surface evaporation is 1/292 or 40 inches, and making the computation for each month, we have the quantities as per column (2):

TOTAL EVAPORATION AND EVAPORATION PER SQUARE MILE OF WATER SURFACE IN MUSKINGUM BASIN

Month	(1) Total evaporation	(2) Evaporation per square mile of water surface
January	1.00	0.0034
February	1.10	.0037
March	1.70	.0058
April	3.00	.01029
May	4.60	.01578
June	5.65	.01938
July	6.10	.02092
August	5.60	.01921
September	4.15	.01423
October	3.35	.01149
November	2.25	.00772
December	1.50	.00514
	40.00	....

With some allowance for percolation, leakage, etc. the total is taken at 0.40 of an inch per year. Analyzing the first period, we find that for 24 months there was an average flow of 0.76 inch per month, for 12 months an average flow of 0.67 inch, and for 9 months an average flow of 0.43 inch.

The second low-water period was from May, 1891, to January, 1893, inclusive, a period of 21 months, during which time the net runoff was 17.2 inches, yielding for the whole 21 months an average of 0.82 inch and for 7 months an average of 0.36 inch.

The most extreme low-water period was from April, 1894, to November, 1895, inclusive, a period of 20 months, during which time the net runoff did not exceed under the assumed conditions 7.09 inches. The average runoff for 20 months was 0.354 inch and for 7 months 0.116 inch.

On Genesee river there have been two low-water periods during the time covered by the gagings. The first was from June, 1894, to February, 1896, a period of 21 months, during which time there was a gross runoff of 13.02 inches. Evaporation has been computed for a proposed reservoir of 12.4 square miles water-surface area, with allowance for actual hight of water during the different months. On this basis and with a small allowance for percolation, leakage, etc. the total evaporation loss for the 21 months becomes 0.65 inch, leaving a net runoff of 12.37 inches. The average runoff for 21 months was 0.59 inch, or, if we assume 1.43 inches left in reservoir at end of period, the average allowable runoff becomes 0.52 inch. For 10 months, with some allowance, the average runoff is 0.30 inch and for 7 months 0.10 inch.

The second period was from June, 1896, to December, 1897, a period of 19 months, during which time the net runoff was 13.24 inches. The average runoff for 19 months, with 1.24 inches left in reservoir at end of the period, was 0.63 inch; for 8 months, 0.31 inch, and for 6 months, 0.17 inch. These figures, without being exhaustive, show that the Genesee river is a somewhat better water yielder than the Muskingum river. The relation of the rainfalls is shown in the tables.

A large number of other interesting and valuable tabulations could be drawn from these data, specially those relating to storage. In any case, enough has been said to sustain the statement that streams vary, not only as regards their total capability of yielding water, but as regards their distribution. In order to develop a stream to its maximum capacity for either water power or municipal purposes, it is absolutely indispensable to have a series of carefully prepared gagings. Lacking these, there should be gathered as long a rainfall record as possible, from which, by comparison, the approximate runoff of the stream may be computed. A carefully taken series of gagings is, however, in every way preferable.

We may consider the following data from the Hudson and Genesee rivers:

RAINFALL, RUNOFF, EVAPORATION AND VARIATION FROM THE MEAN ON HUDSON AND GENESEE RIVERS

Hudson river

Year	Rainfall	Variation from mean	Runoff	Variation from mean	Evaporation	Variation from mean
1888	43.92	—1.02	23.64	—0.34	20.28	—0.68
1889	42.96	—1.98	21.71	—2.27	21.25	+0.29
1890	50.35	+5.41	28.56	+4.58	21.79	+0.83
1891	42.96	—1.98	20.56	—3.42	22.40	+1.44
1892	53.87	+8.93	33.08	+9.10	20.79	—0.17
1893	42.18	—2.76	21.91	—2.07	20.27	—0.69
1894	41.37	—3.57	19.37	—4.61	22.00	+1.04
1895	36.67	—8.27	17.46	—6.52	19.21	—1.75
1896	45.21	+0.27	23.63	—0.35	21.58	+0.62
1897	46.51	+1.57	26.19	+2.21	20.32	—0.64
1898	48.30	+3.36	27.65	+3.67	20.65	—0.31
Mean	44.94	—19.58	23.98	—19.58	20.96	—4.24
		+19.54		+19.56		+4.22
		—0.04		—0.02		—0.02

Genesee river

Year	Rainfall	Variation from mean	Runoff	Variation from mean	Evaporation	Variation from mean
1890	47.54	+7.21	21.22	+7.06	26.32	+0.14
1891	38.12	—2.21	14.05	—0.11	24.07	—2.11
1892	41.69	+1.36	15.42	+1.26	26.27	+0.09
1893	39.30	—1.03	13.35	—0.81	25.95	—0.23
1894	47.79	+7.46	19.38	+5.22	28.41	+2.23
1895	31.00	—9.33	6.67	—7.49	24.33	—1.85
1896	40.68	+0.35	12.80	—1.36	27.88	+1.70
1897	34.39	—5.94	9.38	—4.78	25.01	—1.17
1898	42.50	+2.17	15.13	+0.97	27.37	+1.19
Mean	40.33	+18.55	14.16	—14.55	26.18	—5.36
		—18.51		+14.51		+5.35
		+0.04		—0.04		—0.01

On comparing these two streams, as per the foregoing tabulation, it appears that the water yields are quite different. In searching for a reason for the difference which appears, the writer assigns as a principal cause the difference in forestation, the Hudson area being still largely in forest, while the Genesee is almost totally deforested and under cultivation, either for grain farming or grazing.

By way of still better comparing the rainfall, runoff and evaporation of these two catchment areas the following tabulation has been prepared:

COMPARISON OF RAINFALLS, HUDSON AND GENESEE RIVERS

Year	Rainfall of Hudson area	Rainfall of Genesee area	Difference
1890	50.35	47.54	+2.81
1891	42.96	38.12	+4.84
1892	53.87	41.69	+12.18
1893	42.18	39.30	+2.88
1894	41.37	47.79	—6.42
1895	36.67	31.00	+5.67
1896	45.21	40.68	+4.53
1897	46.51	34.39	+12.12
1898	48.30	42.50	+5.80
Mean	45.27	40.33	+4.94

COMPARISON OF RUNOFFS, HUDSON AND GENESEE RIVERS

Year	Runoff of Hudson area	Runoff of Genesee area	Difference
1890	28.56	21.22	+7.34
1891	20.56	14.05	+6.51
1892	33.08	15.42	+17.66
1893	21.91	13.35	+8.56
1894	19.37	19.38	—0.01
1895	17.46	6.67	+10.79
1896	23.63	12.80	+10.83
1897	26.19	9.38	+16.81
1898	27.65	15.13	+12.52
Mean	24.27	14.16	+10.11

COMPARISON OF EVAPORATIONS, HUDSON AND GENESEE RIVERS

Year	Evaporation of Hudson area	Evaporation of Genesee area	Difference
1890	21.79	26.32	—4.53
1891	22.40	24.07	—1.67
1892	20.79	26.27	—5.48
1893	20.27	25.95	—5.68
1894	22.00	28.41	—6.41
1895	19.21	24.33	—5.12
1896	21.58	27.88	—6.30
1897	20.32	25.01	—4.69
1898	20.65	27.37	—6.72
Mean	21.00	26.18	—5.18

It will be noticed that in the first of the two preceding tabulations for the Hudson river, there are eleven years included and that the average of the rainfall is 44.94 inches; the average runoff is 23.98 inches, and the average evaporation is 20.96 inches. The Genesee river, on the contrary, only includes nine years, from 1890 to 1898, inclusive.

In the second tabulation the years 1890-1898, inclusive, have been taken for not only the Hudson river, but also for the Genesee, for purposes of comparison. The taking of the Hudson river for nine years instead of eleven makes a slight difference in the means. The rainfall is 45.27 inches; the runoff, 24.27 inches, and the evaporation, 21 inches. The Hudson river table is not worked up to date, although the data are at hand, for the reason that the Genesee river data do not extend beyond the year 1898. There is no way, therefore, of comparing the two since that year.[1]

Variation in weir measurements. The writer has shown[2] the considerable variation in weir measurements due to the difference in form of weir alone. So great are these that any conclusions based upon the data of sharp-crested weirs applied to other forms

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[1] Partially abstracted from paper, Data of Stream Flow in Relation to Forests, by Geo. W. Rafter. Lecture before engineering classes of Cor. Uni., Ap. 14, 1899. Trans. Assn. of Civ. Engrs. of Cor. Uni., Vol. VII, 1899.

[2] On the Flow of Water over Dams: Trans. Am. Soc. C. E., Vol. XLIV, p. 220.

are extremely unsatisfactory. In one case of a flat-crested weir, the flow at a given depth is only 75 per cent of what it is over a sharp-crested weir. Variations of from 5 per cent to 20 per cent are common, as may be easily observed by examining the tables in the paper on the flow of water over dams.[1]

In view of the importance which gagings are now shown to bear in estimating the value of a stream for water power or city water supply, in future every statement of stream flow should be accompanied by a concise statement of the method of gaging used, thus permitting hydrologists to judge of the general reliability of the method. Had this been done in the past, some of the uncertainty which now attaches to many gaging records would undoubtedly be removed.

Genesee and Hudson gagings reduced to sharp-crested weir measurements. The writer has shown in another place that Genesee river gagings have been reduced to sharp-crested weir measurements. As to the Hudson gagings, pl. CXXVII in the Report to the United States Board of Engineers on Deep Waterways, may be cited. This plate is a comparison of the discharge over weirs by different formulas, and it appears from it that Mullins's formula for a flat-crested weir, which has been used for the Upper Hudson gagings, at a depth of 4 feet gives results less than Francis's formula for a sharp-crested weir by about 10 per cent. However, in order to simplify the computation and to avoid velocity of approach, the width of the crest was taken at 5 feet. Again, the crest at Mechanicville is not flat, but is slightly sloping backward. The sloping front probably affects the flow to increase it somewhat. There are also flashboards used during low water, which are properly computed by Francis's formula for a sharp-crested weir. These several elements undoubtedly make the problem somewhat complicated, but taking everything into account it is probable that the results as computed are not far from right. They may, however, be in error as much as 2 inches per year.[2]

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[1] On the Flow of Waters over Dams; loc. cit.

[2] See the diagrams of Hudson and Genesee rivers on this point.

As regards the relation between mean annual temperature and evaporation, the questions raised by Mr Vermeule are very interesting and have received considerable study from the writer ever since the publication of Mr Vermeule's report in 1894. This study has been specially directed toward determining whether there was any way of showing by diagrams, definitely, that any such relation really existed.

Evaporation

FitzGerald's formula for evaporation. We may consider Mr FitzGerald's formula for evaporation,[1] which is

$$E = \frac{(V - v)\left(1 + \frac{W}{2}\right)}{60}. \tag{30}$$

In this formula V=the maximum force of vapor in inches of mercury corresponding to the temperature of the water; v=the force of vapor present in the air; W=the velocity of the wind in miles per hour; and E=the evaporation in inches of depth per hour. It can be shown that there is going on nearly always a condensation of moisture from the air upon any water surface. At the same time there is going on a loss of moisture from the water surface by evaporation. The intensity of both these operations depends upon the difference in temperature between the air and any water surface with which it may be in contact. When the temperature of air and water is the same, theoretically both processes stop. Broadly, evaporation may be said to measure the difference of these two exchanges. Wind velocity also exerts a decided effect on the intensity of evaporation.

For illustrative purposes, v, the force of vapor present in the air may be computed by the following:

$$v = V - \frac{0.480(t - t')}{1130 - t'} h, \tag{31}$$

In which v=force of vapor in the air at time of observation;
V=force of vapor in a saturated air at temperature of t';
t=temperature of the air in Fahrenheit degrees, indicated by the dry bulb;
t'=temperature of evaporation given by wet bulb;
h=hight of barometer.

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[1] Trans. Am. Soc. C. E., Vol. XV, pp. 581-646.

The temperatures indicated by the foregoing formula (31) are above the freezing point. For temperatures below the freezing point, the denominator of the fraction in the second member of the formula should be 1240.2—*t′*. For Centigrade degrees, the denominator of the fraction should be, when the temperature of the dry bulb is above the freezing point, 610—*t′*, and when the temperature of the wet bulb is below the freezing point, the bulb being covered by a film of ice, the denominator should be 689—*t′*.[1]

There is no difference between evaporation from a water surface and evaporation from land, except that on a water surface it goes on continuously, while on land evaporation may be interrupted from lack of something to evaporate. The preceding formula shows that the force of vapor is dependent upon the difference of the dry and wet bulb thermometers, and not in any degree upon the mean annual temperature.

Evaporation relations. Prof. Cleveland Abbe[2] gives the following relations of evaporation, as established by Prof. Thomas Tate:

a) Other things being the same, the rate of evaporation is nearly proportional to the difference of the temperatures indicated by the wet-bulb and dry-bulb thermometers.

b) Other things being the same, the augmentation of evaporation due to air in motion is nearly proportional to the velocity of the wind.

c) Other things being the same, the evaporation is nearly inversely proportional to the pressure of the atmosphere.

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[1] In the original discussion of this matter, in paper on Relation of Rainfall to Runoff, there is an error of statement in formula (31). The denominator of the second member should be 1130—t′, instead of 689—t′. The former expression is for Fahrenheit degrees, while the latter is for Centigrade degrees, and with the bulb covered by a film of ice.

In formula (30), it will be noted that Mr. FitzGerald makes V the maximum force of vapor in inches of mercury corresponding to the temperature of the water. Recent study of this matter indicates that there is considerable doubt whether formula (31) strictly applies in the computation of V, but since for present purposes an illustration of the matter is all that is needed, it is not attempted to settle these difficult questions in physics here.

[2] Preparatory Studies for Deductive Methods in Storm and Weather Predictions, by Prof. Cleveland Abbe: Ann. Rept. Chief Signal Oficer for 1889, Part I, Appendix 15.

d) The rate of evaporation of moisture from damp, porous substances of the same material is proportional to the extent of the surface presented to the air, without regard to the relative thickness of the substances.

e) The rate of evaporation from different substances mainly depends upon the roughness of, or inequalities on, their surfaces, the evaporation going on most rapidly from the roughest or most uneven surfaces; in fact, the best radiators are the best vaporizers of moisture.

f) The evaporation from equal surfaces composed of the same material is the same, or very nearly the same, in a quiescent atmosphere, whatever may be the inclination of the surfaces: thus a horizontal plate with its damp face upward evaporates as much as one with its damp face downward.

g) The rate of evaporation from a damp surface (namely, a horizontal surface facing upward) is very much affected by the elevation at which the surface is placed above the ground.

h) The rate of evaporation is affected by the radiation of surrounding bodies.

i) The diffusion of vapor from a damp surface through a variable column of air varies (approximately) in the inverse ratio of the depth of the column, the temperature being constant.

j) The amount of vapor diffused varies directly as the tension of the vapor at a given temperature, and inversely as the depth of the column of air through which the vapor has to pass.

k) The time in which a given volume of dry air becomes saturated with vapor, or saturated within a given percentage, is nearly independent of the temperature if the source of vapor is constant.

l) The times in which different volumes of dry air become saturated with watery vapor, or saturated within a given per cent, are nearly proportional to the volumes.

m) The vapor already formed diffuses itself in the atmosphere much more rapidly than it is formed from the surface of the water. (This assumes, of course, that there are no convection currents of air to affect the evaporation or the diffusion.)

Effect of wind and other meteorological elements. That the velocity of the wind must have a very material effect upon evaporation, and hence upon the runoff of streams, is at once apparent on inspection of Mr FitzGerald's evaporation formula, given in a preceding section. Again, on examining the annual summaries in the report of the Chief of the Weather Bureau the average yearly velocity of wind is found to vary from about 3 miles to 16 or 18 miles. With other conditions the same, evaporation will be much larger with a higher wind velocity.

The preceding summary of evaporation relations further shows that evaporation will vary in some degree in proportion to pressure, temperature, moisture—which may be taken to include dewpoint, relative humidity, vapor pressure, precipitation, and cloudiness—and, finally, in proportion to average velocity of the wind. It may also be expected to vary in some degree in proportion to electrical phenomena—thunderstorms, auroras, etc.—but as yet we know so little about these that they can be no more than mentioned. The writer, however, believes that studies in the direction here indicated would be very prolific of results. For this purpose two or three stations, observing all the elements herein enumerated, should be established in each catchment area.

In the present study an attempt has been made to correlate these elements with the runoff, but, aside from the rainfall, the data are too indefinite for satisfactory results. It is for these reasons, with others, that the writer is able to give only tentative conclusions in regard to the relation of rainfall to the runoff of streams.

Persistency of evaporation. The persistency of the amount of evaporation for any given stream at about the same figure through long periods of time was first pointed out by Messrs. Lawes, Gilbert, and Warrington in their classical paper On the Amount and Composition of Rain and Drainage Waters Collected at Rothampsted, published in the Journal of the Royal Agricultural Society of England for 1881. As to why evaporation exhibits such persistency these distinguished authors consider it largely due to the fact that the two principal conditions which determine large evaporation—namely, excessive heat and abundant rain—very rarely occur together. The result is, specially in the English climate, a balance of conditions unfavorable to large evaporation. In a wet season, when the soil is kept well supplied with water, there is at the same time an atmosphere more or less saturated, with an absence of sunshine; while in dry seasons the scarcity of rain results in great dryness of the soil, with scant, slow evaporation.[1]

Negative evaporation. In a strictly scientific sense this term is taken to mean that when the temperature of the evaporating surface is lower than the dewpoint, water is deposited on that surface. As regards the rainfall, runoff, and evaporation tables, herewith included, negative evaporation means that the runoff for certain months is greater than the rainfall. Sometimes this may legitimately happen when a heavy rainfall comes at the end of the month, or when, with much snowfall, the temperature of the month is mostly below freezing. In order to show as much as possible in regard thereto, the writer gives the detail for each of the tables of Muskingum, Genesee, Croton and Hudson rivers, together with a tentative view as to the real significance of the so-called negative evaporation.

On Muskingum river, during the 8 years gaged, negative evaporation is shown only twice for one month.

On Genesee river the detailed tabulation shows negative evaporation 5 times for one month and once for two consecutive months, a total of 7 months in all.

On Croton river, for the entire period of 32 years, negative evaporation is shown 29 times for one month and 6 times for two consecutive months, a total of 41 months in all.

On Hudson river negative evaporation is shown 7 times for one month and 4 times for two consecutive months, a total of 15 months.

The writer has no doubt that, except in very cold climates, when negative evaporation occurs for three or more consecutive months, there is an error in the gagings. He also doubts their accuracy somewhat when negative evaporation appears for two consecutive months. As regards the storage period, there is no difficulty in

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[1] Since the presistency of evaporation has been extensively discussed in the writer's paper on Stream Flow in Relation to Forests, it is merely touched on here.

accepting it for one month as true, because rainfall or snowfall at the end of the month can be easily carried over to the next. This is also true sometimes for two months, but for the present it seems quite doubtful that other than in exceedingly rare cases would negative evaporation occur for three consecutive months. Its occurrence for six consecutive months, or for the entire storage period, is believed to be impossible. It may, however, be again pointed out that its occurrence renders an attempt at monthly diagrams showing the relation between rainfall and runoff absurd.

Assuming that the foregoing propositions are reasonably true, it follows that the frequency of the occurrence of negative evaporation in gaging records may be in some degree a criterion as to their accuracy. The writer, however, does not wish to urge this very strongly, but merely to point it out as a possibility. The writer has no desire to be insistent on this point. There is very little on the subject of negative evaporation in engineering literature, and the writer will be glad to have the observations and conclusions of others.

In a report on the flow of the river Thames, by A. R. Binnie, Chief Engineer of the London County Council,[1] the matter of negative evaporation is elaborately discussed, and in order to obtain all the information possible about it Mr Binnie applied to George J. Symons, F. R. S., to assist him in arriving at some approximate idea on the subject. Mr Symons submitted an exceedingly lucid and conclusive report. Eleven distinct cases of negative evaporation were submitted to him for study and comment. In regard to these he arrived at the following conclusions:

1) Under normal conditions a fall of rain will increase the flow at Teddington weir on the second day after it falls.

2) Under normal conditions the water running off from any given fall of rain will all reach Teddington weir before the tenth subsequent day.

3) In the winter an interval of two months, or in extreme cases even more, may elapse between the precipitation of moisture from the clouds and its flow over Teddington weir.

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[1] Report on the Flow of the River Thames, by A. R. Binnie. Publication of the London County Council, dated November 1, 1892.

As a consequence of (2) it is clear that a heavy rainfall on the last days of any month may not appear at the point of gaging until the next month. Mr Symons also states that the one great fact which has been impressed upon him by these investigations is the effect of winter frosts in regulating the flow of the river Thames and in mitigating winter floods.

These conclusions are more specially intended to apply to the river Thames. Hence, while it is true that so-called negative evaporation exists on all of the streams considered, the conditions are nevertheless very different, and in the United States the effect of holding back the flow of streams by frosts is in very many cases to precipitate a flood of water later on. This element would hardly be considered with us as either a river regulator or as mitigating floods.[1]

Evaporation at Ogdensburg. Observations of the amount of evaporation from water surfaces in New York were made by Prof. James Coffin, Principal of Ogdensburg Academy, in 1838. The following are Professor Coffin's results for the year 1838, as taken from the Regents' reports for 1839:

Month	Rainfall, inches	Evaporation, inches	Mean temperature F°
January	2.36	1.65	24.8
February	0.97	0.82	12.3
March	1.18	2.07	32.9
April	0.40	1.62	39.8
May	4.81	7.10	52.5
June	3.57	6.75	66.5
July	1.88	7.79	71.7
August	2.55	5.42	68.3
September	1.01	7.40	59.2
October	2.73	3.95	44.6
November	2.07	3.66	29.7
December	1.08	1.15	19.4
Total	24.61	49.36	43.5

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[1] Negative evaporation is discussed somewhat more extensively in the writer's paper, The Relation of Rainfall to Runoff, than it is here.

Professor Coffin's results were obtained by observing the variations of weight of a dish of water of the same size as the rain gage, with which the evaporation determinations are compared. This method would probably give results considerably in excess of the truth. Moreover, a single year is too short a period for safe results.

Croton Water Department evaporation records. Table No. 29 presents the results of evaporation for certain indicated months (1) for the years 1867-1870, at Boyd's Corners storage reservoir, Putnam county, as determined by J. J. R. Croes,[1] from a wooden tank sunk in the earth; (2), for certain indicated months, 1864-1869, inclusive, from a wooden tank sunk in the earth at the receiving reservoir in the City of New York; (3), from a wooden tank in a batteau at the receiving reservoir in New York, and (4), from a tin box in a batteau at the receiving reservoir in New York.

The foregoing evaporation experiments are referred to in a paper by Mr Croes on the flow of the West Branch of Croton river. The gage used was a tight wooden tank 4x4x3 feet, sunk in the earth in an exposed situation and filled with water. As indicated, the mean evaporation at Boyd's Corners for the indicated months was 24.47 inches, while at a similar tank at the reservoir in New York city it was 34.06 inches. Mr Croes attributes the difference in these results to the different methods of observation and measurement, and states that the Boyd's Corners observations were made twice a day, and any discrepancies that might have occurred were thus found and corrected at once, while the observations at the reservoir in New York city were made only once a month, the difference between the reading of the gage on the tank and the observed rainfall being taken as evaporation. Mr Croes therefore considers the work done at Boyd's Corners reservoir as more reliable.

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[1] Trans. Am. Soc. C. E., Vol. III, 1874.

TABLE NO. 29—EVAPORATION EXPERIMENTS OF THE CROTON WATER DEPARTMENT

(Depth in inches)

Wooden tank sunk in earth at Boyd's Corners storage reservoir

YEAR	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1867	0.31	3.79	3.44	3.95	3.63	4.44	2.96	3.69	1.41	0.04	27.66
1868	0.28	1.69	1.91	2.74	3.98	3.23	3.37	1.70	1.18	....	20.08
1869	....	2.28	3.75	3.77	4.25	3.90	2.85	1.81	1.00	....	23.61
1870	....	2.10	3.69	3.71	5.06	4.74	2.90	....	....	....	....
Mean	0.30	2.46	3.20	3.54	4.23	4.08	3.02	2.40	1.20	0.04	24.47

Wooden tank sunk in earth at receiving reservoir.

YEAR	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1864	....	....	....	....	....	....	....	....	....	....	37.12
1865	1.62	2.87	3.66	3.65	7.53	5.75	5.30	3.47	1.13	0.26	35.24
1866	1.36	2.13	5.18	5.49	6.05	7.29	4.19	2.85	2.60	0.47	37.61
1867	0.40	3.68	3.62	5.13	4.81	5.01	3.82	2.61	2.00	....	31.08
1868	....	0.52	3.18	3.44	4.97	7.65	8.87	2.48	2.07	....	33.18
1869	....	3.79	3.71	3.46	4.53	5.66	3.25	2.05	3.40	....	29.85
Mean	1.13	2.60	3.87	4.23	5.58	6.27	5.09	2.69	2.24	0.36	34.06

TABLE No. 29—EVAPORATION EXPERIMENTS OF THE CROTON WATER DEPARTMENT —(*Concluded*)

Wooden tank in batteau

YEAR	Mar	April	May	June	July	Ang.	Sept.	Oct.	Nov.	Dec.	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1864											37.53
1865	1.25	2.02	3.79	5.59	8.52	6.52	3.87	3.45	0.84	0.20	36.05
1866	1.16	2.03	5.21	5.82	7.26	7.53	4.50	3.26	4.31	0.47	41.55
1867	0.60	4.00	3.97	5.45	5.65	4.84	3.97	3.11	1.79		33.38
1868		0.93	3.40	3.76	5.30	7.97	9.16	2.68	1.86		35.06
1869		3.68	4.45	4.28	5.42	6.85	3.61	2.66	3.62		34.57
Mean	1.00	2.53	4.16	4.98	6.43	6.74	5.02	3.03	2.48	0.34	36.72

Tin box in batteau at receiving reservoir

YEAR	Mar	April	May	June	July	Ang.	Sept.	Oct.	Nov.	Dec.	Total
1864											39.97
1865	1.12	2.33	3.91	5.70	8.49	7.21	6.05	3.36	0.68	0.34	39.19
1866	1.12	2.01	6.26	5.99	6.86	8.16	4.70	4.49	3.78	0.47	43.84
1867	0.64	3.94	3.74	6.00	5.88	5.23	4.96	2.18	2.18		34.75
1868		0.52	3.23	4.31	5.55	8.22	10.24	4.03	1.47		37.57
1869		3.99	5.08	4.86	6.04	8.03	4.80	3.42	3.71		39.93
Mean	0.96	2.56	4.44	5.37	6.56	7.37	6.15	3.50	2.36	0.41	39.68

Evaporation at Rochester. Tables Nos. 30 and 31 give evaporation at Rochester[1] for the indicated months of the years 1892–1903, inclusive. The data of table No. 30 have been obtained by observing the changes in elevation of the water surface in a tub floating on the surface of Mount Hope reservoir of the Rochester waterworks, and may be taken as representing the approximate evaporation from a free water surface in western New York.

Table No. 31 gives evaporation from a water surface in an exposed tub on land for the same years and months as are included in table No. 30.

Observations of evaporation from water surfaces for a month or two have been reported from one or two other places, but so far as results of any value in actual work are concerned, the foregoing include everything thus far determined in this State.

Drain gages at Geneva. In 1882 the Agricultural Experiment Station at Geneva constructed three drain gages or lysimeters for the purpose of collecting and measuring drainage and evaporation from the soil. These gages are described in the annual report of the Agricultural Experiment Station for the year 1882, as follows:

> Box frames a little over twenty-five inches square and three deep, internal diameter, were made of oak plank, strongly ironed at the corners. These boxes were lined with heavy copper fastened to the boxes at intervals by means of heavy copper tacks, and the projection of the copper at the top and bottom bent over the wood and securely tacked, the area measuring after the copper was in place 25.04 inches square, or one ten-thousandth of an acre. The copper was strongly soldered at the joinings, and the tack heads securely soldered into place after being slightly countersunk. May 29 these frames, three in number, were fitted with a temporary cutting edge of angle iron screwed to the lower surface, the cutting edge being parallel with the inside face of the box, and the bevel toward the outside and placed over the sod. By means of a heavy weight placed on top, aided by heavy mauls with which blows were struck upon each of two opposite corners consecutively, a ditch being dug along the outside as the box entered the soil, these frames were forced their whole depth into the soil. A heavy flat section of boiler iron, the edge sharpened, was

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[1] Annual Report of Executive Board and of the City Engineer of Rochester.

TABLE NO. 30—EVAPORATION FROM A WATER SURFACE AS OBSERVED AT ROCHESTER 1892–1903, INCLUSIVE

(In inches)

MONTH (1)	1892 (2)	1893 (3)	1894 (4)	1895 (5)	1896 (6)	1897 (7)	1898 (8)	1899 (9)	1900 (10)	1901 (11)	1902 (12)	1903 (13)	Mean (14)
January	......	......	......	......	0.45	0.59	0.56	1.53	0.79	0.73	0.44	0.34	0.68
February	......	......	......	......	0.45	0.62	1.01	0.87	1.29	0.60	0.76	0.85	0.81
March	......	......	......	......	0.91	1.76	1.56	2.25	1.11	0.93	1.68	1.38	1.45
April	2.78	2.78	2.59	2.72	2.72	2.45	3.41	2.96	3.02	2.15	2.79	3.20	2.80
May	3.26	3.33	3.22	4.60	5.72	3.36	3.64	3.55	4.04	2.82	3.88	5.37	3.93
June	4.62	4.61	3.62	5.75	6.04	5.01	5.65	5.81	5.83	4.88	3.68	3.00	4.88
July	6.06	5.80	5.31	5.92	5.19	4.43	6.85	6.40	5.08	5.39	3.64	4.73	5.40
August	4.85	5.36	6.20	5.13	5.23	5.37	4.98	6.05	4.94	3.87	2.64	4.43	4.92
September	4.61	3.47	3.76	5.14	3.38	4.66	3.95	4.36	4.58	3.53	3.42	4.12	4.08
October	3.28	3.27	2.96	3.61	2.45	3.33	2.57	2.59	3.31	2.55	1.88	2.41	2.85
November	......	......	......	1.51	1.50	1.33	1.57	1.69	1.51	1.24	1.52	1.92	1.53
December	......	......	......	1.23	1.20	0.96	1.54	1.31	0.98	0.95	1.80	0.97	1.22
Total	......	......	......	......	35.24	33.87	37.29	39.37	36.48	29.64	28.13	32.72	34.55

TABLE NO. 31—EVAPORATION FROM AN EXPOSED TUB ON LAND AS OBSERVED AT ROCHESTER 1892–1902, INCLUSIVE

(In inches)

MONTH	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
January	......	......	......	......	......	......	......	......	......	......	......	......
February	......	......	......	......	......	......	......	......	......	......	......	......
March	......	......	......	......	......	......	......	......	......	......	......	......
April	4.59	4.59	4.39	4.91	4.46	4.31	4.32	4.95	5.73	4.79	4.49	4.68
May	4.93	6.02	5.52	8.84	7.88	5.26	5.25	5.52	6.66	4.91	5.92	6.07
June	7.21	8.33	7.67	9.53	8.03	6.91	6.97	8.18	9.46	8.07	6.62	7.91
July	8.58	8.65	8.86	8.81	7.10	7.14	9.01	8.73	8.82	8.87	6.98	8.32
August	6.85	7.35	7.85	7.19	6.93	6.99	6.22	7.48	7.97	6.06	5.93	6.89
September	6.08	4.83	5.19	6.91	4.30	5.69	4.99	4.70	6.00	5.01	4.76	5.32
October	3.46	4.38	3.32	4.08	2.51	3.92	2.63	2.80	4.96	3.53	3.01	3.51
November	1.49	1.49	1.49	1.49	1.78	1.11	1.93	1.48	2.23	1.81	2.43	1.70
December	......	......	......	......	......	......	......	......	......	......	......	......
Total	43.19	45.64	44.29	51.76	42.99	41.33	41.32	43.84	51.83	43.05	40.14	44.45

then forced underneath, cutting the frame and contents free, the box and contents inverted, and a bottom of copper, dishing slightly to a common center, where a pipe was inserted and securely soldered, and to which a perforated guard was attached, was strongly fastened into position by bending the copper sides over the edge of this bottom piece and securely soldering.

These three boxes were then carried from the point of filling to the drain-gage lawn, where they were placed carefully in position, their surfaces level with the surrounding ground and the pipe which passed from their bottom carried into a subterranean alcove built below them, and upon the arch of which the boxes rested, with the intervention of about six inches of soil. These alcoves branched from a pit carefully arched and to which admittance is obtained by steps. A bottle kept under each drain gage and to which the pipe leads enables us to collect all the water which drains through, and a graduated measure enables us to measure this water in thousandths of an inch, thus making a ready comparison with the rainfall, a record of which is kept by one of Green's eight-inch gages located alongside.

In order to estimate the drainage from different kinds of soil, these gages have different classes of surfaces. On the surface of No. 1 is a heavy sod; of No. 2 the surface is bare and undisturbed; while of No. 3 the surface is kept pulverized during the open season by frequent stirring with a trowel.

An edging of hard brass, one inch high, extends around the top of the frames, accurately defining the area. Hence, all the rainfall over the area is compelled to enter the soil and by measuring the amount percolating, we can account for the balance which evaporates. Having the three gages we can calculate the amount of water evaporated from growing sod, from a bare surface and from a stirred surface, respectively. The difference between the precipitation and drainage from such gages is taken to represent the evaporation from the ground.

In order to show the meteorological conditions existing at Geneva, table No. 32, Precipitation at Geneva Agricultural Experiment Station for the Water Years 1883–1889, Inclusive, is given. This table, however, while apparently a table of precipitation, does not give a complete record of precipitation in the form of snow and is somewhat deficient as to quantity during the winter months. Nevertheless there is a tendency to very low

TABLE NO. 32—PRECIPITATION AT THE GENEVA AGRICULTURAL EXPERIMENT STATION FOR THE WATER YEARS 1883–1889 INCLUSIVE

(In inches)

MONTH (1)	1883 (2)	1884 (3)	1885 (4)	1886 (5)	1887 (6)	1888 (7)	1889 (8)	Mean (9)
December	0.55	0.73	0.97	0.76	1.24	1.35	1.24	....
January	0.48	1.83	1.07	1.13	0.18	0.78	2.99	....
February	1.44	2.01	0.61	0.95	2.97	1.04	0.25	....
March	0.88	2.54	0.12	1.13	0.48	1.43	0.66	....
April	1.58	0.83	1.26	4.13	1.37	3.09	3.28	....
May	4.45	2.49	1.58	1.92	0.46	2.79	1.21	....
Storage period	9.38	10.43	5.61	10.02	6.70	10.48	9.63	8.89
June	4.12	2.01	2.49	2.92	2.01	3.88	7.47	....
July	2.98	2.33	4.64	4.41	6.37	0.99	4.57	....
August	3.47	1.44	5.02	2.86	3.03	4.02	1.98	....
Growing period	10.57	5.78	12.15	10.19	11.41	8.89	14.02	10.43
September	2.12	3.17	2.11	2.31	0.75	2.73	2.50	....
October	2.10	1.67	2.88	1.39	1.74	3.47	3.32	....
November	1.54	1.01	1.36	3.48	1.58	2.02	3.44	....
Replenishing period	5.76	5.85	6.35	7.18	4.07	8.22	9.26	6.67
Yearly total	25.71	22.06	24.11	27.39	22.18	27.59	32.91	25.99

records at the north ends of the valleys in this vicinity, as at Hemlock lake, Avon, Penn Yan, Lyons and a number of other places, and the Geneva record is probably not very far out of the way.

In order to compare the precipitation record with that of the drain gages the precipitation for the water years 1883 to 1889, inclusive, is given—the yearly mean for the period is 25.99 inches. The yearly mean precipitation at Hemlock lake for the water years 1877–1900, inclusive, is 27.70 inches. The mean of the storage period at Geneva from 1883–1889, inclusive, is 8.89 inches, while at Hemlock lake it is 12.21 inches, indicating that if these two records are otherwise comparable the Geneva record is short in the storage period a little over 3 inches.

Continuous records were kept at Penn Yan from 1829–1867. The mean rainfall for the water year of this period of forty-eight years was 27.93 inches, or substantially the same as Hemlock lake.

For the calendar year of 1899 the recorded precipitation at the Geneva Agricultural Experiment Station was 19.35 inches, while at Lyons for the water year 1899 it was 20.91 inches. On account of the uncertainty as to the winter months, the Geneva record is not used in compiling the average precipitation of the Oswego basin as given in table No. 34.

In table No. 33, Percolation of Drain Gages at Geneva Agricultural Experiment Station for the Water Years 1883–1889, Inclusive, we have the runoff of the three drain gages given for the water years, divided into storage, growing and replenishing periods, and in table No. 34, Runoff Data of Oswego River at High Dam for the Water Years, 1897–1901, Inclusive, we have given the rainfall, runoff and evaporation for these years. This table shows that the average runoff for the years included was 11.07 inches, while the preceding table shows that the average runoff from the sod for the seven years, 1883–1889, inclusive, was 5.07 inches; from bare soil, 7.55 inches, and from cultivated soil, 11.12 inches. The average rainfall during the years 1883–1889, inclusive, was according to the record at Geneva 25.99 inches, while during the years 1897–1901, inclusive, it was 36.50 inches. This excess of rainfall in the period 1897–1901, over what it was in the period 1883--1889, would, by itself, cause a largely increased runoff. In

TABLE No. 33—PERCOLATION OF DRAIN GAGES AT GENEVA AGRICULTURAL EXPERIMENT STATION FOR THE WATER YEARS 1883–1889, INCLUSIVE

(In inches)

MONTH	1883			1884			1885			1886			1887		
	Sod	Bare soil	Cultivated soil	Sod	Bare soil	Cultivated soil	Sod	Bare soil	Cultivated soil	Sod	Bare soil	Cultivated soil	Sod	Bare soil	Cultivated soil
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	0.0	0.271	0.249	0.165	0.043	0.031	0.0	0.432	0.352	0.275	1.145	0.906	0.500	0.320	0.320
January	0.007	0.052	0.006	0.059	0.229	0.055	0.0	0.266	0.256	1.240	1.280	1.130	0.140	0.045	0.307
February	0.142	0.0	0.0	2.062	1.540	1.769	0.0	0.0	0.0	1.015	1.140	0.330	1.885	1.477	1.400
March	0.001	0.001	0.001	1.320	1.629	1.611	0.0	0.0	0.0	1.387	1.620	0.780	0.540	0.185	0.790
April	0.001	1.291	1.566	0.190	0.062	0.210	0.074	0.798	1.640	2.490	2.550	2.350	0.520	0.140	0.530
May	1.204	2.439	3.010	0.0	0.510	1.070	0.0	0.0	0.0	0.0	0.003	0.430	0.035	0.040	0.135
Storage period	1.355	4.054	4.832	3.796	4.013	4.746	0.074	1.496	2.248	6.407	7.738	5.926	3.620	2.207	3.482
June	1.204	1.151	2.154	0.015	0.228	0.090	0.0	0.012	0.826	0.0	0.440	0.620	0.0	0.0	0.0
July	0.006	0.320	0.469	0.0	0.278	0.316	0.0	1.566	1.640	0.0	1.405	1.770	0.0	0.140	0.148
August	0.0	0.959	1.352	0.0	0.0	0.0	0.008	1.351	1.559	0.0	0.140	4.250	0.0	0.695	1.055
Growing period	1.210	2.430	3.975	0.015	0.506	0.406	0.008	2.929	4.025	0.0	1.985	6.640	0.0	0.835	1.203
September	0.0	0.227	0.632	0.0	0.103	0.350	0.0	0.196	2.510	1.350	0.175	0.320	0.0	0.0	0.0
October	0.083	0.964	1.353	0.0	0.157	0.165	0.0	1.041	1.012	0.0	0.525	5.250	0.0	0.0	0.0
November	0.935	0.801	0.935	0.0	0.0	0.0	0.0	0.713	0.640	0.250	0.279	2.645	0.0	0.300	4.000
Replenishing period	1.018	1.992	2.920	0.0	0.260	0.515	0.0	1.950	4.162	1.600	0.979	8.215	0.0	0.300	4.000
Yearly total	3.583	8.476	11.727	3.811	4.779	5.667	0.082	6.375	10.435	8.007	10.702	20.781	3.620	3.342	8.685

TABLE No. 33—PERCOLATION OF DRAIN GAGES AT GENEVA AGRICULTURAL EXPERIMENT STATION—*Concluded*

(In inches)

MONTH	1888			1889			MEAN			Mean of all	MEAN WITH YEARS 1886 and 1889 OMITTED			Mean of all with 1886 and 1889 omit'd
	Sod	Bare soil	Culti-vated soil	Sod	Bare soil	Culti-vated soil	Sod	Bare soil	Culti-vated soil		Sod	Bare soil	Culti vated soil	
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(6)
December	*0.0	*0.0	*0.0	1.550	1.200	1.320	......	......	......	......	......	......	......	......
January	0.0	0.155	0.153	1.820	1.150	1.310	......	......	......	......	......	......	......	......
February	0.0	0.0	0.0	0.050	0.025	0.050	......	......	......	......	......	......	......	......
March	0.0	0.0	0.0	0.480	0.320	0.180	......	......	......	......	......	......	......	......
April	1.770	1.150	0.610	1.920	1.835	1.130	......	......	......	......	......	......	......	......
May	0.0	0.0	0.0	0.070	0.970	0.860	......	......	......	......	......	......	......	......
Storage period	1.770	1.305	0.763	5.890	5.500	4.850	3.273	3.759	3.835	3.622	2.123	2.615	3.214	2.651
June	0.0	0.900	1.150	2.320	1.920	2.320	......	......	......	......	......	......	......	......
July	0.0	0.0	0.0	0.0	1.220	1.370	......	......	......	......	......	......	......	......
August	0.0	0.930	0.980	0.030	0.320	0.530	......	......	......	......	......	......	......	......
Growing period	0.0	1.830	2.130	2.350	3.460	4.220	0.512	1.996	3.228	1.912	0.247	1.706	2.348	1.434
September	1.530	0.555	0.810	0.0	0.400	0.810	......	......	......	......	......	......	......	......
October	0.0	1.060	1.670	0.240	1.250	1,250	......	......	......	......	......	......	......	......
November	0.765	0.880	0.830	3 840	2.940	3.190	......	......	......	......	......	......	......	......
Replenishing period	2.295	2.495	3.310	4.080	4.590	5.250	1.285	1.795	4.053	2.378	0.662	1.399	2.981	1.680
Yearly total	4.065	5.630	6.203	12.320	13.550	14.320	5.070	7.550	11.116	7.912	3.032	5.720	8.543	5.765

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* It is uncertain from the report whether record for December, 1887, was taken.

order to compare the two we may plat diagrams showing the relation between precipitation and runoff in the years 1897–1901, inclusive. These diagrams may be extended so that they will show

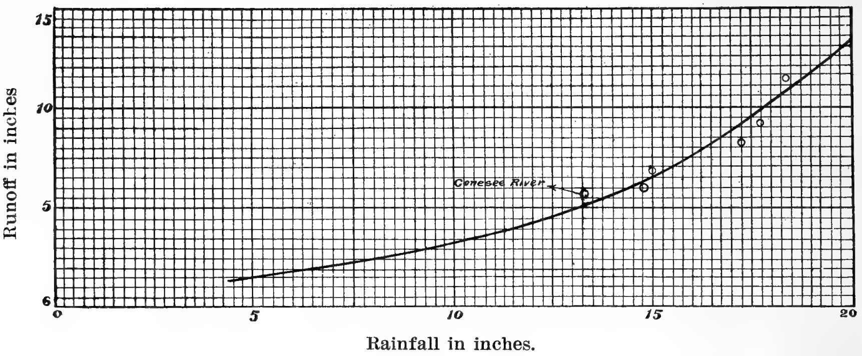

Fig. 1 Diagram showing the relation between precipitation and runoff in the Oswego river catchment during the storage period.

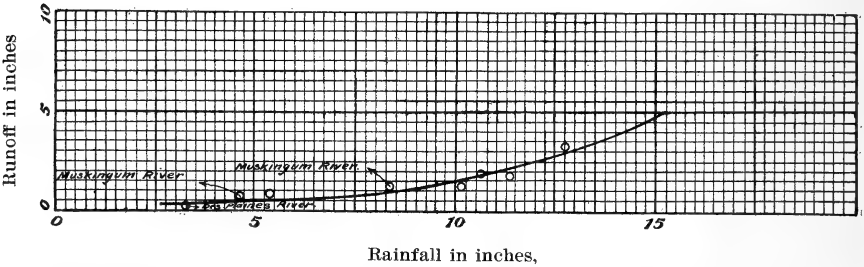

Fig. 2 Diagram showing the relation between precipitation and runoff in the Oswego river catchment during the growing period.

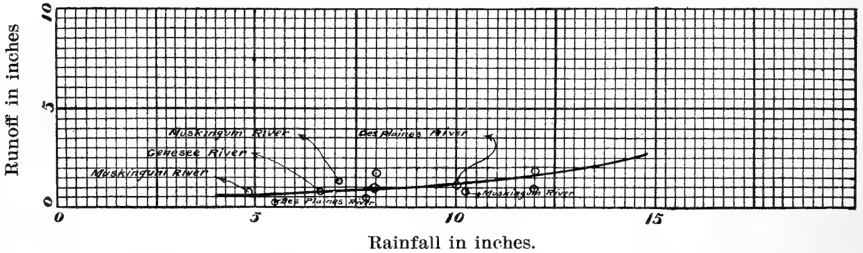

Fig. 3 Diagram showing the relation between precipitation and runoff in the Oswego river catchment during the replenishing period.

approximately the runoff with a lower rainfall, as in the water years 1883–1889, inclusive. Figures No. 1, 2 and 3 are such diagrams as platted from the record of the runoff of Oswego river, 1897–1901, inclusive.

In order to extend these diagrams to lower limits, there are a few points platted from the extreme low water of Desplaines, Muskingum and Genesee rivers, these latter being indicated on the diagrams. Taking from these diagrams the probable runoff of Oswego river for the water years 1883–1889, inclusive, we have for:

	Inches
1883—	
Storage	3.00
Growing	1.75
Replenishing	0.80
Yearly total	5.55
1884—	
Storage	3.40
Growing	0.50
Replenishing	0.80
Yearly total	4.70
1885—	
Storage	1.70
Growing	2.60
Replenishing	0.70
Yearly total	5.00
1886—	
Storage	3.30
Growing	1.60
Replenishing	0.85
Yearly total	5.75
1887—	
Storage	2.00
Growing	2.20
Replenishing	0.50
Yearly total	4.70

TABLE No. 34—RUNOFF DATA OF OSWEGO RIVER AT HIGH DAM FOR THE WATER YEARS 1897–1901, INCLUSIVE

(In inches on the catchment area of 5,000 square miles)

MONTH	1897			1898			1899		
	Rainfall	Runoff	Evaporation	Rainfall	Runoff	Evaporation	Rainfall	Runoff	Evaporation
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	......	....	......	0.95	....	......	0.90	....
January	......	......	....	......	1.13	....	......	0.98	....
February	......	......	....	......	1.29	....	......	0.51	....
March	......	......	....	......	2.29	....	......	1.12	....
April	......	2.23	....	......	1.68	....	......	1.70	....
May	......	1.78	....	......	1.78	....	......	1.55	....
Storage period	14.75	*6.00	8.75	17.77	9.12	8.65	15.03	6.76	8.27
June	......	0.85	....	......	0.97	....	......	0.44	....
July	......	0.49	....	......	0.41	....	......	0.17	....
August	......	0.54	....	......	0.20	....	......	0.14	....
Growing period	10.56	1.88	8.68	11.27	1.58	9.69	6.17	0.75	5.42
September	......	0.28	....	......	0.30	....	......	0.13	....
October	......	0.24	....	......	0.46	....	......	0.12	....
November	......	0.40	....	......	0.99	....	......	0.24	....
Replenishing period	7.99	0.92	7.07	12.04	1.75	10.29	7.79	0.49	7.30
Yearly total	33.30	8.80	24.50	41.08	12.45	28.63	28.99	8.00	20.99

* Computed—a pproximate.

Table No. 34—Runoff data of Oswego river at high dam—*Concluded*

(In inches on the catchment area of 5,000 square miles)

MONTH	1900			1901			MEAN		
	Rainfal	Runoff	Evaporation	Rainfall	Runoff	Evaporation	Rainfall	Runoff	Evaporation
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	0.36	....	......	2.08	....	......	......	....
January	......	0.70	....	......	1.23	....	......	......	....
February	......	0.96	....	......	0.38	....	......	......	....
March	......	1.14	....	......	1.67	....	......	......	....
April	......	3.12	....	......	3.80	....	......	......	....
May	......	1.76	....	......	2.30	....	......	......	....
Storage period	17.61	8.04	9.57	18.63	11.46	7.17	16.76	8.28	8.48
June	......	0.69	....	......	1.83	....	......	......	....
July	......	0.22	....	......	0.86	....	......	......	....
August	......	0.15	....	......	0.45	....	......	......	....
Growing period	10.12	1.06	9.06	12.76	3.14	9.62	10.18	1.68	8.50
September	......	0.14	....	......	0.41	....	......	......	....
October	......	0.19	....	......	0.49	....	......	......	....
November	......	0.53	....	......	0.65	....	......	......	....
Replenishing period	11.99	0.86	11.13	8.01	1.55	6.46	9.56	1.11	8.45
Yearly total	39.72	9.96	29.76	39.40	16.15	23.25	36.50	11.07	25.43

	Inches
1888—	
Storage	3.50
Growing	1.15
Replenishing	1.00
Yearly total	5.65
1889—	
Storage	3.10
Growing	3.95
Replenishing	1.05
Yearly total	8.10
Mean	5.63

Comparing the foregoing mean of 5.63 inches with the mean of runoff from sod, bare soil and cultivated soil, as per table No. 33, we see that the mean of all is 7.91 inches. If, however, we omit the years 1886 and 1889, which appear to be abnormally high, we find that the mean of all is 5.77 inches, which compares very closely with the mean found by the computation. Undoubtedly there is some inaccuracy in the record of the drain gages, as well as in the record of the precipitation, and the foregoing computation is given chiefly to show that with good data the computation of runoff from a rainfall record can be made with considerable precision.

In the Sixth Annual Report of the Geneva Agricultural Experiment Station (1887) it is stated that discussion of the results from these drain gages has been deferred, hoping that sufficient data would reconcile the discrepancies existing between the drain gage results and what apparently takes place in outside soils.[1] In regard to the discrepancies, the foregoing discussion as to oversight in precipitation records largely explains them and probably further discussion is unnecessary.

Nevertheless, it should be stated that in an ordinary drain gage, since the soil within the gage is not in connection with a permanent water table, the acquisition of water by capillarity from

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[1] Report of Agricultural Experiment Station at Geneva for 1887, p. 389.

beneath is excluded and the conditions within the gage are different from those existing in outside soil. This leads to the earth within the gage becoming abnormally dry in times of drought, and on the advent of rain absorbing more water than it would if not thus isolated. In order to obviate some of these possible difficulties, new drain gages were constructed in 1888, which differ from the preceding gages by being provided with an artificial water table which is kept at a nearly constant hight by the addition of sufficient water, daily, to make up the loss by evaporation.

An even distribution of water is insured by a layer of pebbles placed at the bottom covered with another of clean sand, the latter reaching up far enough to cover the drain pipe. The soil above, while not directly in contact with water, rests upon a saturated layer of sand. Four drain gages were constructed on the new plan—two contain a column of soil three feet in depth, exclusive of the sand at the bottom, while the other two contain a column of soil six feet in depth. One of each pair was filled with soil in place in order to preserve its natural composition and solidity. The other was filled with air-dried and sifted garden soil. Each drain gage was made of whiteoak staves of equal width, cylindrical in form and lined with sheet copper. The area was one ten-thousandth of an acre as before.

The cylinders filled with soil in place were sunk about the columns of soil by excavating on the outside and dressing down the column to fit the inside of the cylinder. The cylinder having been sunk to the desired depth was inclined to one side sufficiently to break the column of soil at the lower end, when the plank bottom was inserted into the fissure thus formed. After various manipulations which it is not necessary to describe, the cylinder was lifted with jackscrews until it could be rolled out of the excavation, after which it was loaded upon a wagon and hauled to the pit prepared for it, where it was unloaded, with the end intended to enter the soil upward. The plank bottom was removed and six inches of earth taken out to make room for the layer of sand and gravel upon which the column of soil rests. The drain tube was inserted, soldered to place, after which the copper bottom was soldered on. The space between the copper bottom and the end of the cylinder was fitted with a false bottom, after which a plank bottom was put on and securely fastened by means of angle iron. The drain gage was then lowered to position by means of an inclined plane and a windlass. After connecting drain pipe with drain gage pit, it was inserted and soldered to place.

The apparatus for supplying water to these gages is quite different from the usual form. When there is percolation from the drain gage, the water percolated flows out through a drain cock and is collected in a bottle beneath it. On the other hand, if the soil of the drain gage absorbs some of the bottom water, the level of the latter falls, permitting a bubble of air to enter, which passes upward and is conducted into the upper part of a reservoir outside the gage. This allows an equal quantity of water to pass out of the reservoir into the drainage tube.

Table No. 35, New Drain Gage Record, June to December, Inclusive, 1889, from the Report of the Agricultural Experiment Station for 1890, gives some of the particulars of the workings of these new drain gages.

These new drain gages were not satisfactory and the record was discontinued after December, 1899.

The hight of water in wells. The hight of water in wells is related to evaporation, and in order to show some of the phenomena connected with the movements of ground water, a series of measurements were made during 1887–1889, inclusive, of the hight of water in an abandoned well at the Geneva Agricultural Experiment Station. The well is forty feet deep and situated near the top of a ridge of such a hight that in three directions it is necessary to go only a few hundred feet before reaching land lower than the bottom of the well, while in the fourth direction there is a railroad cut, the bottom of which is but slightly above that of the well.

The measurements began December 1, 1886, and were continued daily until the end of 1889. In table No. 36, Hight of Ground Water in an Abandoned Well at the Geneva Agricultural Experiment Station from December, 1886, to December, 1889, Inclusive,

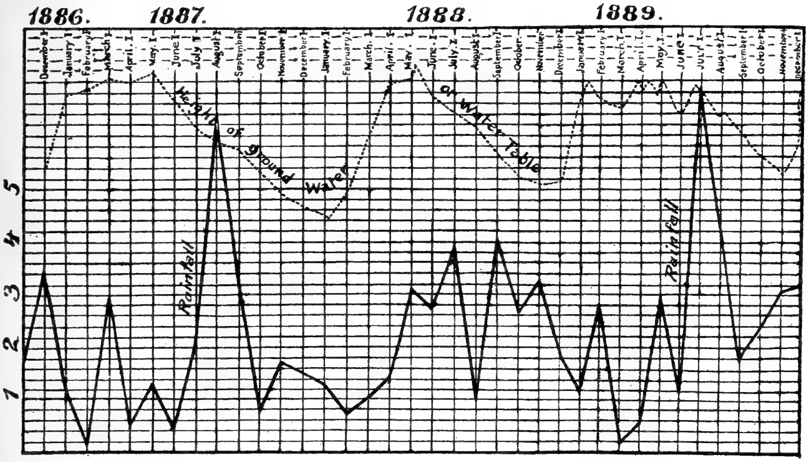
TABLE No. 35—NEW DRAIN GAGE RECORD, JUNE TO DECEMBER, 1889, INCLUSIVE
(In litres)

New drain gages		June	July	Aug.	Sept.	Oct.	Nov.	Dec..
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
No. 1	Rainfall	76.777	46.868	20.299	25.695	34.123	35.356	16.650
	Absorption from reservoir	0.198	0.085	0.042	0.027	0.008	0.010	0.012
	Total water supplied	76.975	46.953	20.341	25.722	34.131	35.366	16.662
	Drainage	28.500	19.200	5.300	8.900	6.500	31.550	13.700
	Per cent drainage to rainfall	37.25	40.96	26.11	34.64	....	....	....
No. 2	Rainfall	76.777	40.868	20.299	25.695	34.123	35.356	16.650
	Absorption from reservoir	0.113	0.180	0.070	0.115	0.096	0.030	0.036
	Total water supplied	76.890	47.048	20.369	25.810	34.219	35.386	16.686
	Drainage	16.500	0.250	3.300	5.200	12.000	28.200	12.750
	Per cent drainage to rainfall	21.49	0.53	16.26	20.24	....	....	....
No. 3	Rainfall	76.777	46.868	20.299	25.695	34.123	35.356	16.650
	Absorption from reservoir	0.186	0.123	0.001	0.071	....	0.595	0.288
	Total water supplied	76.963	46.991	20.300	25.766	34.123	35.951	16.938
	Drainage	33.463	10.500	9.000	4.800	8.000	22.550	+23.400
	Per cent drainage to rainfall	43.58	22.40	44.34	18.69	....	....	....
No. 4	Rainfall	76.777	46.868	20.299	25.695	34.123	35.356	16.650
	Absorption from reservoir	0.104	3.798	0.560	0.248	0.386	0.013	0.010
	Total water supplied	76.881	50.666	20.859	25.943	34.509	35.369	16.660
	Drainage	35.600	14.800	7.000	9.300	15.800	35.500	+19.350
	Per cent drainage to rainfall	46.37	31.60	34.46	36.19	....	....	....

TABLE NO. 36—HIGHT OF GROUND WATER IN AN ABANDONED WELL AT THE GENEVA AGRICULTURAL EXPERIMENT STATION FROM DECEMBER, 1886, TO DECEMBER, 1889, INCLUSIVE

DATE	1886		1887		1888		1889	
	Distance to water, feet	Rainfall of preceding month, inches	Distance to water, feet	Rainfall of preceding month, inches	Distance to water, feet	Rainfall of preceding month, inches	Distance to water, feet	Rainfall of preceding month, inches
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
January 1	......	....	6.33	1.24	17.29	1.35	4.56	1.24
February 1	......	....	5.67	0.18	15.27	0.78	5.10	2.99
March 1	......	....	4.85	2.97	9.98	1.04	6.02	0.25
April 1	......	....	5.06	0.48	5.14	1.43	4.27	0.66
May 1	......	....	4.18	1.37	4.67	3.09	3.64	3.28
June 1	......	....	6.83	0.46	6.23	2.79	6.62	1.21
July 1	......	....	9.16	2.01	7.84	3.88	4.52	7.47
August 1	......	....	10.48	6.37	9.21	0.99	6.92	4.57
September 1	......	....	11.25	3.03	11.62	4.02	8.64	1.98
October 1	......	....	13.35	0.75	13.77	2.73	10.84	2.50
November 1	......	....	15.37	1.74	14.33	3.47	12.50	3.32
December 1	13.16	3.48	16.75	1.58	12.67	2.02	4.58	3.44

we have given the distance from the curb to the water surface on the first day of December, 1886, and on the first day of each month thereafter, and also the rainfall of the preceding month.



(Scale for hight of ground water in feet and for rainfall in inches.)

Fig. 4 Diagram showing the relation between rainfall and hight of ground water at the Geneva Agricultural Experiment Station, from December 1, 1886, to December 1, 1889.

In the cut, figure No. 4, the figures in table No. 36, have been platted, showing graphically the relation between rainfall and hight of ground water for the three years from December 1, 1886, to December 1, 1889, inclusive. In discussing these records, the Acting Meteorologist of the Agricultural Experiment Station notes the following facts:

1) Fluctuations in the precipitation from month to month did not much affect the hight of the water-table. The very light precipitation of January, 1887, did not stop the rise of the water-table, nor did the extremely large rainfall of July of the same year cause the water-table to stop falling.

2) The rapid rise in the water-table from January 7 to April 1, 1888, or from December 1, 1888, to January 1, 1889, was not due to large precipitation during this time, nor was the fall from May 7 to November 1, 1888, due to small precipitation.

3) The rapid rise of water from November 18 to December 1, 1889, was in part at least due to the heavy rainfall of the 18th to 23d, which found the soil nearly or quite saturated. The rainfall for that time was 2.60 inches, followed by 0.51 inch more during the latter days of November.

Although evaporation played an important part in the fluctuations, so far as appears from the report, this element was not taken into account in drawing the foregoing conclusions.

The error in precipitation, due to not fully taking into account the amount of snow, should also be considered.

Relation of Geologic Structure to Runoff

Among the principal factors affecting stream flow should be noted the structure and texture of the rocks, specially those of the surface. For example, in regions with stiff, heavy, clay soils, a larger proportion of the winter rainfall runs off on the surface, passing immediately into the streams, than is the case in regions with open, porous soils or extensive sandy areas, while in summer a much smaller proportion runs off. But such streams have a very much smaller groundwater flow, from whence it results that the total runoff per year is smaller than for streams with open, sandy soils. The Genesee and Hudson rivers represent the extremes of the State in this particular. A general knowledge of the surface geology is therefore desirable in a study of the water resources of the State. The relative position and area of the different geologic formations are best shown on the large Geologic Map of New York prepared by Dr F. J. H. Merrill, State Geologist, in 1901 (scale 5 miles to the inch). A similar but smaller map by the same author, showing essentially the same features was also printed in 1894 under authority of the Regents of the University to accompany the Report on the Mineral Exhibit of New York at the World's Columbian Exposition, this being on the scale of approximately 14 miles to an inch. This map was also published with Bulletin 15 of the State Museum and was reproduced in 1901 by Edward A. Bond, State Engineer, in his report on the proposed barge canal. On examining either of these maps one will note the preponderance, so far as area is concerned, of two classes of rocks—the ancient crystallines, which cover a large area in the northern part of the State, and the conglomerates, sandstones and shales of the Devonian, which form the greater part of the Appalachian plateau, stretching from Lake Erie across the State to within a short distance of the Hudson river, this being the area classified by the State Weather Bureau under the names of the Eastern and Western plateaus. The streams from the northern crystalline area undoubtedly furnish the best water supply of the State. This is probably not due wholly to the character of the rocks, as many other factors contribute to this result.

The sandstones of the Upper Devonian along the northern boundary of Pennsylvania are bounded on the north by the long narrow belts of outcrop of the underlying rocks stretching in a general easterly and westerly direction. The streams pursuing a general northerly course pass in succession across these. As a rule, the soils of the region are heavy, with considerable clay, and the rainfall being absorbed somewhat slowly, a considerable portion of it flows directly into the watercourses. The primeval forest has for the most part been cut away and heavy floods are common, such as those of the Genesee and Chemung rivers, described more fully on a later page.

The only streams of this region on which extensive discharge measurements have been made are the Genesee river and its tributary, Oatka creek. Streams of similar character in western Pennsylvania, however, have been measured for a number of years by the Philadelphia Water Department, and the results of these measurements are available for comparison and discussion. The results obtained on the Pennsylvania streams, the Neshaminy, Tohickon and Perkiomen, are applicable particularly in estimates of the flow of the tributaries of Delaware river, rising in New York State, and to the more easterly streams which form the Susquehanna.

The catchment basins of the Oswego, Mohawk and Hudson rivers are so highly composite as regards geologic formations and embrace such a wide variation in topography and surface geology that no definite deductions concerning the effect of the formations on water flow have been drawn. The streams of Long Island, rising among the sands, tills and gravels of comparatively recent, unconsolidated formations, offer peculiar conditions, which are discussed on a later page.

We have seen in the preceding that it is somewhat uncertain whether difference in soil due to difference in character of rocks has much influence on the runoff, although casually it appears that sandy soils, from their porousness, do considerably affect the result. Recent European studies of this subject have shown (1) that in many river basins the annual runoff stands in a nearly constant relation to the rainfall, and (2) that this constancy is more marked when the excess rainfall above a certain minimum annual depth is considered. This latter statement is equivalent to saying that if the yearly rainfall is less than such minimum depth little or no runoff will take place.[1]

The general truth of this proposition is shown by many western streams where the runoff is little or nothing. In New Jersey 12 inches of rain during the summer season produce a runoff of 1.5 inches, though others have stated a somewhat different relation. In the State of New York from 1.7 to 2 inches may be considered the general range. As to the amount of rain required to produce any runoff at all, from 12.5 to 16.5 inches have been given. For this minimum many western streams do not run more than 0.25 to 0.5 inch, and some even are perfectly dry. These statements indicate that the character of the soil, nature of vegetation, the elevation, etc. are of comparatively small importance as regards relation between the yearly volumes of rainfall and runoff. If, however, we consider the rainfall and runoff of the several periods, as shown by the accompanying tables, it is not entirely certain that these propositions are other than approximately true. The weight of evidence indeed is, on the whole, negative. Mr Vermeule is disposed to attribute nearly all of the differences between streams to difference in geology, and accordingly gives a geologic classification for the New Jersey streams. Mr Vermeule says:

> As a rule, the watersheds which lie upon the same geological formation will be found to have a strong resemblance, both in the character of flow and in the chemical composition of the waters.

Yet, as will be shown later, the Genesee and Oswego rivers, two streams with approximately the same runoff, lie mostly in differ-

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[1] Barge Canal Report, p. 798.

ent geologic formations. As regards quality of soils, Mr Vermeule also says:

> It may be inferred that the kind of soil has much less to do with the amount of evaporation than has the temperature.

As regards the relation between geology and runoff, it is undoubtedly complicated, although it is interesting to note that in the State of New York streams which flow from the north into the Mohawk river, after crossing over a narrow strip of Trenton limestone and Calciferous sand rock, and which head in the Laurentian granite of the Adirondacks, have larger flows than those coming to the Mohawk from the south, which lie mostly in the horizon of the Hamilton shales, the headwaters of some of them—as, for instance, Schoharie creek—being in the sandstones of the Chemung and Portage groups. In their lower reaches they cross over the sandstones and shales of the Hudson and Utica groups, with narrow strips of Helderberg limestone, Oriskany sandstone, and Onondaga limestone.

However, there is another consideration. The headwaters of the streams to the north of the Mohawk nearly all lie in a region heavily timbered—some of it is still primeval forest—while those to the south are from a highly cultivated country, practically deforested.

We may now consider the case of the Genesee and Oswego rivers, referring to the large Geologic Map of the State of New York.

Genesee river has an average rainfall of about 40 inches and Oswego river of about 37 inches. That portion of Genesee river which has been gaged lies almost entirely in the shales and sandstones of the Portage and Chemung groups. Oswego river, on the contrary, lies in the horizon of the Portage sandstones and shales, Hamilton shales, Onondaga and Helderberg limestones, Oriskany sandstone, the rocks of the Salina or Salt group, the Lockport limestone, Clinton limestone and shales, Medina sandstones, and Utica sandstones and shales, including the Oswego sandstone. The Chemung, Portage, and Hamilton formations have a wide outcrop, while the Onondaga, Oriskany, and Helderberg are comparatively narrow bands. The Salina, Lockport, Clinton, and Utica formations are all of considerable extent. Both of these streams are practically without forests, although slight exception to this statement may be noted on the extreme headwaters of the Genesee river in Pennsylvania, where there is still a small area of partially cut forest.

It is an interesting circumstance that the geologic formations in which the Genesee and Oswego rivers lie all have a slope to the south or southwest of from 10 to 30 feet per mile. The main trend of the Genesee river is south and north, while the two main branches of Oswego river—Seneca and Oneida—lie east and west. The Mohawk also flows from west to east. On this basis the Portage, Hamilton, Onondaga, Oriskany, Helderberg, and Salina groups lie mostly south of the Seneca and Oneida rivers, while a portion of the Salina, Niagara, Clinton and Medina groups lie mostly to the north. It is interesting, therefore, to speculate as to whether it is possible that considerable water escapes through these formations, finally appearing far to the south, but in the lack of any certain evidence this must be considered as merely a speculation.

It may be also noted that for tributaries of the Mohawk river lying to the north, the stratified formations—Utica shales, Trenton group, Calciferous sand rock, etc.—slope toward the stream, and hence may be expected, if there is anything in this view, to deliver more water than that merely due to the rainfall of the catchment as measured on the surface.

On the Upper Mohawk there is some evidence that this is true. The limestones here are open, and at several places streams on the surface sink, to reappear, in one case at any rate, with greatly increased volume several miles farther down. This condition is specially marked on the headwaters of the main Mohawk a few miles south of Boonville. Again, at Howe's Cave, in Schoharie county, there is a large stream of water flowing in the cave which, so far as known, does not appear anywhere on the surface.

The Muskingum river may be mentioned. This stream lies in the unglaciated region in southeastern Ohio, mostly in the horizon of the Conglomerate group of the Carboniferous. The main Muskingum river flows generally from north to south, with its main branches to the east and west, that to the west going a short distance into the Waverly group, which is chiefly sandstone and shale, a subdivision of the Carboniferous. The dip is from north to south. In view of the extremely low runoff of this stream, it seems tolerably evident that there can be no material contribution by percolation through these strata.

As other examples of underground flow, the writer may mention Toyah creek, in Texas, where a stream of (his recollection is) 40 or 50 cubic feet per second flows from the base of a mountain with no indication as to its source. The well-known streams in Mammoth and Luray caves are doubtless familiar to all. There are also a number of river channels in the west where the water sinks into the porous soils, to reappear at some point lower down; but these are hardly allied to the cases under consideration, because the source is here visible.

A stream at Lausanne, Switzerland, may also be mentioned. In 1872 there was a serious epidemic of typhoid fever at Lausanne, Switzerland, which, on investigation, was found to proceed from a brook irrigating lands about a mile distant from a public well, from which the 800 inhabitants of the village mostly took their water supply. Ten years before, or in 1862, a hole had appeared in the channel of the brook at a certain point, 8 feet deep and 3 feet wide, which disclosed at its bottom a running stream, apparently fed by the brook from a point higher up. The brook itself was led into this hole, with the result that the water all disappeared and in an hour or two streamed out at the public well, showing a connection which had been suspected for years. On refilling the hole the brook returned to its bed.

After the epidemic had ceased in 1872 an investigation was held, the hole was reopened and a large quantity of salt thrown in; its presence in the public well was easily ascertained by a chemical examination.

This case discloses some points of interest. Here was a considerable stream flowing underground which was easily increased from the water of the brook, which was on the surface. Again, the flow here was through coarse gravel.

Moreover, we may consider the origin of those bodies of fresh water which sometimes rise up in the sea, as in the Mediterranean near Genoa, the Persian Gulf and in the Gulf of Mexico. It is stated that in two of these cases the flow is so great as to permit of ships taking water. In the Gulf of Mexico the water surface over the outflow is stated to be several feet higher than the surrounding sea.

In the literature of canal construction there are a number of cases cited in which large losses of water have taken place either through coarse gravel or seamy rocks. Doubtless there are numerous other cases, which, however, are not specially important, for it is the writer's intention only to point out, in a general way, reasons why such losses may sometimes take place.

The outflow from Skaneateles lake has been cited as showing a large loss, presumably by percolation through strata, but on reference to the original authority it is clear enough that an error has been made in so citing it, because the flow measured was really through 9 miles of natural channel and 8 miles of canal, to Montezuma. It may be mentioned that the problem to be determined by this measurement was the discharge into Seneca river and it is quite possible that there may have been a deficiency from the west.

Skaneateles lake lies at an elevation of 867 feet above tidewater and a distance of about 9 miles south of the Erie canal, for which it has been used as a feeder since 1844. In 1859 Mr S. H. Sweet made measurements of the flow to the canal and through the same to Montezuma, where the surplus water is discharged into Seneca river, to which it was found to deliver 125 cubic feet per second. Measurements were also made at the foot of the lake, where the flow amounted to 188 cubic feet per second. The loss was 63 cubic feet per second, or one-third of the whole. Skaneateles lake itself lies in the Hamilton formation, and its outlet, on its way to the Erie canal, flows across the Onondaga, Oriskany, Helderberg and Salina formations. The dip is here from north to south, while the stream, which is tributary to the Seneca river, the main westerly branch of the Oswego, flows from south to north, or in the right direction to realize the maximum possible leakage, or percolation, through the strata. Inasmuch as no such leakage is mentioned, it may be reasonably concluded that none occurred.

Cazenovia lake and Erieville reservoirs are also mentioned, and considerable loss of water is given, which when analyzed is found to be loss of water in the canal, and hence not in any degree attributable to leakage through strata. Cazenovia lake and Erieville reservoirs both lie south of the Erie canal, and flow across substantially the same strata as the outlet of Skaneateles lake.[1]

Such facts as these, while lacking the proof of a scientific demonstration, are still very interesting and indicate that we have yet much to learn of the peculiarities of stream flow. On the whole, while they point to a moderate loss from percolation, so far as the writer can see they do not indicate any great probability of very large loss from this cause. They do emphasize the fact that every catchment area will have its own formula.

By way of showing that the theory of large evaporation on deforested catchment areas is broadly more reasonable that the theory that there is any great loss of water by seepage owing to inclination of the strata, we may consider the Croton record as given by the appended table, where it will be noted that the evaporation from this area is substantially the same as that from Muskingum and Genesee rivers; that is to say, it is the evaporation of a deforested area—the area in forest on this catchment does not exceed 10 per cent. In placing it at 10 per cent the writer means the equivalent in actual effect of dense forest. As regards geologic formation this catchment lies almost entirely in granites and gneisses, in which, from their homogeneous character, it is difficult to assume any loss by percolation through strata. There is, however, a small area of metamorphic Hudson formation, consisting of slate, schist and quartzite, and also a

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[1] Ann. Rept. State Engineer and Surveyor for 1862, pp. 403-404.

small area of metamorphic Trenton and Calciferous limestones, but it is exceedingly improbable that any rocks which have been subjected to metamorphic changes are in any degree permeable. This catchment must therefore be considered as underlain by an impermeable formation. All of the water falling upon it except that absorbed by evaporation, chemical changes, etc. reappears as runoff in the streams. It may be safely assumed that there are no other losses. Nevertheless, the evaporation of this stream is that tentatively placed upon other deforested areas. Moreover, there is another interesting consideration of which brief note may be taken at this place. In deference to the Water Supply Department of the City of New York, the writer has used in computing the monthly runoff the catchment area of 339 square miles. Mr Vermeule, however, asserts that this area is not the true one. He says the true area above old Croton dam is 353 square miles. If we assume this to be true, it follows that the average runoff, instead of being 22.8 inches, is over 4 per cent less, or is, roundly, 21.8 inches. This raises the evaporation from 26.6 inches to 27.6 inches. In his report on forests, Mr Vermeule has placed the evaporation of his second Croton series, which the writer understands him to consider more reliable, at 22.6 inches, a difference of 5 inches from the foregoing figures, which it may be remarked is based upon the latest revision and is presumably more likely to be correct.

On the upper Hudson river, with a catchment above Mechanicville of 4500 square miles, the average rainfall for the fourteen years from 1888 to 1901, inclusive, was about 44.2 inches, the average runoff 23.3 inches, and the evaporation 20.9 inches. Above Glens Falls this stream lies almost entirely in the Precambrian gneiss, from which it is improbable that there is any loss of water. Its main tributary to the west, Sacandaga, is, by observation, an exceedingly prolific water yielder. To the east, the Battenkill and Hoosic rivers have a different geologic history. The Battenkill flows across the Hudson shales, the Georgia limestones and shales, finally rising in the metamorphic Hudson and Trenton formations. The Hoosic river has a similar geologic history. The runoff of the Hoosic river is, without doubt, considerably less than that of the main Hudson. The average precipitation in western Massachusetts from 1887 to 1895, inclusive, was 38.98 inches, as against 43.29 inches in the northern plateau from 1889 to 1895, inclusive, a difference of 4.31 inches. Should such difference continue, the runoff of Hoosic river might be expected to be, on an average, about 20 inches. Moreover, the Hudson river above Glens Falls (catchment about 2800 square miles) is still largely in forest—probably about 85 per cent—but on the catchments of Wood creek, Battenkill and Hoosic rivers the proportion of forest is very much less—as an offhand estimate, the writer would say perhaps 20 to 30 per cent. The runoff of Schroon river, which is perhaps 70 per cent of an equivalent to fairly dense forest, is for four years 26.84 inches. There is, however, some doubt whether this record is entirely reliable, and for the present it is not intended to more than merely call attention to the general proposition that this stream, which issues from an impermeable catchment with 70 per cent of it in forest, has a rather large runoff. The whole catchment area of the Upper Hudson of about 4500 square miles, will probably not exceed 50 to 60 per cent of forest.

The following are the catchment areas of the several streams here considered: Hoosic, 711 square miles; Battenkill, 438 square miles; Sacandaga, 1057 square miles, and Schroon river, 570 square miles.

The Pequannock river in New Jersey, not far from the New York line, is an interesting case. This stream is characterized by sharp slopes throughout its whole extent. Its headwaters are at an elevation of about 1500 feet, while the mouth is only 170 feet above tide. The catchment is about 14 to 16 miles long by 4 to 7 miles wide. Mr Vermeule states that its headwaters lie in the Precambrian highlands. The sharp slopes, combined with small catchment area, undoubtedly account for the relatively large runoff of this stream. There is also an uncertainty of 1 or 2 inches in the rainfall record. The catchment is judged by the writer to be 70 per cent forest.

In riding over the Pequannock catchment several times the writer was much struck by the fact that aside from the main valleys there are no gulleys throughout this area. The record shows that precipitation is frequently very heavy, but it has been thus far without effect. The indications appear to be that the rainfall, however intense it may be, sinks almost entirely into the ground, and without doubt this peculiarity has its effect on the runoff.

It may be pointed out that the geology of Muskingum and Genesee rivers is substantially the same, while the geology of Croton river is entirely different. Nevertheless, when analyzed by aid of the diagrams, these streams are all seen to have substantially the same evaporation and runoff, although the rainfall on Croton river is different from that of Muskingum and Genesee rivers. Hudson river, however, which has much the same geology as Croton river, has still a very different runoff and evaporation. Oswego river, which lies in a different formation from Genesee river, has still nearly the same evaporation.[1]

These several facts favor the view that deforestation is the real cause of the smaller runoff of Muskingum, Genesee, Oswego and Croton rivers.

Forests

Do forests increase rainfall? The evidence on this point is conflicting. The variation of the observed from the true rainfall being so great, as has just been shown, the answer to this question must be regarded as very uncertain. It has been discussed by Professor Abbe and Dr Hough.[2] The following summation by Dr Hough, although made 26 years ago, may be accepted as expressing the fact at the present day.

> The reciprocal influences that operate between woodlands and climate appear to indicate a close relation between them. It is observed that certain consequences follow the clearing off of forests, which can scarcely be otherwise regarded than as a direct

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[1] The evaporation of Oswego river is, in fact, a little greater, due to the existence of large marsh areas on Oswego river.

[2] Report upon Forestry, by Franklin B. Hough, U. S. Department of Agriculture (1877).

effect, such as the diminution of rivers and the drying up of streams and springs. Other effects, scarcely less certain, are seen in the occurrence of destructive floods, and of unseasonable and prolonged droughts, with other vicissitudes of climate which it is alleged did not occur when the country was covered with forests. These appear to have been brought about by their removal, and might, in a great degree, be alleviated by the restoration of woodlands to a degree consistent with our best agricultural interests.

On the other hand, there are many facts tending to show that the presence or absence and the character of forests are the effect of climate, and that their cultivation generally, or the planting of particular species, is closely dependent upon it. These conditions of climate should be understood before forest cultivation is attempted. It is also to be noticed that differences of opinion have been expressed among men of science as to the extent of influence that forests exert upon the climate, and it is quite probable that the advocates of extreme theories may have erred on both sides. But where principles depend upon facts that may be settled by observation, there should be no differences of opinion; and as there is no fact in this subject that may not be verified or disproved, the existence of such differences only shows the want of accepted evidence derived from trustworthy records.

The interested reader is referred to Dr Hough's report, which may be easily obtained, for an extended discussion on this point.

Relation of forests to stream flow. The extent of forestation has probably a considerable effect on the runoff of streams. With similar rainfalls, two streams, one in a region having dense primeval forests, the other in a region wholly or partially deforested, will show different runoff. The one with the dense forests will show larger runoff than the stream in the deforested area. In some parts of the State of New York these differences may amount to as much as 5 or 6 inches in depth over the entire catchment area. Yet it must be said that this proposition is, for the present, tentative in its character.

The writer is particular to specify dense forests, because a good deal of discussion has clustered around this point. Of such forests, the most effective are those composed of spruce, pine, and other evergreen trees. Where the forest is more or less open to wind and sunshine, its effect, while considerable, is still much less marked than that of dense evergreen forests where the sun seldom penetrates and the wind effect, even in a gale, is only slight. On a catchment area where there are only scattered patches of forest, the effect is practically the same as on a deforested area. The same proposition is generally true on a catchment with young trees. What is wanted for the maximum effect is a mature evergreen forest.

This proposition, however, though definitely stated here, has been nevertheless the subject of considerable discussion, and owing to its complex nature, it is improbable that a final conclusion concerning it will very soon be reached.

The subject of the influence of forests on runoff has assumed considerable importance in New York because of the policy of the State government to purchase large tracts of land in the Adirondack and Catskill mountains (1), for the creation of extensive State parks, and (2), for the purpose of conserving the runoff of the streams issuing from these regions. The creating of State parks is commendable and does not enter specially into the present discussion, but whether the creation of forest areas in the Adirondack and Catskill mountains will materially increase stream flow is a question on which widely varying views have been expressed. It is proposed, therefore, to give an indication of the probable bearing of forests on stream flow, and in order to make the discussion as valuable as possible, numerical values will be used.

The Forest preserve. In 1893 the Legislature passed an act creating the Forest preserve and the Adirondack park. The Forest preserve is defined as including:

> The lands now owned or hereafter acquired by the State within the counties of Clinton, except the towns of Altona and Dannemora, Delaware, Essex, Franklin, Fulton, Hamilton, Herkimer, Lewis, Oneida, Saratoga, St Lawrence, Warren, Washington, Greene, Ulster, and Sullivan, except (1), lands within the limits of any village or city; and (2), lands, not wild lands, acquired by the State on foreclosure of mortgages made to the commissioners for loaning certain moneys of the United States usually called the United States deposit fund.[1]

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[1] Chap. 332, laws of 1893.

The Adirondack park. The Adirondack park is situated within the Forest preserve. It is defined as:

> Lands now owned or hereafter acquired by the State within the county of Hamilton; the towns of Newcomb, Minerva, Schroon, North Hudson, Keene, North Elba, Saint Armand and Wilmington, in the county of Essex; the towns of Harrietstown, Santa Clara, Altamont, Waverly and Brighton in the county of Franklin; the town of Wilmurt in the county of Herkimer; the towns of Hopkington, Colton, Clifton and Fine, in the county of St Lawrence; the towns of Johnsburgh, Stony Creek and Thurman, and the islands in Lake George, in the county of Warren . . . shall constitute the Adirondack park. Such park shall be forever reserved, maintained and cared for as ground open for the free use of all the people for their health and pleasure and as forest lands, necessary to the preservation of the headwaters of the chief rivers of the State, and a future timber supply; and shall remain part of the Forest preserve.[1]

From the foregoing it may be seen that the Forest preserve is much more extensive than the Adirondack park. The Adirondack park, as shown on the accompanying map, includes the whole of Hamilton, and parts of Warren, Herkimer, St Lawrence, Franklin and Essex counties, and includes 2,807,760 acres (4387 square miles), or about one-eleventh of the land area of the State. In 1893 the lands within the Adirondack park were classified, lot by lot, with the following result:

	Acres	Square miles
Primeval forest	1,575,483	2,461.7
Lumbered forest	1,027,955	1,606.2
Denuded	50,050	78.2
Burned	13,430	21.0
Waste	18,526	28.9
Water	57,104	89.2
Wild meadows	495	0.8
Improved	64,717	101.1
Total	2,807,760	4,387.1

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[1] Chap. 332, laws of 1893.

In that year the State owned 1142.9 square miles, of which 861.1 square miles were situated within the lines of the Adirondack park. In 1897 the Forest Preserve Board was created, consisting of three members, whose duties were to acquire for the State, by purchase or otherwise, land, structures or water in the territory embraced in the Adirondack park. Under this act, purchases were made within the limits of the park, between May, 1897, and January 1, 1900, amounting to 497 square miles. The total owned by the State, therefore, in the park in 1900 was 1358.1 square miles. There are 101.1 square miles of improved lands within the lines of the Adirondack park. It is not proposed to purchase these lands, although if any should be abandoned or offered for sale at woodland prices, they might be purchased for reforesting. The soil of the Adirondack plateau is mostly worthless for agriculture. Over a considerable portion of the region frosts occur in every month except July, and it is impossible to cultivate any of the cereals except oats, as well as many of the ordinary crops of the lowlands. Hay is the principal crop. The region generally is valuable only for forestry and water storage.

Area of Forest preserve. The following area, with small deduction as previously noted, is included in the Adirondack Forest preserve:

	Square miles
Essex county	1,926
Hamilton county	1,745
Warren county	968
St Lawrence county	2,880
Franklin county	1,718
Herkimer county	1,745
Clinton county	1,092
Fulton county	544
Lewis county	1,288
Oneida county	1,215
Saratoga county	862
Washington county	850
Jefferson county	1,868
Total	18,701

The Catskill Forest preserve includes the following:

	Square miles
Delaware county	1,580
Greene county	686
Ulster county	1,204
Sullivan county	1,082
Total	4,552

Adding the area of the Adirondack Forest preserve to the area of the Catskill Forest preserve, we have a total of 23,253 square miles. There is, however, some deduction from this, but the entire area is over 20,000 square miles. The total land area of the State of New York is about 47,620 square miles. Hence, we reach the conclusion that the originators of this act propose to ultimately reforest perhaps 42 per cent of the total land area of New York.

Catskill park. Thus far the Catskill park has not been defined by law, although considerable time has been spent by the Superintendent of Forests in a personal examination of the Catskill region in order to determine the portion best adapted to forestry purposes. For the present the proposed Catskill park includes 703 square miles, which the Forest Preserve Board deems advisable to purchase in this region. It is described as follows:

This area includes the towns of Hardenburgh, Shandaken, Denning, Woodstock and the westerly portion of Olive and Rochester, in Ulster county; the greater part of the towns of Hunter and Lexington, in Greene county; that portion of the towns of Colchester, Andes and Middletown, in Delaware county, which lie south of the Delaware river; and that part of the towns of Neversink and Rockland, in Sullivan county, which are situated in great lot 5 of the Hardenburgh patent.

This area, forming the proposed Catskill park, may be described also in a general way as bounded on the north by the Delaware river, Schoharie creek, and the line of the railroad running from Hunter to Kaaterskill station; on the east by the line of the Great Hardenburgh patent; on the south by the southerly line of the great lot 5, and on the west by the town line between Lexington and Halcott.

In addition to the territory thus outlined, the Board is willing to make purchases of forest land, if offered at a reasonable price, on the mountain ranges, including the peaks known as Black Head, Black Dome, Thomas Cole, Acra Point, and Windham High Peak. These are the mountains which are in full view from the Hudson River valley, between Hudson and Saugerties. These ranges could not well be included in the boundary previously referred to, as they are separated by wide valleys that are entirely occupied by well-cultivated farms, several villages and a large population.[1]

The preceding figures show that the total amount of land in the Adirondack and Catskill parks, proposed to be purchased and held as public parks forever, is 5,090 square miles. As regards the purchase of these lands for park purposes, the writer wishes to express the fullest sympathy, but as regards the conservation of streams and prevention of floods, that is quite another question—one, indeed, permitting of somewhat broad discussion. While it is conceded that forests are of considerable value in this direction, it is nevertheless believed that the effect has been overestimated.

In 1901 the purchase of lands by the Forest Preserve Board was discontinued, Governor Odell vetoing the appropriation on the ground that we need to know a great deal more about the results and effects before proceeding further on these lines. Since that veto there has been a good deal of discussion, but without much clarifying the subject.

Effect of forests. The difference in runoff between a forested and a deforested area in New York State may be taken at an average of 5 inches. That is to say, when forested with dense forests of spruce, pine, balsam and hemlock, the runoff will be, roundly, 5 inches per year,[2] more than it will when deforested, but in order to secure such result the entire catchment area of a stream must be in dense, primeval forest. It will not do to have a few hundred square miles at the headwaters in primeval forest and

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[1] From 4th An. Rept. of Forest Preserve Board, p. 14.

[2] The average annual runoff varies from about 23.26 inches on Hudson river to about 14.2 inches on Genesee river. Hence, the excess runoff due to forests is 21 per cent of the average annual runoff on Hudson river and 35 per cent on Genesee river.

the balance deforested. The reason why dense, primeval forest is specified is because such forest acts more efficiently as a wind-breaker than does an open forest. It has been common to assume that even when the soft wood (pine, spruce, hemlock, etc.) is removed from an area the hard wood still forms about as efficient a covering as before the removal of the soft wood. The writer, however, thinks that anybody who has spent much time in the forest will understand that this is a mistake. Certainly during the late fall, winter and early spring, a period of from six to seven months, when the leaves are absent from the hard woods, they are not a very efficient wind-breaker, although without doubt considerably better than nothing. As an estimate based on judgment, it is considered that a hardwood forest is not equivalent in water protective influence, on an average, to more than 50 per cent to 60 per cent of dense, primeval forests of spruce, pine, balsam and hemlock. Moreover, the weight of evidence goes to show that the soft wood consumes less water than hard wood.

In the Adirondack forest beech, maple, birch, elm, ash and other hard woods are mingled with the soft woods spruce, pine, hemlock, balsam and to some extent, larch. If we remove the soft woods, we have done two things to lessen the protection from evaporation: (1), we have opened up the area for the admission of wind, which by itself will materially increase the evaporation, consequently leaving less water to run off, and which will be specially operative during the six or seven months of the year when the leaves are absent from hardwoods; and (2), we have left on the area the hard woods, which, so far as the evidence goes, consume more water than the soft woods. The writer has no way of proving the proposition, but assuming that the data as to transpiration of hard woods as compared with soft woods are measurably true, he has no doubt that the combined effect of transpiration and evaporation will be, on an area from which the soft woods have been removed, from 2 to 2½ inches more than on the same area with the soft woods standing.

We have seen in the foregoing that the area of the Adirondack park is 4387 square miles, of which a little over one-half was, in

1893, primeval forest, while the balance was largely lumbered forest—that is to say, forest with the soft woods removed. Probably the proportion of primeval forest is somewhat smaller at the present time, and may be taken at 50 per cent. For the whole 4387 square miles, we may say that the forest protection is now equivalent to 3½ inches additional runoff due to the cover. If, therefore, the entire Adirondack park were reforested with dense primeval forests, we might expect an addition of an inch and a half per year in the runoff from this area.

On reference to table No. 61, Runoff Data of Hudson River for the Water Years 1888–1901, Inclusive, it will be seen that the average runoff per year for fourteen years is 23.27 inches. The maximum runoff, of 33.08 inches, occurred in 1892, and the minimum, of 17.46 inches, in 1895. With dense, primeval forests over the entire area of the Adirondack park we may expect an average of about 24.75 inches annual runoff, or the increase of about 6½ per cent over the present runoff—an amount of water which, distributed over the entire year, as it will be, is inappreciable in its influence on the flow of streams.

In the Catskill region the soft woods have long since disappeared and the hard-wood forest is mostly open, presenting less satisfactory protection than does the Adirondack hard-wood forest. It is doubtful if the open hard-wood forests of the Catskill region are equivalent, in protective effect, to over 25 per cent to 30 per cent of a dense, primeval forest of spruce, pine, balsam and hemlock, or we may say that the present runoff of the Catskill streams is only an inch and a half more than it would be if the region were substantially deforested. The effect, therefore, of reforesting with soft woods would be to increase the flow of streams annually about 3½ inches in depth over the area actually reforested. But the reforested area is so small a proportion of the whole area that the total effect on the flow of any given stream is so slight as to be scarcely perceptible. This proposition is reiterated because in the extensive discussions of this question which have recently appeared it has been tacitly assumed that the reforestation of the Adirondack park would have so great an effect on the streams issuing therefrom as to make water storage in New York not only unnecessary but undesirable. In the case of the Hudson river there is perhaps 1500 square miles of the catchment area within the Adirondack park, which, if entirely reforested, would, as we have seen, increase the present flow of the stream 1½ inches, but this increase of 1½ inches is only obtained on the 1500 square miles actually reforested. The catchment area of Hudson river above Mechanicville, the point where the gagings shown in table No. 61 have been made, is 4500 square miles. The net effect, therefore, at this point is only one-half inch of water, distributed throughout the entire year, an effect which is inappreciable.

However, there is another consideration. Owing to less rainfall on the eastern plateau than on the northern plateau, streams in the Catskill region do not flow as much as those in the Adirondacks. As we have seen, the average flow of the Hudson river for fifteen years is 23.27 inches. Taking the difference in rainfall of these two districts at 4 inches, the flow of the streams in the Catskill region, provided forestation were equal to that of the Adirondacks, would be over 19 inches. But taking into account the existing differences in forestation, the flow of streams in the Catskill region does not average over 16 or 17 inches per year. It follows, therefore, that an increase of 3½ inches in the Catskill region is relatively of more value than a corresponding increase in the Adirondack region. As has been shown, for the Adirondacks the increase of 1½ inches is equivalent to 6½ per cent of the present annual flow of streams issuing from that region, while in the Catskills, 3½ inches is equivalent to 22½ per cent of the present annual flow of streams. Reforestation, therefore, is considerably more valuable in the Catskills than it is in the Adirondacks. But the foregoing does not mean that 5 inches more water will flow over the entire area of the streams issuing from the Catskill region, but only from that portion of the region on which forest has been restored. As we have seen, the area of the proposed Catskill park is 703 square miles, while the area of the Catskill Forest preserve is about

4500 square miles. The area, therefore, of the proposed Catskill park is only about 15 per cent of the area of the Catskill Forest preserve, which includes the catchment area of the headwaters of the streams as enumerated on a preceding page. The balance of the territory is mostly deforested, and chiefly in use for grazing purposes. In the Catskill region therefore, the forested area would be, on this basis, about 1/7 of the deforested, or the real effect on stream flow would be to increase it 1/7 of 5 inches. An average annual increase of about 0.7 of an inch may be expected.

Moreover, if forestation is valuable in increasing stream flow, there should be a number of other forest parks in various parts of the State. Genesee river issues from the Allegheny water center. With the exception of a small tract of timber at the extreme headwaters, this stream is practically deforested, with the result, as shown by table No. 43, Runoff Data of Genesee River, that the average annual runoff for a period of nine years is only 14.2 inches, while the minimum runoff is 6.7 inches. If forestation is specially valuable for increasing the flow of a stream, here is a marked case to which it could be applied. The writer, however, does not wish to be understood as stating that forestation is not of value, and he cites from the Genesee River Storage Report[1] the following specific case, showing that on Genesee river forestation has value in increasing the summer flow. The proposition is that, by itself, it is not of enough value to justify any such expenditure as has been proposed. The benefits, in short, are not commensurate with the expense.

Gagings of the low-water flow of Genesee river were made by Daniel Marsh, C. E., in July and August, 1846, and the quantity flowing at that time was found to be 412 cubic feet per second. Mr Marsh gives this figure as the average of nine gagings made at various times during the summer of 1846. The meteorological records of western New York for the years 1844-46 show that the period covered was one of low rainfall. At Rochester the rainfall for the storage period of 1846 was only 11.57 inches, and the total for the year was 36.03 inches; in 1845, the total for the

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[1] 3d Genesee River Storage Report, Jan. 1, 1897, pp. 40-41.

year was 34.66 inches, while in 1844, we have for the storage period, 10.52 inches, and the total for the year of 26.46 inches. At Middlebury Academy, for the storage period of 1845, the rainfall was 12.59 inches; for the growing period, 4.82 inches; for the replenishing period, 8.6 inches, and the total for the year was 26.01 inches. The record for the year 1846 at Middlebury Academy is not given, but it is clear, so far as we have any definite meteorological record, that the gagings made by Mr Marsh were at a time of very low water.

Gagings made in 1895 show that in the month of July the flow at Rochester may have been as low as 232 cubic feet per second, and in September, 221 cubic feet per second. These results are derived from actual gagings at Mount Morris by comparison of catchment areas. Taking approximate gagings made at Rochester, at the Johnson and Seymour dam, for the same year, we have 220 cubic feet per second for the mean of the month of October. Moreover, gagings made at the raceway of the Genesee Paper Company during the summer of 1895 indicate that on several occasions the flow was less than 200 cubic feet per second. The canal, however, was low during these years and was drawing some water through the feeder at Rochester—probably, on an average, about 50 cubic feet per second. We have, then, a total low-water flow at Rochester of about 250 cubic feet per second during the period July-October, 1895. This quantity is 162 cubic feet per second less than the low-water flow of 1846, as determined by Mr Marsh.

The catchment area of the Genesee river at Mount Morris, where the gagings were made, is 1070 square miles, and at Rochester, with deductions for the area at Hemlock lake, used as a water supply for Rochester, etc. 2365 square miles. In 1846 the upper Genesee area was still largely in forest—probably for the entire area above Rochester the primeval forest was from 50 per cent to 60 per cent of the whole.[1] We have here, therefore, a

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[1] In Allegany county, according to the State census of 1855, the unimproved area was 60 per cent of the whole, but in Livingston and Monroe counties it was considerably less. Since the rapid removal of the timber did not begin until after the construction of the Erie railroad, it is considered that in 1846, 50 per cent to 60 per cent is not far from right.

marked case where the deforestation of a large area has materially reduced the minimum runoff, but it should not be overlooked that of the total area of 2365 square miles, 55 per cent was still in dense, primeval forest, consisting over a considerable portion of the area of pine and hemlock. The cleared area, therefore, was only 45 per cent of the whole, or 1060 square miles. Hence, we have over 1300 square miles still in primeval forest.

The writer has no doubt that deforestation not only decreases the yield of streams, but may increase the hight of floods somewhat. At present the data are not complete enough to justify final conclusions, but it is considered that the effect of deforestation is more marked in decreasing the yield of streams than in increasing the hight of floods.[1]

Apparently this view occurred to the original framers of the Forest law of 1893, because they provided therein for a Forest preserve of over 20,000 square miles, and should this amount of territory be reforested, it would undoubtedly materially assist the low-water flow of the streams issuing from the reforested area, the amount of assistance on any particular stream being in proportion to the reforested area in comparison with the deforested. But even with these 20,000 square miles of territory reforested, there would still remain 27,600 square miles of the State practically deforested, and in which the streams are exposed to low water in the summer and destructive high water in the late winter and spring. The conclusion seems, therefore, irresistible that if reforestation is of such importance for 5000 square miles, it is of more importance for 20,000 square miles, and of still greater importance for the entire area of the State of 47,600 square miles. But this conclusion reduces to an absurdity. The reforestation of the whole State would mean not only very material reduction of its productive capacity, but would mean that a large proportion of the population must move to other states.

In regard to the decrease in productive capacity, if the entire area were in forests it would produce not to exceed $2 per acre

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[1] For extended discussions see 3d Genesee Storage Report.

per year[1] in the way of forest products; or since for 47,620 square miles there are 30,476,800 acres, we may say that the forest products would be worth about $61,000,000 per year. But according to the United States Census of 1900, the agricultural products of New York were worth $245,000,000 per year, or, as an average, about $8 per acre. It is absurd, therefore, to discuss the reforestation of the whole State of New York in order to increase the low-water flow of streams and to decrease the hight of floods. Were this to be done the productive capacity of the State would be reduced over $180,000,000 per year.

The long-time element in forestry may also be taken into account, and the following statement by Mr B. E. Fernow, Director of the New York State College of Forestry of Cornell University, is pertinent.[2]

> The one thing in which the forestry business differs from all other business is the long-time element, for it takes a hundred years and more to grow trees fit for the use of the engineer, the builder and the architect; hence, the dollar spent now in its first start must come back, with compound interest, a hundred years hence.

In view of this statement it is well to keep in mind that reforestation will be substantially without effect for fifty years and of only partial effect in one hundred years, and that for its full effects in increasing the flow of a stream about one hundred and fifty years must elapse. In many parts of New York the flood flows of streams are very destructive—a conservative estimate places the loss in 1902 at over $3,000,000. The question, therefore, may be asked, Must we wait from one hundred to one hundred and fifty years, while forests are growing, in the meantime suffering nearly every year from the devastating effects of extreme floods?

Whatever question there may be as to the influence of forests on rainfall, there is, in the opinion of the writer, none as to such

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[1] 6th An. Rept. of Forest, Fish and Game Commission of New York, for 1900, p. 96.

[2] The Forester, an Engineer, by B. E. Fernow. In Jour. of Western Soc. of Engrs., Vol. VI, No. 5 (Oct. 1901).

influence on stream flow. Yet this proposition has also been discussed pro and con and is likely to give rise to further discussion, and the conclusion will therefore for the present be considered tentative in its character.

It seems to the writer that the removal of forests decreases stream flow by allowing freer circulation of the air and by causing higher temperature and lower humidity in summer and so producing greater evaporation from water surfaces, as well as from the ground.

That the removal of forests renders stream flow less equal throughout the year and so causes floods and periods of dryness in rivers seems to be beyond reasonable question, for the forest litter and root masses serve as storage reservoirs, tending to equalize the flow of streams.

Space will not be taken to discuss these propositions, because very little can be added to previous discussions. The reader is referred to the Bulletin No. 7, of the Forestry Division of the Department of Agriculture on Forest Influences, as well as to Dr. Hough's report on forests, for fairly complete discussions.

Forestation of the Croton catchment area. In a paper[1] read before the American Forestry Association in 1901, Mr Vermeule proposes the question whether the forestation of the catchment area of the Croton water supply is advisable. In considering this question it may be pointed out that if the Croton catchment were forested, there is no probability of reaping the full benefit under from 75 to 150 years.

For the sake of the argument we will assume that on this catchment in 120 years the full effect of forestation would be realized. This would give, as an average, an increase of from 4 to 6 inches in runoff. For the purposes of this discussion we may assume it at 5 inches.

In order to forest the catchment it would be necessary to acquire the entire area, which, so far as the writer can ascertain, could hardly be done for less than $100 per acre. Probably the price would be much greater than this, but to avoid an overestimate

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[1] New Jersey Forests and their Relation to Water Supply, by C. C. Vermeule: The Engineering Record, Vol. XLII, No. 1 (July, 1901).

it may be fixed at $100 per acre. At this rate the catchment area of 339 square miles would cost $21,696,000. The planting out of trees could hardly cost less than $20 per acre additional, but in order to make the estimate as reasonable as possible we will take it at $10 per acre, which makes an additional sum of $2,169,900, or a total of $23,865,900.

If we assume the annual interest at 3 per cent, and place this sum at compound interest for 120 years, we have at the end of that time the sum of $779,510,000. The present safe yield of the Croton catchment, with all available storage, is about 280,000,000 gallons per day. We would pay, therefore, this large sum for, perhaps, 75,000,000 gallons additional per day at the end of 120 years. It is true there would be some increase in water supply after about 30 years, and the supply might be expected to go on increasing until the average increase of yield was attained in 120 years. But the increase in water supply would not be at all commensurate with the increase of capitalization. It is very evident that an expenditure of this sum of money would procure a far greater quantity of water from other sources. Hence it does not seem expedient to suggest the forestation of the Croton catchment area as a method of obtaining an increased water supply. As to whether it is desirable to reforest this area as a forestry investment is another question which is not discussed here.

Another objection to the forestation of the Croton catchment as a remedy for the water difficulties of New York city may be found in the fact that a considerably increased water supply is wanted at once; it is entirely out of the question to wait 120 years for such increased supply.

As a broad proposition, however, catchment areas from which municipal water supplies are drawn should be in forests, and undoubtedly as time goes on this condition will be more and more attained. Already various European and American municipalities have recognized the advisability of owning the catchments from which their municipal water supplies are drawn. From this point of view it is desirable to reforest the Croton catchment.

Details Concerning Tables and Diagrams

Topographic relations of catchment areas of some of the main streams tabulated. The following gives an outline of the topography of Muskingum, Genesee, Croton and Hudson rivers.

The headwaters of Muskingum river lie at an elevation of about 1100 feet, and it flows into the Ohio river, near Marietta, at an elevation of about 500 feet. The Muskingum river proper has a length of 109 miles, with its main tributaries, the Walhonding and the Tuscarawas, having an additional length of about 100 miles, thus giving the basin a length of 200 miles. From the head of the Tuscarawas to the junction of the two main tributaries there is a fall of about 2 feet per mile, and from this point to the mouth of the main Muskingum the descent is about 1.5 feet per mile. On the Walhonding the descent is more rapid. At its headwaters, near Mansfield, the stream is from 400 to 450 feet above what it is at its junction with the Tuscarawas.

The Genesee river rises in Potter county, Pa., and flows in a northerly direction across the State of New York, emptying into Lake Ontario at Rochester, having a total length of about 115 miles. Its headwaters are at an elevation of over 2000 feet, while Lake Ontario lies at a mean elevation of 247 feet. This stream is specially characterized by two sets of falls. The three falls at Portage have an aggregate of about 270 feet, while at Rochester the river falls 263 feet, also in three falls, with some intervening rapids. This stream flows for several miles, at Rochester and Portage, over bare rocks.

The Croton river flows into the Hudson at Croton Landing at an elevation of practically tidewater. Its extreme headwaters in Dutchess county are at an elevation of about 700 feet above tide. Its length is about 35 miles.

Hudson river, at Mechanicville, is about 60 feet above tide, while at its extreme headwaters it is about 3400 feet above tide level. The catchment area above Glens Falls is from 40 to 50 miles from east to west and from 60 to 65 miles from north to south. Below Glens Falls the catchment extends well into southern Vermont and Massachusetts. The length of the stream above Mechanicville is from 120 to 125 miles.

Family resemblance of streams. In tables Nos. 42, 43, 61 and 66 we have the mean rainfall, runoff and evaporation of the storage, growing and replenishing periods for Muskingum, Genesee, Croton and Hudson rivers. Those tables show what may be termed the family resemblance between streams. For instance, for the Muskingum and Genesee rivers the mean rainfall of the storage period is about 19 inches, with a runoff of about 10 inches and an evaporation of about 9 inches. For the growing period the mean rainfall of each of these two streams is about 12 inches, with runoff 1.7 inches and evaporation 10 inches. For the replenishing period the mean rainfall of each is about 9 inches, with runoff about 2 inches and evaporation 7.5 inches. The total rainfall of the whole year is 40 inches for each stream—runoff 13.5 inches and evaporation 26.5 inches.

The Croton river has a much higher rainfall. Twenty-four inches in the storage period produces 17 inches of runoff, with an evaporation of 7 inches. From 13.6 inches of rain in the summer we have 2.6 inches of runoff, with 11 inches of evaporation. The rainfall for the year is 49.4 inches, or, say, 9 inches more than for Muskingum and Genesee rivers. The runoff is also about 9 inches in excess of that of these two streams. The evaporation is, however, the same, pointing very strongly to a similar cause.

The Hudson river shows apparently the effect of an impermeable catchment, combined with a large forest area. It has a mean annual rainfall of 44.2 inches, yielding 23.3 inches runoff, with 20.9 inches evaporation. For the storage period 20.6 inches rainfall yields 16.1 inches runoff, with 4.5 inches evaporation. For the growing period 12.7 inches rainfall yields 3.5 inches runoff, with 9.3 inches evaporation. For the replenishing period 10.9 inches rainfall yields 3.7 inches runoff and 7.1 inches evaporation.

The classification here given is experimental merely, and is subject to modification with the gathering of more complete data.[1]

In the foregoing the classification is, with the exception of Muskingum river, not only limited to the State of New York but

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[1] For more extended discussion of classification of streams see paper on Relation of Rainfall to Runoff.

is further mostly limited to streams with considerable length of record.

Description of Muskingum, Genesee, Croton and Hudson rivers. Table 42 gives the rainfall, runoff, and evaporation of the storage, growing and replenishing periods, as well as the total of these three items, on the Muskingum river, for the years 1888-1895, inclusive. The minimum year was 1895, the total runoff being 4.90 inches. The maximum occurred in 1890, with a total runoff of 26.84 inches. The mean runoff for the entire period is 13.1 inches.

Table 43 gives the same facts for the Genesee river for the years 1890-1898, inclusive. In this table, for the years 1890-1892, the record of Oatka creek which was gaged by the writer, has been used. For a portion of 1893 the results are computed. The dam at Mount Morris, at which gagings were taken, was carried away by a flood early in 1897, and for the years 1897 and 1898 the gaging record has been deduced by comparison of the rainfalls with those at Rochester, where gagings are kept by the City Engineer. The results, aside from those for the years 1894-1896, must be considered somewhat approximate, although probably within 10 per cent of the truth. The mean evaporation for the years 1894-1896 was 27.21 inches.

Tables 66 and 67 exhibit the rainfall, runoff, and evaporation of the storage, growing, and replenishing periods for Croton river, from 1868-1899, inclusive, a period of thirty-two years. This record has been revised as per experiments at Cornell University, described by John R. Freeman, member American Society Civil Engineers, in his report to the Comptroller in 1900. As shown by Mr Freeman, the rainfall record from 1868-1876, inclusive, is not very reliable, and accordingly two sets of means are given. The mean rainfall from 1868-1876, inclusive, was 45 inches, the mean runoff 23.37 inches, and the mean evaporation 21.63 inches. For the second period the rainfall from 1877–1899, inclusive, has been so rationally treated by Mr Freeman as to leave nothing to be desired. The means for this second period are: rainfall, 49.33 inches; runoff, 22.81 inches, and evaporation, 26.52 inches. A comparison of these two sets of means shows how dangerous it is to draw final conclusions from data about which there is considerable doubt. The rainfall differs by 4.33 inches and the evaporation by 4.89 inches, or from 20 per cent to 25 per cent.

In preparing these tables the figures of table No. 26 of Mr. Freeman's report have been used. This table is in million gallons per 24-hour day, and has been reduced to inches per month on the catchment area of 338.8 square miles. The following gives the water surfaces exposed to evaporation at different periods:

	Per cent
5.8 square miles, 1868–1873,	=1.73
6.2 square miles, 1873–October, 1878,	=1.83
6.9 square miles, 1878–1891,	=2.03
8.4 square miles, 1891–1893,	=2.48
9.5 square miles, 1893–1895,	=2.82
11.0 square miles, 1895–1897,	=3.28
12.0 square miles, 1897–1900,	=3.56

It may at first thought be imagined that these large water surfaces exposed to evaporation have considerably increased the ground evaporation over the entire catchment. When, however, one considers that it is only the difference between what a water-surface evaporation and what a ground-surface evaporation would be, the difference is seen to be not very much. For instance, assuming the water-surface evaporation at 36 inches per year and the ground surface evaporation at 27 inches per year, the difference becomes 9 inches. With 12 square miles of water surface in 1900, giving 3.56 per cent of the whole, the excess of water-surface evaporation over ground-surface evaporation is 0.32 of an inch, a quantity which is so far within the limit of possible error in other directions as to be negligible. At the most, taking the catchment area at 338.8 square miles, it would only reduce the evaporation from 26.5 inches to 26.2 inches.

The minimum year in this table is seen to be 1880, when only 13.71 inches ran off. In 1883 the runoff was also very low, being only 13.74 inches.

Table 61 gives the rainfall, runoff, and evaporation of the storage, growing, and replenishing periods for the Hudson river area for a period of 14 years, from 1888-1901, inclusive. The minimum year was 1895, when 36.67 inches of rainfall yielded 17.46 inches as runoff in the stream.

Description of diagrams. We may now consider a few of the large number of diagrams which have been prepared.

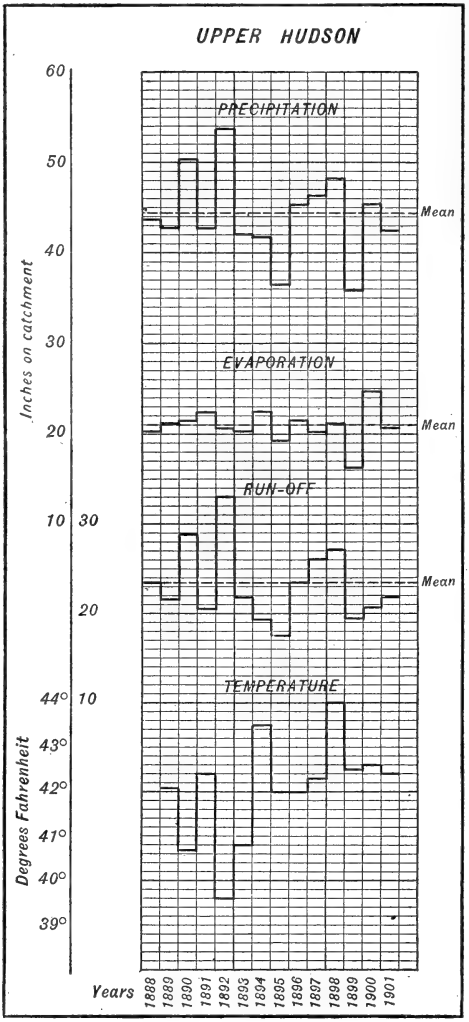


Fig. 5 Diagram showing relation between precipitation, evaporation, runoff and temperature on the Upper Hudson river.

Fig. 5 shows, for the Upper Hudson, precipitation, evaporation, runoff, and mean annual temperature for the years 1888–1901, inclusive, platted in the natural order.

Fig. 6 shows, for the same area, evaporation and mean annual temperature, platted in the order of evaporation.

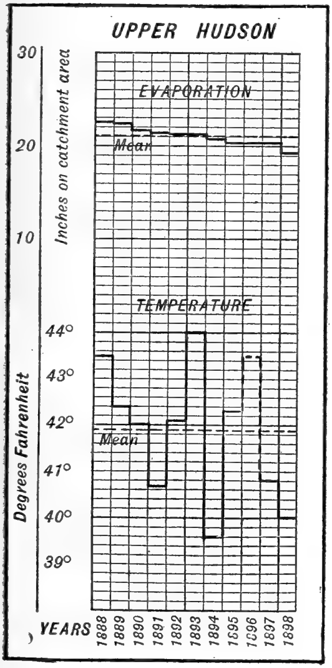


Fig. 6 Diagram showing the relation between evaporation and temperature on the Upper Hudson river, the years being arranged according to the amount of evaporation.

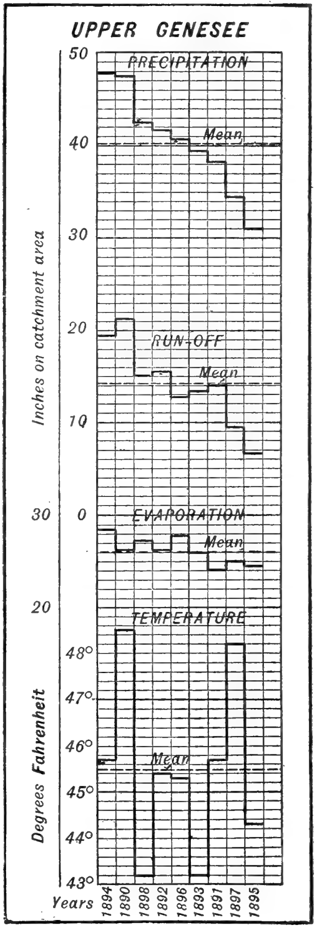


Fig. 7 Diagram showing the relation between precipitation, runoff, evaporation and temperature on the Upper Genesee river, the years being arranged in order of dryness.

Fig. 7 shows, for the Upper Genesee, precipitation, evaporation, runoff, and mean annual temperature, platted in the order of the precipitation.

Fig. 8 shows, for the Muskingum river, precipitation, evaporation, runoff, and mean annual temperature, platted in the order of the precipitation.

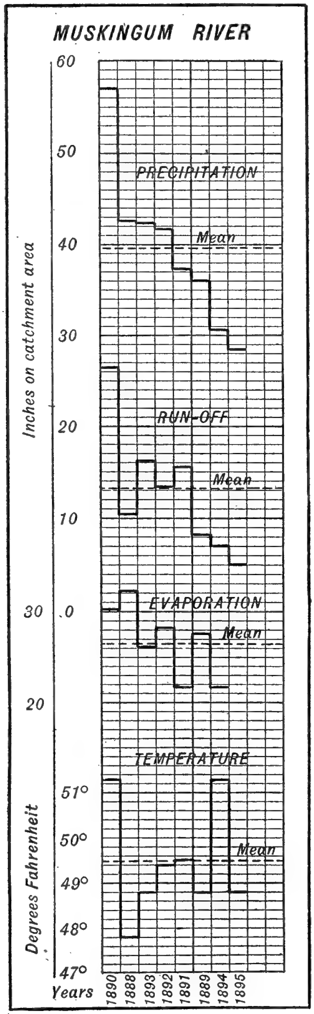


Fig. 8 Diagram showing the relation between the precipitation, runoff, evaporation and temperature on the Muskingum river, Ohio, the years being arranged in order of dryness.

On fig. 9 the relation between precipitation and runoff, for the Upper Hudson, has been expressed by the formula $P^2=84.5$ R. These diagrams (figs. 5 to 14) all show, together with many

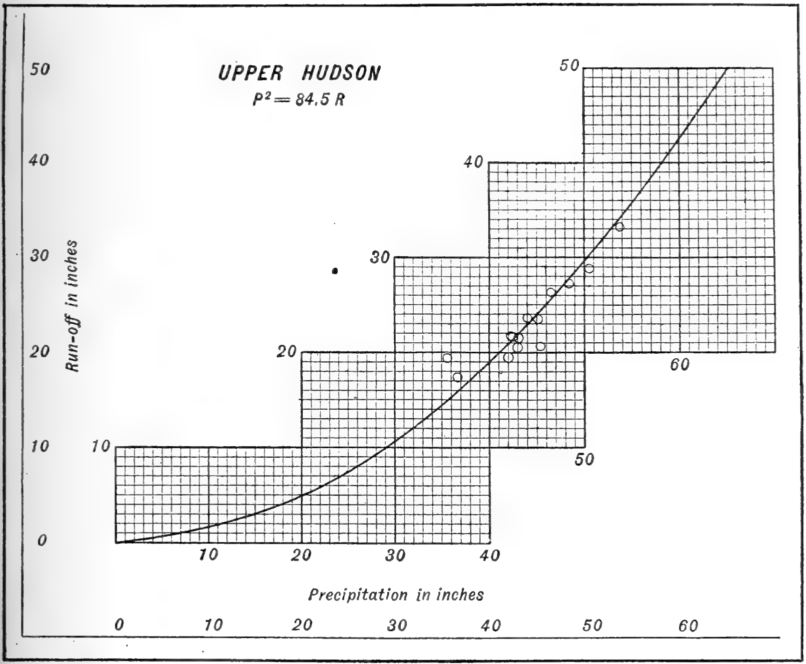


Fig. 9 Diagram showing the relation between the precipitation and runoff, in inches, on the Upper Hudson river.

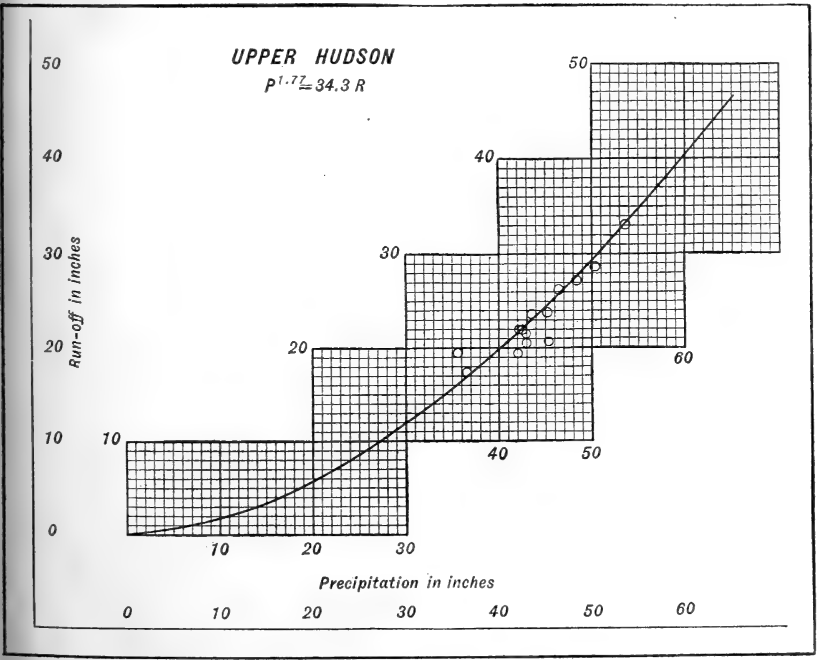
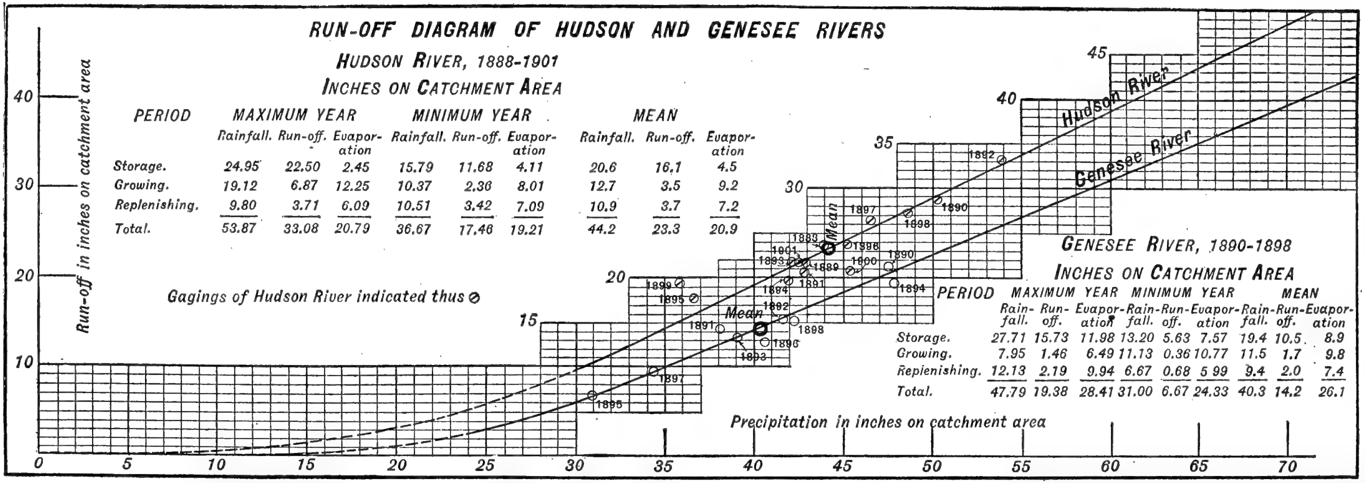


Fig. 10 Diagram showing the relation between the precipitation and runoff, in inches, on the Upper Hudson river, expressed by exponential formula.



RUN-OFF DIAGRAM OF HUDSON AND GENESEE RIVERS

HUDSON RIVER, 1888-1901

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation
Storage.	24.95	22.50	2.45	15.79	11.68	4.11	20.6	16.1	4.5
Growing.	19.12	6.87	12.25	10.37	2.36	8.01	12.7	3.5	9.2
Replenishing.	9.80	3.71	6.09	10.51	3.42	7.09	10.9	3.7	7.2
Total.	53.87	33.08	20.79	36.67	17.46	19.21	44.2	23.3	20.9

Gagings of Hudson River indicated thus ⊘

GENESEE RIVER, 1890-1898

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation
Storage.	27.71	15.73	11.98	13.20	5.63	7.57	19.4	10.5	8.9
Growing.	7.95	1.46	6.49	11.13	0.36	10.77	11.5	1.7	9.8
Replenishing.	12.13	2.19	9.94	6.67	0.68	5 99	9.4	2.0	7.4
Total.	47.79	19.38	28.41	31.00	6.67	24.33	40.3	14.2	26.1

Fig. 11 Runoff diagram of Hudson and Genesee rivers.

others not here published, that there is no definite relation between evaporation and mean annual temperature.

Exponential formula. On fig. 10 this relation is expressed by an exponential formula, after the manner proposed by Mr FitzGerald in his paper, Flow of Water in 48-inch Pipes.[1] Such a curve has the advantage that it is the best approximation possible to obtain from the given data. It will be noticed that it differs slightly from the curve of fig. 9. At 30 inches rainfall this difference amounts to about 1.3 inches of runoff.

While on the subject of exponential formulas it may be remarked that their chief advantage lies in the possibility of taking any set of data and deducing the curve which best suits the conditions.

Description of runoff diagrams. Fig. 11 is a runoff diagram of the Hudson and Genesee rivers, Hudson river for 1888–1901, inclusive, and Genesee river for 1890–1898, inclusive. In preparing this and the following diagrams it is considered that if both runoff and precipitation were correctly measured the points would fall in a regular curve approximately like those shown on figs. 9 and 10. Such diagrams may therefore be taken as a criterion of the accuracy with which the observations have been made. It is easier, however, to measure the runoff than it is to measure the precipitation, and hence when large variation occurs, as it does in these several diagrams, we may first look for it in the precipitation records. As regards the Hudson area, it has been the writer's custom to take the rainfall of the northern plateau of the State Weather Bureau as, on the whole, best representing the rainfall of the Upper Hudson area. With the exception of the years 1899 and 1900 the points all fall within from an inch to an inch and a half of the curve. Those two years have, however, been computed by a less accurate method than the preceding ones. It is concluded, therefore, that aside from 1899 and 1900 the curves represent the rainfall and runoff of the Hudson and Genesee rivers with considerable accuracy.

Fig. 12 shows in a similar manner a runoff diagram for Muskingum river from 1888 to 1895, inclusive.

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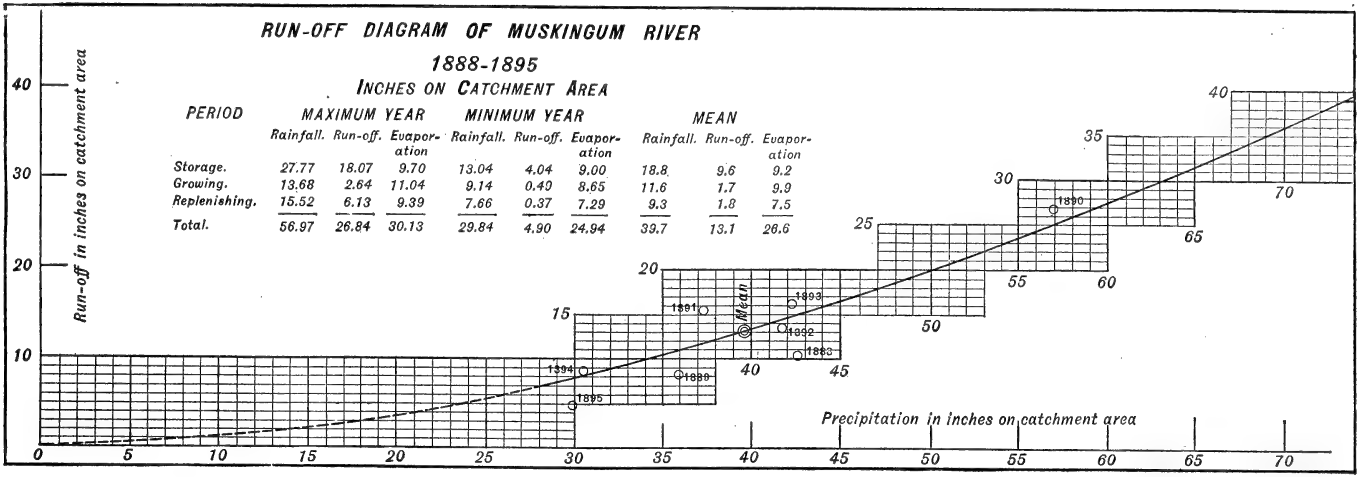
[1] Trans. Am. Soc. C. E., Vol. XXXV, p. 241.



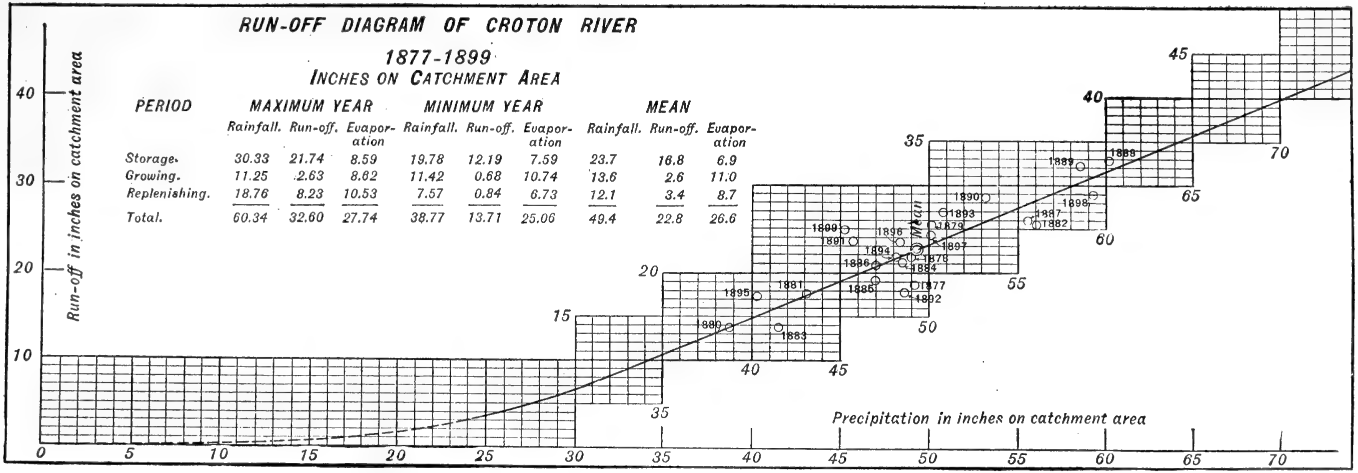
RUN-OFF DIAGRAM OF MUSKINGUM RIVER

1888-1895

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation
Storage.	27.77	18.07	9.70	13.04	4.04	9.00	18.8	9.6	9.2
Growing.	13.68	2.64	11.04	9.14	0.49	8.65	11.6	1.7	9.9
Replenishing.	15.52	6.13	9.39	7.66	0.37	7.29	9.3	1.8	7.5
Total.	56.97	26.84	30.13	29.84	4.90	24.94	39.7	13.1	26.6

Fig. 12 Runoff diagram of Muskingum river.



RUN-OFF DIAGRAM OF CROTON RIVER

1877-1899

INCHES ON CATCHMENT AREA

PERIOD	MAXIMUM YEAR			MINIMUM YEAR			MEAN		
	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation	Rainfall.	Run-off.	Evaporation
Storage.	30.33	21.74	8.59	19.78	12.19	7.59	23.7	16.8	6.9
Growing.	11.25	2.63	8.62	11.42	0.68	10.74	13.6	2.6	11.0
Replenishing.	18.76	8.23	10.53	7.57	0.84	6.73	12.1	3.4	8.7
Total.	60.34	32.60	27.74	38.77	13.71	25.06	49.4	22.8	26.6

Fig. 13 Runoff diagram of Croton river.

Fig. 13 is a diagram of the revised gagings of Croton river from 1877 to 1899, inclusive.

The maximum, minimum, and mean runoff may be obtained from the tabulations on each figure.

It is evident that proceeding in the same way as for the foregoing diagrams, figs. 11 to 13, inclusive, diagrams may be prepared for the storage, growing, and replenishing periods, and a curve drawn from which the runoff for a given rainfall may be taken.

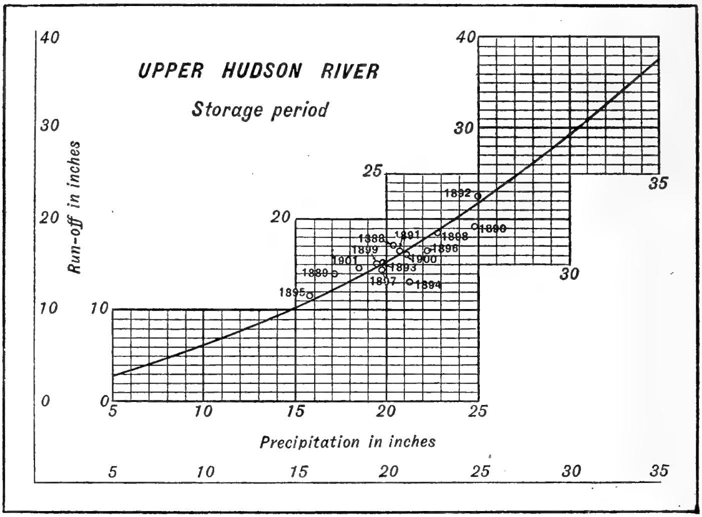


Fig. 14 Diagram showing the relation between precipitation and runoff in the Upper Hudson river catchment during the storage period.

Fig. 14 is such a diagram for the storage period on the Upper Hudson river for the years 1888–1901, inclusive. This diagram shows that aside from the years 1890 and 1894 the runoff of this catchment area was substantially accurate during the storage period. It is probable that in these two years their accuracy may have been interfered with by ice, although just the cause is not definitely known—it may have been in the rainfall.

Fig. 15 is a similar diagram for the Upper Hudson river during the growing period for the same years. This diagram shows that aside from 1897, the runoffs were substantially right during this period.

Fig. 16 is a similar diagram for the Upper Hudson during the replenishing period for the same years. This diagram shows that in 1890 and 1900 there was a discrepancy, which, as in the previous cases, was presumably in the precipitation of that period.

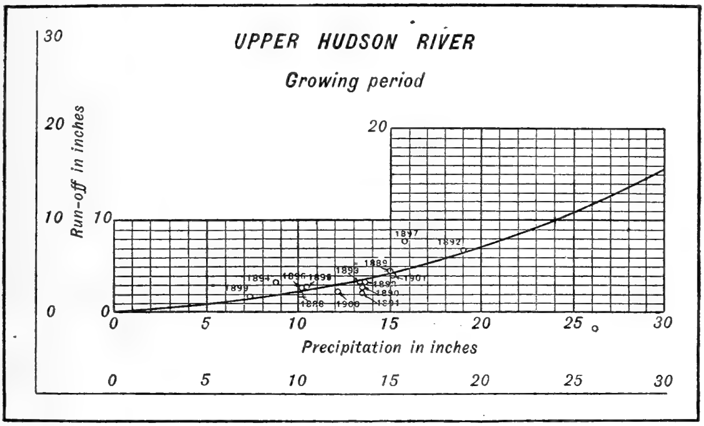


Fig. 15 Diagram showing the relation between the precipitation and runoff in the Upper Hudson river catchment during the growing period.

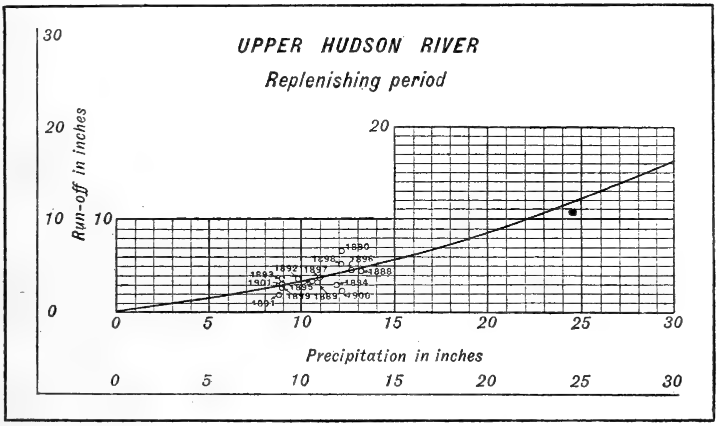


Fig. 16 Diagram showing the precipitation and runoff in the Upper Hudson river catchment during the replenishing period.

Proceeding on similar lines, the writer prepared, several years ago, a series of curves, from which the monthly runoffs may be taken. But, unfortunately, owing to negative evaporation in the storage period, the individual months of that period were too discordant for publication. The writer, therefore, does not give any such diagrams in this connection. His present view is that, for the reason stated, they can not be safely used.

One or two general conclusions of some interest may be drawn from figs. 11 to 13, inclusive. Taking the extreme low water as represented by the year 1895, on Muskingum river, at 4.9 inches for the whole year, with a rainfall of 29.8 inches, it is interesting to observe that in the preceding year of 1894, there was a total runoff of 8.7 inches, with a total rainfall of 30.5 inches. That is to say, the rainfall for the year 1894 was 0.7 inch greater than in 1895, but the runoff was 3.8 inches greater. This extreme difference may be ascribed to the difference in the hight of ground water. In 1895 ground water stood much lower than in 1893, with the result of a lower runoff.

On fig. 11, for the Genesee river, with a precipitation of 30 inches, the runoff is found to be 6 inches, while on fig. 8, with a precipitation of 30 inches, runoff ordinarily may be expected to be about 8 inches. This statement is made on the assumption that the curve is drawn in a mean position, or in such a way as to give average mean results, but it should not be overlooked that Muskingum river observations are too few to draw absolute conclusions. The diagram, fig. 12, shows that there is some lack of accuracy in at least one-half of them.

Fig. 11 shows that on Hudson river, if during any year the total rainfall should sink to 30 inches, the runoff may be expected to be somewhat less than 10 inches, though the modifying effect of full or low ground water may be taken into account in reaching such conclusion. Probably there would be, due to elevation of ground water, a variation of perhaps 2 inches.

On the diagram of Croton river, fig. 13, it is also seen that 30 inches precipitation may be expected to produce a little less than 7 inches of runoff, showing also that this stream has substantially the characteristics of Genesee river.

In all of the foregoing statements as to minimum runoff, it should be understood that the actual quantity appearing in the stream as runoff from a given precipitation will vary, depending on whether ground water is high or low at the beginning of the period considered. All such statements, therefore, are necessarily approximate—they may have a plus or minus variation from the diagram of one or two inches. Possibly the maximum variation may be more than this.

RIVER SYSTEMS

Classification of rivers. The rivers of the State may be classified into seven general systems, whose relative position is shown by the accompanying map, fig. 17. These are:

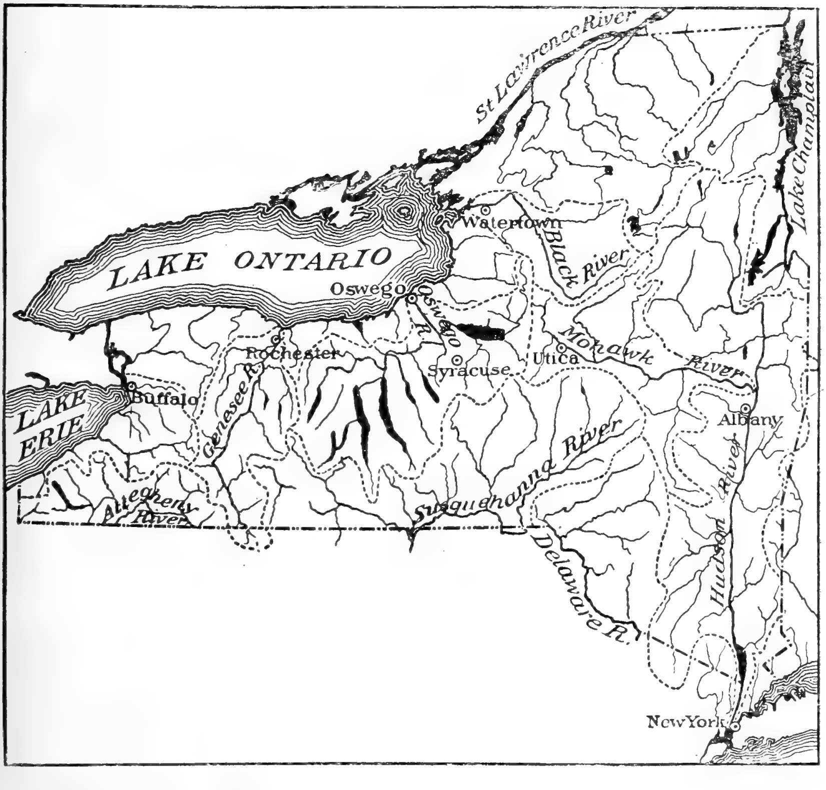


Fig. 17 Map of rivers of New York.

1) St Lawrence system, which includes all waters draining to Lakes Erie and Ontario, and Niagara and St Lawrence rivers.

2) Champlain system, including all streams in the State tributary to Lakes Champlain and George. The Champlain system is in reality a subdivision of the St Lawrence, but made separate here merely for convenience in discussing the river systems of the State.

3) Hudson river system, including all streams tributary to the Hudson and its main branch, the Mohawk.

4) Allegheny river system.

5) Susquehanna river system.

6) Delaware river system.

7) The streams of Long Island tributary to Long Island sound and the Atlantic ocean.

The Ten Mile river, one of the headwaters of the Housatonic river in Connecticut, flows out of the State to the east, while the headwaters of Ramapo river, in Rockland county, flow from New York into New Jersey. These latter are of possible future importance by reason of the necessity of water for the supply either of Greater New York or, in the case of Ramapo river, also for the municipalities of northern New Jersey. Chateaugay river and tributaries of the St Lawrence also flow northward into the Dominion of Canada.

St Lawrence River System

This group embraces the streams tributary to Lake Erie, Niagara river, Lake Ontario and St Lawrence river. On the extreme southwest, in Chautauqua county, the watershed line approaches within a few miles of Lake Erie, but at an elevation of several hundred feet above, and as a consequence the streams are short and rapid. A small amount of power is developed on Chautauqua creek at Westfield, and on Canadaway creek near Fredonia. Cattaraugus, Buffalo, Tonawanda and Oak Orchard creeks are tributaries of Lakes Erie and Ontario and Niagara river in western New York. Buffalo creek is important as forming a large portion of Buffalo harbor at its mouth. Several of these streams will be discussed in detail on a later page. Tonawanda creek, which flows into Niagara river at Tonawanda, is used for several miles as a part of Erie canal. This stream is sluggish throughout nearly its whole course and affords only a small amount of power. The water supply of the village of Attica is taken from its headwaters.

Lake Erie and Niagara river drainage. There are a number of streams tributary to Lake Erie and Niagara river, but with the exception of Cayuga, Buffalo and Cazenovia creeks, which unite to form Buffalo river, within the city of Buffalo, Eighteen Mile creek (tributary to Lake Erie), Cattaraugus creek, Tonawanda creek and Ellicott creek, none of these streams are very large. The catchment areas of these different streams, as determined from Bien's atlas, are as follows:

	Square miles.
Cayuga creek	127
Buffalo creek	145
Cazenovia creek	141

Below the junction of these several streams Buffalo river has a catchment of about 7 square miles, making a total of 420 square miles. The following are the catchment areas of the remainder of the streams tributary to Lake Erie and Niagara river:

	Square miles.
Smoke creek	25
Big Sister creek	50
Muddy creek	15
Cattaraugus creek	560
Walnut creek, Silver creek	60
Canadaway creek	35
Chautauqua creek	32
Tonawanda creek, Ellicott creek	610

Cayuga creek. Cayuga creek rises in the western part of Wyoming county and flows through generally level country to its junction with Buffalo creek. Buffalo creek also rises in the western part of Wyoming county and flows westerly. Its headwaters are at an elevation of about 1500 feet above tide.

Cazenovia creek. Cazenovia creek rises in the extreme southwestern part of Erie county and flows in a northerly direction to its junction with Buffalo creek, to form Buffalo river. The headwaters of this stream are in hilly country.

Eighteen Mile creek. Eighteen Mile creek flows into Lake Erie about eleven miles west of the city of Buffalo. It rises in the south part of Erie county.

Cattaraugus creek. Cattaraugus creek is the boundary line between Erie and Cattaraugus counties. Its main branch rises in the southwestern part of Wyoming county. Its course is generally west and northwest. The elevation of its headwaters is about 1600 feet to 1800 feet above tide.

Smoke creek, Big Sister creek, Muddy creek, Silver creek, Walnut creek, Canadaway creek and Chautauqua creek are none of them very important streams.

Tonawanda creek. Tonawanda creek rises in the western part of Wyoming county, flows northerly through Attica to Batavia and thence westerly to the Niagara river at Tonawanda, at which place its chief tributary, Ellicott creek, joins the main stream. For the first thirty miles of its flow the creek drains hilly and rolling country, having a sharp descent. Its extreme headwaters in Wyoming county are at an elevation of about 1200 feet. From Batavia to Tonawanda, a distance of nearly sixty miles by the stream, the topography is flat, having a total fall between these points of about 310 feet. A considerable portion of the catchment area of this section is not only flat and marshy, but also narrow. Between Batavia and Tonawanda the creek has been modified by two artificial interruptions: (1), by the diversion of a portion of its water through a diversion channel into Oak Orchard creek, from which water is drawn to the Erie canal at Medina; and (2), at Tonawanda the creek is artificially raised by the State dam and the stream canalized and used as a part of Erie canal for a distance of twelve miles to Pendleton. The major portion of the water supply of the western division of the Erie canal is drawn from Lake Erie through this canalized portion of

Tonawanda creek. It will be noticed that the current of Tonawanda creek is reversed here for twelve miles.

The Tonawanda creek, in its relation to Oak Orchard creek, will now be briefly discussed. Although Tonawanda creek is not a tributary of this catchment, the fact that the catchment areas are merged into one another, and also owing to the fact that a portion of the water of Tonawanda creek is diverted into the Oak Orchard swamp by the Oak Orchard feeder, makes it necessary to discuss it briefly here.

The dam diverting water into the Oak Orchard creek is about one-half mile east of the west line of Genesee county. From the point where the Tonawanda creek crosses this western boundary the creek is the boundary between Erie and Niagara counties. The fall in Tonawanda creek from Batavia to Oak Orchard dam is about 260 feet. From the Oak Orchard dam to Pendleton, where the Erie canal leaves Tonawanda creek, the fall is about 45 feet. On this portion the channel is extremely sinuous, the total length of the channel between Oak Orchard dam and the canal being 29 miles, while the direct distance is 15 miles.

Niagara river. Niagara river forms a portion of the boundary between the Dominion of Canada and the State of New York. The difference in elevation between Lakes Erie and Ontario is, approximately, 325 feet, of which about 160 feet are at Niagara Falls. Between Lake Erie and Niagara Falls the river divides into two channels around Grand Island, which is 10 miles long and 4 or 5 miles wide. The general course of the river is from south to north, but in passing around Grand Island the eastern channel bends westward, and for 3 miles from the foot of the island the course of the river is west.

Goat Island lies at the foot of this westerly stretch. On the New York side the American channel finds its way around the island to the American falls, which break over the rough ledge at right angles to the main river. The Horseshoe falls, on the Canadian side, are about 3000 feet higher up and lie between the west end of Goat island and the Canadian shore. At the Canadian falls the main river again turns to the north and pursues that general course to Lake Ontario.

The elevation of the water surface at the head of the rapids above the falls is 560 feet above tidewater, thus giving a fall from the Lake Erie level to that point of from 12 to 13 feet, of which from 4 to 5 feet are included in the rapids at the city of Buffalo, in front of and just below Fort Porter. The descent in the river from the head of the rapids to the brink of the falls is about 50 feet. At the narrows, half a mile above the whirlpool, the elevation of the water surface is 300 feet, while that of the surface of the still water opposite Lewiston is 249 feet; the fall in this section, which is from 4 to 4.5 miles in length, may therefore be taken at 51 feet, while from Lewiston to the mouth at Fort Niagara the fall is only 2 feet in a distance of 7 miles. The total length of Niagara river is about 37 miles. The catchment area of Niagara river above Niagara Falls is 265,095 square miles.

On account of the immense water-power developments now taking place at Niagara Falls the runoff of Niagara river must necessarily receive extended discussion in a complete account of the Hydrology of New York.

Lake Ontario catchment area. This catchment comprises the strip of territory draining directly into Lake Ontario and extending from the Niagara river to beyond the Black river. The important streams of this section are Genesee river, Oswego river, Salmon river west and Black river. The less important are Eighteen Mile creek (tributary to Lake Ontario), Johnson creek, Oak Orchard creek, Sandy creek (Orleans county), West creek, Salmon creek (Monroe county), Irondequoit creek, Salmon creek (Wayne county), Wolcott creek, Red creek, Sodus creek, Nine Mile creek, Fish creek, Little Salmon river (Oswego county), Beaver Dam brook, Sandy creek (Oswego county), north and south branches of Sandy creek (Jefferson county), Skinner creek, Little Sandy creek, Stony creek, Perch river and Chaumont river. None of these small streams are of any great importance, although some of them have considerable water power upon them.[1]

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[1] For statement in detail of water power on streams tributary to the proposed Black river feeder canal, see table No. 129, water power in use on streams tributary to proposed Black river feeder in 1898, at pp. 857-861 of the Deep Waterways Report.

The following are the catchment areas of a few of these streams:

	Square miles
Eighteen Mile creek (tributary to Lake Ontario)	90
Johnson creek	105
Oak Orchard creek	295
Sandy creek	85
West and Salmon creeks	110
Irondequoit river	135

The following notes on these streams have been collected from various sources:

Eighteen Mile creek. Eighteen Mile creek rises near Gasport, and flows first westerly and then northerly to Lake Ontario at Olcott. A small branch of the stream flows through the city of Lockport, rising two or three miles south of that city. Ever since the construction of the Erie canal the Lockport branch has received a considerable quantity of water which is discharged by the water powers at Lockport drawing their supply from the canal.

Oak Orchard creek. Oak Orchard creek rises in the eastern part of Orleans county, whence it flows to West Shelby and then turns northeasterly, reaching Lake Ontario at Point Breeze. Above West Shelby it mostly flows through swamps and swampy channels, while below that point the country is dry and rolling. The distance from the head of the swamp to its foot near West Shelby is sixteen miles in a direct line, but upwards of twenty miles following the stream channel. The fall of the stream is 37 feet, making the average slope 1.8 feet per mile. The topography of the country adjacent to the swamp is level and its boundaries are accordingly indefinite. Large areas of land around the margin of the swamp are wet during the fall and spring and dry during the summer. There are about 20,000 acres of imperfectly drained or marshy land lying along this portion of the Tonawanda creek and about 25,000 acres in Oak Orchard swamp proper. Swamp lands occur in the towns of Alabama, Byron, Elba and Oakfield in Genesee county. The catchment area of Oak Orchard swamp is about 133 square miles.

Genesee river. This river issues from the highlands of the Allegheny plateau in Potter county, Pennsylvania, a few miles south of the New York State boundary. Entering Allegany county, it first runs northwesterly for upward of 30 miles to near the village of Caneadea, at which point it turns northeasterly, this direction being generally maintained to the mouth. It flows entirely across the county of Allegany and then for several miles forms the boundary between Livingston and Wyoming counties, after which it crosses the northeast part of Livingston into Monroe county, through which it continues to its mouth at Charlotte. Above Portage its course from the State line is chiefly through an alluvial valley.

From Portage to Mount Morris the river flows through a deep and in some places narrow canyon for a distance of over 20 miles. The Portage falls, with a total descent including the intervening rapids of about 330 feet, are at the head of this canyon. The Upper Portage falls have a descent, including the rapids, of about 70 feet. Half a mile below are the Middle falls, with a descent of 110 feet; while 2 miles below begin the Lower falls, consisting of a series of rapids about half a mile long with an aggregate fall of 150 feet. These three falls may be taken as aggregating about 270 feet, exclusive of the rapids. At present no power developments exist. Formerly a sawmill was located at the Middle falls, but on account of the extinction of the lumber business on the stream it has not been operated for many years.

At Mount Morris, Genesee river issues into a broad, level, alluvial valley from 1 to 2 miles wide, which continues to near Rochester, where there is a descent of 262 feet in about 3 miles. The Upper falls at Rochester, 90 feet in hight, are a cataract in the Niagara limestone, while at the Lower falls, 94 feet in hight, the Medina sandstone appears. The foregoing figures do not include the dams above the falls.

The principal tributaries of the Genesee river are Canaseraga, Honeoye and Conesus creeks from the east, and Oatka, Black and Wiscoy creeks from the west. Honeoye, Canadice and Hemlock lakes are tributary to the Honeoye creek, and Conesus lake to

Conesus creek. Silver lake is another small body of water in the Genesee basin and tributary to the river by the Silver lake outlet. Canaseraga creek joins Genesee river near Mount Morris. From Dansville to its mouth, a distance of 16 miles, this creek flows through a broad alluvial valley with very little fall. Above Dansville the stream is more rapid, but the comparatively small, deforested catchment area limits its value for water power. Honeoye creek, which is the outlet of Honeoye, Canadice and Hemlock lakes, furnishes some water power. There are also several mills on the outlet of Conesus lake.

Formerly there were a number of mills on the Silver lake outlet, but changed business conditions have led to their decay. The other tributaries of the Genesee have little significance as mill streams. It appears, then, that the two places of importance on Genesee river, from the water-power point of view, are Portage and Rochester.

The following table gives the detail of the several subdivisions of the catchment area of Genesee river:

TABLE NO. 37—CATCHMENT AREAS OF TRIBUTARIES OF GENESEE RIVER

(In square miles)

Creek	Catchment area	Area above mouth	Area below mouth
Cryder	43.3	99.9	143.2
Chenunda	30.0	181.0	211.0
Dykes	68.3	214.0	282.3
Vandemarck	21.6	301.3	322.9
Knights	22.3	323.9	346.2
Phillips	32.3	372.8	405.1
Van Campens	55.7	410.4	466.1
Angelica	82.1	481.1	563.2
White	15.9	569.2	585.1
Black	31.1	595.5	626.6
Crawford	11.8	637.6	649.4
Caneadea	63.3	651.0	714.3
Cold	41.0	745.3	786.3
Rush	35.3	787.0	822.3
Wiscoy	108.6	833.6	942.2

Creek	Catchment area	Area above mouth	Area below mouth
Wolf	19.3	974.9	994.2
Silver lake	30.4	1,029.2	1,059.6
Cashaqua	82.0	1,059.6	1,141.6
Canaseraga	258.7	1,148.4	1,407.1
Beards	41.3	1,423.1	1,464.4
Conesus lake	88.8	1,555.5	1,643.9
Honeoye	262.6	1,675.9	1,938.5
Allens	198.1	1,947.1	2,145.2
Black	211.8	2,168.5	2,380.0

The total catchment area of Genesee river at its mouth is 2446 square miles.

The following tabulation gives the elevation of Genesee river at various points:

	Feet
Mean surface of Lake Ontario	247
Crest of the feeder dam in south part of the city of Rochester	510
Low-water surface of river at New York, Lake Erie & Western railway bridge near Avon	538
Crest of old Mount Morris power dam	605
Water surface just above Upper falls at Portage	1,080
Water surface at New York, Lake Erie & Western railway bridge near Belvidere	1,333

The extreme headwaters in Potter county, Pennsylvania, are about 2500 feet above tide.

Water power of Genesee river. Aside from a few unimportant flour mills on the Upper Genesee river, there is no water-power development except at Rochester and Mount Morris. Tabulations in detail of these water powers may be found in table No. 31 of the report on Genesee River Storage Surveys, dated January 1, 1897. These tabulations are too extensive to be reproduced in detail here, but the total power, according to the manufacturers' rating, on Genesee river at and near Mount Morris and Rochester is given at 19,178 horsepower. If we consider 75 per cent efficiency as developed by the water, the total power becomes 17,248 horsepower, of which 570 horsepower was at that time in use at Mount Morris.[1] Probably 17,248 horsepower is too high, because there are a number of wheels in use which do not yield over 50 per cent efficiency.

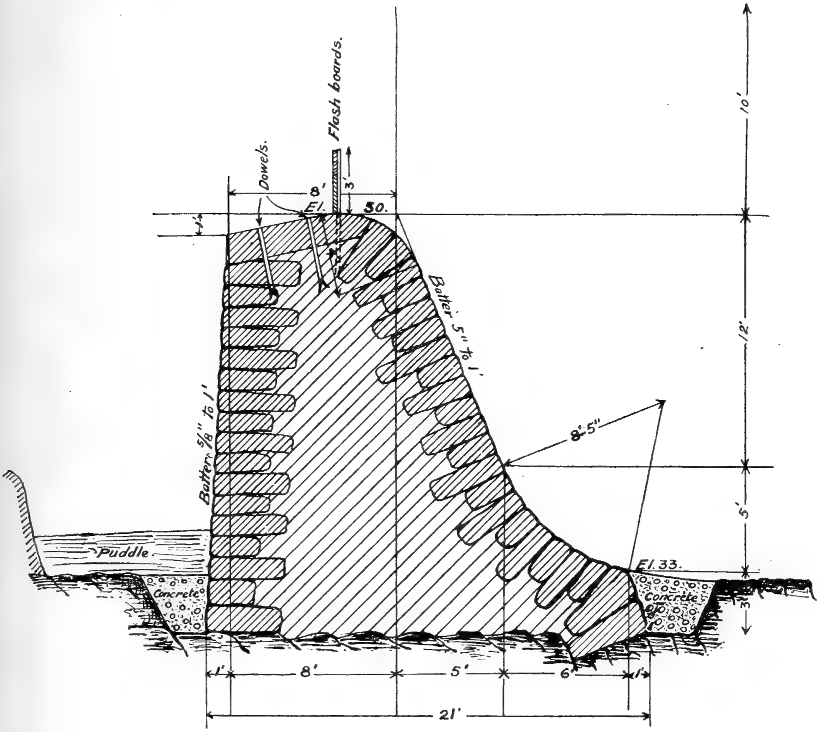

Fig. 18 Section of power dam on Genesee river at Mount Morris, at north end of same.

These statistics were gathered in the fall of 1896. Since that time some further extension has been made at Rochester, so that

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[1] The power dam at Mount Morris was destroyed by a flood early in 1897 and was only rebuilt in 1903. In the meantime, the manufacturing establishments there have been running by steam. Statements are not at hand as to whether all of these establishments are again running by water power.

at the present time there is, on the basis of 75 per cent efficiency, fully 20,000 horsepower in use when there is water enough to supply it. In some years, however, there is a deficiency of power for several months, and in extreme low water the total power of the river does not exceed an average of about 4700 or 4800 gross horsepower. On 75 per cent efficiency the total horsepower of Genesee river in extreme low water does not exceed 3600 to 3800 net horsepower.

In addition to the water power in use at Rochester, there is a considerable amount of steam power. From a canvass made in 1900 it appears that there were at that time engines set capable of producing over 15,000 horsepower. Since 1900 extensions have been made of the Rochester Gas & Electric Company's plant and of the Citizens Light & Power Company's plant to the extent of 5000 or 6000 horsepower, so that there is, in 1904, over 20,000 horsepower from steam in use at Rochester. These figures do not include auxiliary engines in use in mills propelled by water power, but which, from lack of water, necessarily rely on the engines in some years for several months. It is an interesting circumstance that the water power manufacturing district of Rochester, while situated on the brink of the gorge below the Upper Genesee falls, has a chimney attached to every mill, and the appearance, in times of low water, is that of steam power rather than of water. If the auxiliary engines are included there were over 30,000 horse power of steam at Rochester in 1904.

Oswego river. This stream, with a total catchment area at its mouth of 5002 square miles, flows into Lake Ontario at the city of Oswego. It is formed by the junction of Oneida and Seneca rivers at Three Rivers Point, about twenty-two miles southerly from its mouth. Its main tributary, Seneca river, with a catchment area of 3433 square miles, enters from the west at this point, while the Oneida river enters from the east.

Seneca river. Seneca river rises in the highlands in the south part of the State, the main stream flowing north through Cayuga lake, while its tributaries flow north through Canandaigua, Keuka, Seneca, Owasco, Skaneateles, Otisco, Cross and Onondaga lakes and the outlets of the same, after which the river turns and flows in a generally easterly direction to its junction with Oneida river at Three Rivers Point. The headwaters of Seneca river on the streams entering Canandaigua lake are at an elevation of 1600 feet; on the streams entering Keuka lake they are at an elevation of 1400 feet; on the streams entering Seneca lake, at an elevation of 1600 feet; on the streams entering Cayuga lake, at an elevation of 1400 feet, and so on.[1] Generally we may say, therefore, that the headwaters of Seneca river are at an elevation of from 1200 to 1600 feet above tidewater.

Oneida river. Oneida river rises in the central part of the State. One branch—Fish creek—rises in the highlands of the Lowville water center and flows in a generally southerly direction to its mouth in Oneida lake, while other branches rise in the highlands to the south. The streams flowing from a northerly direction are the west branch of Fish creek, with its main tributary, Mad river; east branch of Fish creek, with its tributaries, Furnace creek, Florence creek and Fall brook; Fish creek enters the extreme east end of Oneida lake; Wood creek is tributary to Fish creek a short distance above its mouth. The streams entering Oneida lake from a southerly direction are Chittenango creek, to which are tributary Butternut and Limestone creeks, all of which have considerable power upon them; Oneida creek, which flows into Oneida lake from the extreme southeast corner, and Canaseraga creek. Onondaga creek flows from the south into Onondaga lake, through the city of Syracuse. The headwaters of Oneida river are at an elevation of from 1400 feet to 1600 feet, the headwaters of the west branch of Fish creek, entering Oneida lake from the north, being about 1600 feet above tidewater and the headwaters of the east branch of Fish creek being about 1800 feet, while the headwaters of streams entering Oneida lake from the south are at an elevation of from 1200 to 1400 feet above tide.

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[1] These figures are general, as taken from the topographical map; in some cases they are somewhat exceeded, while in others they are less.

Water power of Fish creek. The following tabulation shows the principal water powers developed on the west branch of Fish creek:

Number of dam	Number of mills	Location	Manufacture	Effective head, feet	Number of employees	Horsepower of water wheels
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1	Taberg	Sawmill	8	......	......
2	2	McConnellsville	Woodworking	6	40	111
3	4	Camden	Woodworking	7–9	22	114
4	2	Camden	Foundry and knit'g mill	9–10	220	136
5	1	Camden	Gristmill	10	2	157
6	1	Camden	Saw and grist mill	5	2	53
7	2	West Camden	Chair factory	5	21	92
8	2	Williamstown	Saw and grist mill	16	5	66
9	1	Williamstown	Gristmill	9	4	185

The following are the elevations above tide, areas of water surface and catchment areas of the lakes tributary to Seneca and Oneida rivers:

Lake	Elevation above tide, in feet	Area of water, in square miles	Catchment area, in square miles
Canandaigua	686	18.6	175
Keuka	720	20.3	187
Seneca	444	66.0	707
Cayuga	381	66.8	1,593
Owasco	710	12.4	208
Skaneateles	867	12.8	73
Otisco	784	3.0	34
Cross	375	4.3	......
Onondaga	364	4.0	233
Cazenovia	1,190	2.8	9
Oneida	370	80.0	1,265

The following are the catchment areas of Oswego river and its principal tributaries:

	Square miles
Oswego river at mouth	5,002
Below junction of Seneca and Oneida rivers	4,835
Oneida river	1,402
Seneca river	3,433

The subdivisions of the catchment area of Seneca river are as follows:

	Square miles
At junction with Oneida river	3,433
At Baldwinsville	3,103
At Montezuma	2,472
Below Cayuga lake	1,593
At entrance to Cayuga lake	780
At Seneca Falls	771
Waterloo	745
At foot of Seneca lake	707
Keuka lake outlet	213
Catherines creek	94
Onondaga creek, not including Onondaga lake	122

The catchment areas of Cayuga lake and its tributaries are as follows:

	Square miles
At outlet	813
Cayuga inlet, including Cascadilla creek	173
Fall creek, not including Cascadilla creek	152
Salmon creek	90
Taughannock creek	60

Clyde river, a tributary of Seneca river, is formed by the junction of Canandaigua outlet and Mud creek. The latter stream rises in the southern part of Ontario county and flows first north and then east, uniting with Canandaigua outlet at Lyons. Clyde river joins Seneca river at Montezuma. The following are the catchment areas of Clyde river and tributaries:

	Square miles
At mouth	869
At Clyde	807
At Lyons, at junction of Canandaigua outlet and Mud creek	729
Mud creek at Lyons	298
Canandaigua outlet at junction with Mud creek	431
Canandaigua outlet at Phelps	390
Canandaigua lake at foot	175
Canandaigua inlet	85

Owasco lake discharges into Seneca river through an outlet 15 miles in length. The following are the catchment areas of Owasco outlet:

	Square miles
At mouth	230
At Auburn	212
Owasco lake at foot	208
Owasco inlet	120

The catchment areas of Oneida river and its principal tributaries are as follows:

	Square miles
Oneida river at mouth	1,402
Oneida lake at foot	1,265
Fish creek	406
Chittenango creek, including Cazenovia lake	309
Oneida creek	149
Wood creek	127

Owing to its large amount of lake storage, Oswego river, with its tributaries, is one of the best power streams in the State. As early as 1880 the power of this stream and its tributaries was fully utilized. According to a statement in the Report on the Water Power of the Region Tributary to Lake Ontario, made in 1883, there was over 30,000 horsepower in use. This power was developed upon Oswego river, Oneida river and small tributaries, Canaseraga creek and tributaries, Chittenango creek and tributaries, Fish creek and tributaries, Oneida creek and tributaries, sundry other small tributaries of Oneida lake, Seneca river, Cayuga outlet and sundry tributaries of Cayuga lake, Mud creek and tributaries, Canandaigua outlet and tributaries, Owasco outlet and tributaries, Skaneateles outlet and tributaries, Nine Mile creek and tributaries and Onondaga creek and tributaries.

No statements are at hand as to the total power of Oswego river in 1904, but it is doubtful if for the whole region it is greater than in 1883. Probably the power in use on Oswego river proper has increased somewhat, but there are many flour mills and other small establishments throughout the region which are out of use, making the net result about the same as in 1883.

Skaneateles outlet. Skaneateles outlet, which is one of the best power streams of the region, has a fall of about 500 feet in a few miles. According to a statement made by W. R. Hill, formerly Chief Engineer of the Syracuse Waterworks, there is about 3000 horsepower on this stream. However, in consequence of the city's taking Skaneateles lake as a water supply for Syracuse, the water rights on this stream have either been purchased or condemned by that city. Some of them are still in use in 1904, but definite statements are not at hand as to whether they all are.

The following streams of the Oswego catchment are more or less utilized for a water supply to the Erie canal: Owasco, Spring, Putnam, Skaneateles Carpenter, Nine Mile, Butternut, Limestone, Chittenango, Cowaselon and Oneida creeks. The total catchment area above the point of diversion amounts to about 750 square miles. On the headwaters of Limestone creek there is a diversion from De Ruyter reservoir, artificially supplied from the headwaters of Tioughnioga creek, which naturally drains to the Susquehanna river.

Salmon river west. The next stream of any importance tributary to Lake Ontario is Salmon river west, which rises in the highlands of Lewis county and flows first southerly, then westerly, into Lake Ontario. Its headwaters are at an elevation of over 1600 feet above tide.

In 1889 this stream was extensively considered as the source of a public water supply for the city of Syracuse. The Salmon river catchment, above the proposed point of diversion, comprises 70 square miles of forest land from 1000 to 1600 feet above tidewater, and distant northeast from Syracuse about 40 miles. The brooks tributary to the main stream head in springs and generally flow for the first few miles through swamps. Above Redfield the fall is rapid along the main stream, and there is stated to be very little vegetation along the shores, which are of sandstone and gravel. The water is clear but of a brownish tint. It is estimated that from 80 to 85 per cent of the catchment is wooded.

A favorable location for a storage reservoir exists about three miles above Redfield on the east branch, where a dam 32 feet high would impound 1,816,000,000 gallons, at an elevation of 590 feet above Syracuse (about 1000 feet above tidewater). Between this point and the mouth of Salmon river there are a number of water powers, some of which are unoccupied—as at High Falls, about five miles east of Sandbank, there is a vertical drop of 110 feet—but there are in operation sixteen mills, the machinery of which is driven by water power, the aggregate capacity of the wheels being 450 horsepower.[1]

The following are the catchment areas tributary to Salmon river west:

	Square miles
Reservoir site, three miles above Redfield	70
Reservoir site, above High Falls	191
At Pulaski	264
At mouth of stream	285

Black river. Between Salmon river west and the mouth of Black river, there are a number of small streams flowing into Lake Ontario, none of which are of special importance. We may therefore pass to a brief description of Black river. This stream rises in the western part of Hamilton county and pursues a southwesterly direction, passing across Herkimer county into Oneida county; it then bends to somewhat west of north through Lewis county, but soon after passing the northwesterly boundary of that county it changes to a general westerly course, flowing into Black River bay at the extreme eastern end of Lake Ontario. Extensive water-power developments are in use on this stream and its tributaries, at Watertown, Lyon Falls, Carthage, Black River, Brownville, Dexter and other points. There are also a number of State reservoirs on the headwaters which are discussed on another page. The following gives the elevation in feet

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[1] Report of the Engineer to the Commissioners on Sources of Water Supply for the City of Syracuse, N. Y., Feb. 21, 1889. By J. J. R. Croes, C. E.

of the main points on Black river above tidewater, according to the best available information:

	Feet.
At mouth	247
Watertown, west line of city	370
Watertown, at head of falls	492
Felts Mills, crest of dam	563
Carthage, at foot of rapids	669
Carthage, crest of State dam	724
Lyon Falls, at foot	733
Lyon Falls, crest of State dam	802
Forestport, crest of State dam	1,129
North Branch reservoir	1,821
Chub lake	1,599
Woodhull reservoir	1,854
South Branch reservoir	2,019
Moose river, at mouth	802
First lake, Fulton chain	1,684
Second lake	1,684
Third lake	1,685
Fourth lake	1,687
Fifth lake	1,691
Sixth lake	1,760
Seventh lake	1,762
Eighth lake	1,803
Little Moose lake	1,772
Big Moose lake	1,787
Beaver river, at mouth	724
Beaver river, at Number Four	1,436

The catchment areas of Black river and its tributaries, in square miles, are as follows:

	Square miles
Black river, at mouth	1,930
At Watertown (Remington's dam)	1,892
At Watertown (waterworks dam at Huntingtonville)	1,889
At Black River village	1,869
At site of Rawson's dam (four miles below Carthage)	1,824
At Carthage	1,812
Above mouth of Moose river	463

	Square miles
Forestport	268
Beaver river, at mouth	338
Beaver river, at Beaver Falls	322
Moose river, at mouth	416
Moose river, at Agar's mill	407
Deer river, at mouth	102
Deer river, at Deer River village	101
Woodhull creek	108
Otter creek (one-half mile above mouth of creek)	63
Independence creek, at mouth	99
Independence creek (three miles above mouth)	93

The length of Black river, measured along its course from its mouth at Black River bay to the headwaters, is 112 miles.

The section drained by the upper river in Herkimer and Hamilton counties is a rugged, mountainous region, with numerous lakes, a number of which have been utilized by the State of New York as storage reservoirs to compensate for water taken for the supply of the Black river and Erie canals.

The extreme headwaters of the main river are Canachagala lake, North lake and South lake. Other lakes on the headwaters of the main river are Woodhull, Little Bisby Chain lakes, Little Woodhull, Chub, Long, White and a number of others. The chief tributaries of Black are the Moose and Beaver rivers, both of which rise in Hamilton county and flow across Herkimer into Lewis county. The principal lakes at the head of Moose river are Two Sisters, Pigeon, Big Moose, Second, Cascade, Fulton Chain, Lime Kiln and Little Moose lakes. The principal lakes at the headwaters of the Beaver river are Lakes Lila and Francis, Josephine, Nehasane, Big Rock, Little Rock, Salmon, Loon and Twitchell lakes and others.

Other smaller tributaries of Black river are Black creek, Little Woodhull creek, Big Woodhull creek, Crystal brook, Otter creek, Independence creek, Crystal creek, Swiss creek, Moose creek, Sugar river, Whetstone creek, Roaring creek, Mill creek, Deer river and other small streams.

Moose river. This stream has a rapid fall throughout its entire extent. The catchment area of 416 square miles is precipitous and still very largely in primeval forest. There is a catchment of 41 square miles at the headwaters, which is regulated by storage, controlled by the State dam at Old Forge at the foot of the Fulton Chain lakes. There are a number of undeveloped water powers at Lyonsdale, Millers falls and other points on the stream. The following tabulation shows the principal developed water powers on Moose river:

Number of dam	Location	Manufacture	Effective head, feet	Number of employees	Horsepower of water wheels
(1)	(2)	(3)	(4)	(5)	(6)
1	Near Lyon Falls	Wood-pulp	18	50	560
2	Near Lyon Falls	Wood-pulp	30	31	1,208
3	Near Lyon Falls	Wood-pulp	35	28	1,736
4	Lyonsdale	Wood-pulp	30	35	850
5	Lyonsdale	Paper	30	2	400
6	Lyonsdale	Pulp and paper	35	40	1,252
7	Above Lyonsdale	Manila paper	30	40	1,000

Beaver river. The catchment area of Beaver river is 338 square miles. There is a storage dam at Stillwater, controlling an area of 153 square miles. In addition to this reservoir there is a large number of natural lakes, in consequence of which a comparatively uniform flow is maintained throughout the year.

From the reservoir above Beaver to Number Four the stream flows over numerous boulder rapids, alternating with stretches of smooth water. Above Beaver lake there is a 60-foot rapids within 500 feet. Below the foot of Beaver lake, for twelve miles, the stream flows over a rocky channel, although the adjacent catchment is sandy and still largely in forest. At Eagle falls, two miles below Beaver lake, there is a series of cascades aggregating 75 feet descent. The foregoing are undeveloped. Water power to the extent of 4400 horsepower is developed at Beaver Falls, Croghan and Belfort. The total head utilized is 133 feet.

At Belfort there is a fall of 50 feet, utilized to generate electricity, which is transmitted to adjacent towns.

Otter creek. This stream rises in Herkimer county and flows westerly into Black river, a few miles north of the village of Greig. Its catchment area is 63 square miles.

Independence creek. Independence creek also rises in Herkimer county and flows westerly into Black river three miles south of Bushe's Landing. The catchment area above the mouth of the stream is 99 square miles.

Deer river. This stream rises in the extreme western part of Lewis county and flows northeasterly into Black river five miles above Carthage. The catchment area of the stream is 102 square miles.

Early water power and manufacturing projects on Black river. Precise knowledge of the region drained by Black river is almost entirely confined to the present century. So little was known of its geography that in a statistical work, Winterbotham's View of the American United States, published in 1796, it is stated that Black river is said to rise "in the high country near the sources of Canada creek, which falls into the Mohawk river and takes its course northwest and then northeast until it discharges into the Cataraqui or Iroquois river not far from Swegauchee; it is said to be navigable for batteaux up to the lower falls, 60 miles." That is to say, Winterbotham understood Black river to be navigable either to Carthage or possibly Lyon Falls, the misapprehension probably having grown out of the accounts given by hunters and trappers of the long, nearly level stretch of about 40 miles between Carthage and Lyon Falls. The Black river is not represented on any of the early French or English maps of the region.[1]

Surveys of Watertown township were made in 1796 by Benjamin Wright, who was later engineer on the Erie canal. His report may be considered the beginning of something like accurate

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[1] See preface to a History of Jefferson county, by Franklin B. Hough, Watertown, 1854.

knowledge of the region. In regard to Watertown township, he states therein:

> Township No. 2, on Black river, is situated about three miles from the mouth of the river. This river is navigable for batteaux about 1¾ miles, but yet with considerable difficulty it may be ascended 2½ miles. . . . There are excellent mill sites along Black river, where they are noted on the map, and many more, which it is impossible to note with certainty, as the river the whole distance of the town is very rapid except at the northeast corner for about three-quarters of a mile. The river is very rocky along the whole distance and appears to be a bed of limestone rocks.

Settlements began in Watertown township on the site of the present city of Watertown in March, 1800, three families having arrived at that time, and these were the only ones remaining during the ensuing winter, although many visited Watertown during the summer of 1800 on prospecting tours, who subsequently settled there. The precise history of the region began, therefore, in the fullest sense with the nineteenth century.[1]

According to Dr Hough, the name of Watertown township was doubtless suggested by the extraordinary amount and convenience of its water power, for which, Dr Hough says, it will compare favorably with any place in the State. "To this cause may be mainly attributed its early and rapid growth and the superiority in wealth and business which it enjoys far beyond any other place in the county."

Watertown is the county seat of Jefferson county. According to the census reports the population of the township in 1800 was 119; in 1810, it was 1841; in 1820, 2766; in 1830, 4768; in 1840, 5027; in 1850, 7201; in 1860, 7567. In 1869 the city of Watertown was erected from territory taken from the townships of Pamelia and Watertown. In 1870 the population of the city of Watertown was 9336, the population of the township being in that year 1373; in 1880, the population of the city was 10,697 and the township 1264; in 1890, the population of the city was

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[1] For early history of settlements on Black river see Hough's History.

14,725 and the township 1215, and in 1900, the city was 21,696 and the township 1159. The township of Pamelia had a population in 1860 of 2789 and in 1870, 1292, the difference in this case being chiefly due to the absorption of a portion into the city of Watertown. As in the case of Watertown township, however, the population of Pamelia has been gradually lessening during the last three census decades. Since the incorporation of Watertown as a city, the development of its manufacturing industries has been very rapid.

In addition to Watertown, the other chief water-power points of the Black river valley are Dexter, Brownville, Black River village, Felts Mills, Great Bend, Carthage, Lyon Falls and Port Leyden. There are also extensive water powers on the Beaver and Moose rivers, tributaries of the Black.

The chief object of this chapter is to present a concise view of the relation which the development of the Black river water power has had to the growth of the region as a whole, such discussion leading to a broad consideration of the effect of materially interfering with the development of the manufacturing interests. We will endeavor, in short, to discuss the economic proposition involved in seriously interfering with the productive industries of an extensive manufacturing community.

Without going into an extended account of the early manufacturing establishments of the Lower Black river, we may still give enough to show that manufacturing has always been a leading occupation of the Black river valley population.

Dexter. At Dexter manufacturing improvements were begun in 1811 by Jacob and John Brown, who built a dam across the river which, however, was carried away by high water the next season. It was replaced and in 1813 a sawmill put in operation. In 1826 John E. Brown erected a gristmill. James Wood & Sons began the erection of a woolen factory about 1830, and in 1836 the Jefferson Woolen Company was formed with $100,000 capital for the construction and operation of a woolen mill. The mill was built in 1837, but the investment soon proved a failure. Subsequently the mill was operated by private parties.

Brownville. Jacob Brown erected a sawmill at Brownville in 1800 and a gristmill in 1802, but it was not until 1806 that a dam was built across Black river at this place. In 1814 a company was formed to construct and operate a cotton mill at Brownville with a capital stock of $100,000. This mill was operated with varying fortunes until about 1860. In 1820 a woolen factory and various other enterprises were inaugurated.

Watertown. At Watertown the first dam was built across the south channel at Beebee's island by Jonathan Cowan in 1802 to operate a gristmill. In 1805 Coffeen's dam was built at the lower falls and about 1814 the dam at Soules island was constructed, but it was not until 1835 that the large dam across the north channel at the head of Beebee's island was built. According to Dr Hough, these four original dams of 1802, 1805, 1814 and 1835 were still standing in 1854, but the flood of 1869, at any rate, worked sad havoc with some of them. The present stone dam across the south channel of Beebee's island was constructed in 1869.

The first important manufacturing industry other than the grist and saw mills was Caswell's paper mill, started in 1808. This mill was the forerunner of the paper industry on Black river. The machinery consisted of a small rag machine, carrying about 150 pounds of rags; two or three potash kettles, set in a brick arch, for boiling rags and preparing sizing; one vat for making the paper sheet by sheet, and a rude standing press to squeeze the water out of the pack. After pressing, the sheets were taken from the pack and hung on poles to dry, and, if intended for writing-paper, were afterwards dipped in sizing and again dried. The entire process was worked without the use of steam or bleaching material. As a substitute for calendering, the sheets were pressed between boards. The output was about 150 pounds of paper per day. This mill continued to make paper until 1833, when it was sold to Knowlton & Rice, who had begun the manufacture of paper on a more extended scale in 1824. This firm continued to be the only paper manufacturers on Black river until 1854, in which year I. Remington & Sons fitted up a mill with four rag machines and an 84-inch Fourdrinier machine. This mill made newspaper only and had a capacity of three tons per day. From these small beginnings have grown up the extensive paper industries of Black river.

As already stated, the first manufacturing industry in the village of Watertown was the primitive gristmill built by Jonathan Cowan in 1802. This was the forerunner of extensive flouring mills at this place later on. The Bailey & Clark and Coffeen mills, of small capacity, were both built at some date previous to 1812, but it was not until 1835 that Joseph Sheldon and Philo C. Moulton built the Union mills, with a capacity of 200 barrels of flour per day. The Excelsior flour mills were erected by Moulton & Simons in 1845. This mill is now operated by the A. H. Herrick & Son Company, incorporated in 1895 with a capital of $50,000 by A. H. and E. W. Herrick and George G. Lee. This mill has a capacity of 100 barrels of wheat flour and 100 barrels of buckwheat per day. The Jefferson flour mills were erected in 1855 and operated until about 1880, when the property was sold to Knowlton Brothers and converted into a pulp mill. The Crescent flour mills were built by Fuller, Isdell & Willard in 1870 and succeeded the old Phoenix mill of earlier years, which was carried away by the flood of 1869. Crescent mill now has 19 stands of rolls, a daily capacity of 200 barrels of flour. The Electric mill, built in 1895, is operated by electrical power derived from wheels of Taggart Brothers Company. It is used exclusively for grinding feed, and has a capacity of 250 barrels per day.

In the early days of Watertown several tanneries were operated, the first industry of this character having been established in 1808, in which year C. McKnight set up a saddle and harness business and prepared and tanned his own leather. Jason Fairbanks established an extensive tannery in 1823, although he had done tanning on a small scale for several years previous thereto. Holt & Beecher established a tannery at some date previous to 1830, which remained in operation until carried away by the flood of 1856. Several other tanneries were started at different times, but with the changed conditions of business they have all passed away. These tanning establishments all used power from Black river for grinding bark.

Beginning with the time of the war of 1812-15, the manufacture of cotton and woolen goods became an important industry on Black river, the Black River Cotton & Woolen Manufacturing Company having been incorporated in 1813 with a capital of $100,000. In 1827 Levi Beebee erected the Jefferson cotton mills, equipped with 10,000 spindles and said to have cost about $200,000, being at that time one of the largest cotton mills in the State. This mill was destroyed by fire in 1833. Watertown Cotton Mills Company was incorporated in 1834 with a capital of $100,000. This company ran 50 looms, but after several years, the business becoming unprofitable, it was discontinued. The Hamilton Woolen Mills Company, which developed the water power at the head of Sewall's island, was established in 1835 with a capital of $100,000. The dam and factory were built in 1836. In 1842 the plant was purchased by the Black River Woolen Company, which built a new mill and carried on a fairly successful business until 1841, when the plant was burned. Subsequently the business was revived by Loomis & Co., who employed about seventy hands in the manufacture of woolen goods. Other manufacturing enterprises of this class were the Watertown Woolen Company and the Watertown Woolen Manufacturing Company. The cotton and woolen manufacturing establishments on Black river are now all out of existence.

The machine shop of Nathaniel Wiley, established about 1820, was the first iron manufacturing establishment at Watertown. In 1823 George Golding established a machine shop on Sewall's island, making mill gearings, factory machines and an occasional steam engine. This shop ultimately led to the founding of the present Bagley & Sewall Company, which is one of the largest establishments of its kind in the northern part of the State, employing about 125 hands, chiefly in the manufacture of paper-mill machinery. The Watertown Steam Engine Company has grown out of a small business established by Hoard & Bradford in 1851. These works employ about 225 men and manufacture high-speed, direct-acting engines, stationary and portable, and agricultural engines and boilers of all kinds. The New York Air Brake Company, which is stated to be the largest manufacturing industry at Watertown, dates back to 1861. The foundry of this company uses water power from the Black river.

A large number of other manufacturing establishments have been established at Watertown, taking water power from Black river, as for instance the Union Carriage & Gear Company, Watertown Brass & Manufacturing Company, Watertown Thermometer Company, the Elwood Silk Company, Harmon Machine Company, the H. H. Babcock Company and others. The H. H. Babcock Company is one of the leading carriage manufacturing industries of the State; when working at full capacity this company employs about 175 hands.

Beaver River village. A sawmill was built at this place in 1806, which was carried away by high water and rebuilt the next year. A gristmill was erected in 1810 and another sawmill in 1815. In 1839 David Dexter founded an extensive chair factory. Other early industries were Poor's chair-stock factory and Wilcox coffin and casket works, which have, however, given way to more recent enterprises. Various other milling industries have been operated at this place at various times.

Felts Mills. A dam was constructed across Black river at this place in 1821, and in 1822 what is known as the old stone mill, which still stands, was erected. It has not been operated for the last ten years. Large sawmills were erected by John Felt in 1824. The Taggart Paper Company, which is now the only industry using water power at Felts Mills, erected its plant in 1889.

Great Bend. A dam was constructed across the Black river at this place in 1806 and a sawmill built, which was soon carried away by high water but at once replaced. Between 1815 and 1824 the place developed a number of milling enterprises, which are not specifically described in the early history. The large mill of the Taggart Paper Company is now the only water-power industry at this place.

Carthage. At Carthage we have what are known as the long falls of Black river, the river falling at this place 55 feet vertically in a distance of 4600 feet. The first water-power establishment was David Coffeen's gristmill, erected on the west bank of the river in 1806, power therefor being furnished by a wing dam extending diagonally up the stream from the mill. A forge, operated by water power, was built in 1816 on the east side of the river, and Coffeen's dam extended entirely across in order to furnish power. A blast furnace taking power from the river was built in 1819. A nail factory was erected in 1828.

In 1830 a tannery was erected on what is known as Tannery island. A gristmill was built on Guyot's island in 1838. Since that time there have been in operation on this island a forge, a rolling mill, a gristmill, nail works, ax factory, broomhandle works, furniture factory, carding mill and general repair shops. The large rolling mill and nail factory of Hiram McCollom was begun in 1845, who also built a foundry on Furnace island in the same year. The foundry is still in operation.

The foregoing brief account of the early manufacturing industries of the lower Black river valley, while only a skeleton, is still extensive enough to indicate how thoroughly manufacturing has been identified with the development of this valley from the very beginning. It is certainly clearly shown that the material prosperity of the region has been greatly advanced by Black river water power.

Water power of Black river. In order to show the development of water power on Black river, we may further consider table No. 128, water power in use on Black and Beaver rivers (approximate), as given in the writer's Report to the Board of Engineers on Deep Waterways, pp. 846-852, inclusive. The following abstract of this table shows that there are twenty dams on Black river from Dexter to Lyon Falls, inclusive, with ninety-three establishments doing business:

Total horsepower of water wheels in use....	54,050
Total steam power used..................	1,482
Value of establishments..................	$7,836,100
Value of the annual product..............	$10,887,170
Number of hands employed in mills........	3,900

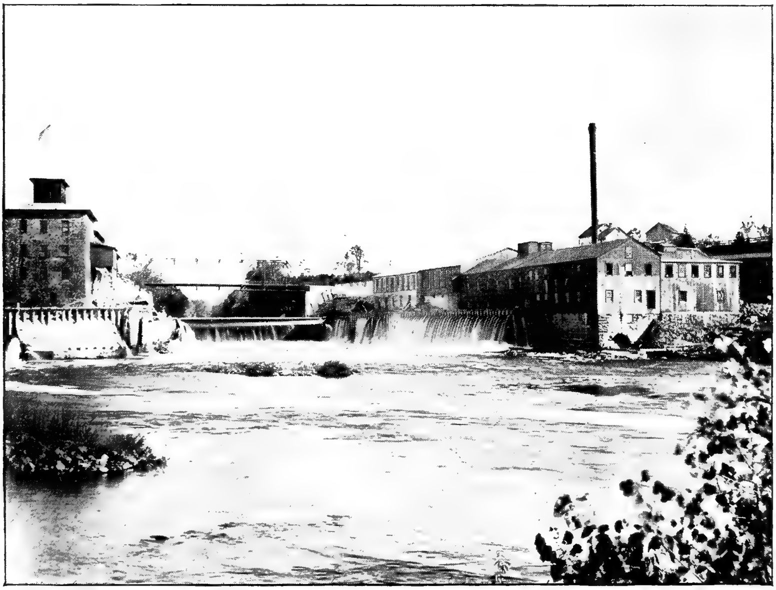
In the Report to the Board of Engineers on Deep Waterways a detailed statement is given of the water power and business at each mill, but these statements are too much in detail to reproduce here. In order to bring these statistics down to date the Water Storage Commission in 1902 sent to each mill owner a printed copy of the statements as to power, valuation of plant and of product, number of men employed, etc. with the request that the statement should be corrected if any of the conditions had been changed. In this way it was learned that a few small shops had been discontinued, a number of new powers had been built and a number had increased their capacity and business. The following is a summary of the results, as taken from the Report of the Water Storage Commission. A number of mills lying on the Moose and Deer rivers are also added, which were not included in the Report to the Board of Engineers on Deep Waterways:

Number of dams furnishing water power...	44
Total horsepower of water wheels in use....	71,133
Total steam power used..................	6,037
Value of establishments..................	$12,302,100
Value of annual product..................	15,101,440
Number of hands employed...............	5,349

The permanency of Black river runoff. In view of the vast commercial interests in the water power of Black river, the question as to the permanency of Black river runoff becomes of considerable importance. It has been shown on a preceding page that reasoning from precipitation data, purely, it is quite possible there may occur a year when the runoff will be less than any thus far observed.

As regards maintaining the observed runoffs of Black river, the conditions are, on the whole, reassuring. For a number of years the writer has been gathering data as to the effects of forests in conserving stream flow, with the result of satisfying himself that it may be tentatively stated that forests do conserve and increase the runoff of issuing streams somewhat. The reasons for this conclusion are stated at length on another page and will not be gone into here.

A. View of Black river at the village of Black River.



B. View of Black river at village of Brownsville.

In order to show the relative proportions of virgin forest, culled area from which the merchantable timber has been removed (which, in the case of the Adirondacks, is soft wood), the cleared area, and the water area for a considerable extent of the Adirondack region, several of the topographical sheets of the United States Geological Survey have been taken and the areas of the different classes, as just detailed, colored in, the data used for this purpose being that gathered by the United States Geological Survey in the original preparation of the maps. The following are the figures derived from three sheets covering areas either in or adjacent to the headwaters of Black river, namely, Old Forge, Wilmurt and Canada Lakes sheets. The following tabulation shows that for these three topographic sheets the total area of virgin forest is 234.91 square miles; of culled area, 358.73 square miles; of cleared area, 39.88 square miles; water area of lakes and ponds, 17.50 square miles; the total area included in the three maps is 651 square miles. The Remsen sheet, which covers an area just in the edge of the great northern forests shows 83.98 square miles of culled area and 133.01 of cleared area, the total of the sheet being 217 square miles. Farther to the north and west, in the vicinity of Carthage, Watertown and in the lower part of the Black river basin, generally the cleared area is proportionately considerably larger than on the Remsen sheet. It is in many places substantially like the Schuylerville and Glens Falls sheets tabulated farther on.

Topographic sheet	Virgin forest, square miles	Culled area, square miles	Cleared area, square miles	Water area, square miles	Total area, square miles
Old Forge..........	59.96	130.85	14.25	11.30	216.40
Wilmurt	4.75	186.23	24.38	1.95	217.30
Canada Lakes	170.20	47.65	1.25	4.25	217.30
Total	234.91	358.73	39.88	17.50	651.00
Remsen	......	83.98	133.01	......	217.00
Final total.....	234.91	442.71	172.89	17.50	868.00

The foregoing sheets are all of the topographic maps of the State, either including or in the vicinity of the Black river catchment area, which were available in 1899. We have, however, eight sheets either included in or in the vicinity of the upper Hudson catchment area, as follows: Newcomb, Bolton, Paradox Lake, Elizabethtown, Mount Marcy, Indian Lake, Schroon Lake and Thirteenth Lake sheets. The statistics of these sheets are given in the following tabulation:

Topographic sheet	Virgin forest, square miles	Culled area, square miles	Cleared area, square miles	Water area, square miles	Total area, square miles
Newcomb	......	186.10	24.50	4.90	215.5
Bolton	......	153.00	43.55	19.85	216.4
Paradox Lake	......	171.55	38.60	5.35	215.5
Elizabethtown	14.45	137.10	61.50	1.95	215.0
Mount Marcy	138.45	9.90	65.00	1.65	215.0
Indian Lake	10.40	193.40	6.15	6.45	216.4
Schroon Lake	1.10	172.10	35.80	6.50	215.5
Thirteenth Lake	0.25	184.55	29.60	2.00	216.4
Total	164.65	1,207.70	304.70	48.65	1,725.7
Fort Ann	......	32.60	184.70	......	217.3
North Creek	......	117.40	96.05	2.95	216.4
Glens Falls	......	77.90	125.60	13.08	217.3
Cambridge	......	56.00	160.00	8.22	218.2
Schuylerville	......	27.55	182.65	8.00	218.2
Total	......	311.45	749.00	32.25	1,087.4
Final total	164.65	1,519.15	1,053.70	80.90	2,813.1

The following are the totals for the foregoing eight sheets: virgin forest, 164.65 square miles; culled area, 1207.70 square miles; cleared area, 304.70 square miles; water area, 48.65 square miles; total area, 1725.7 square miles.

We also have five sheets either in or in the vicinity of the Hudson river catchment area, namely, Fort Ann, North Creek, Glens Falls, Cambridge and Schuylerville. The totals for these five sheets are virgin forest, 0; culled area, 311.45 square miles; cleared area, 749.0 square miles; water area, 32.25 square miles; total area of the five sheets, 1087.4 square miles. In a portion of the region covered by these sheets the tendency is for many of the hard, stony hill farms to revert to forest conditions. We may assume, therefore, that throughout the Adirondack region the forest area is slowly increasing.

As a summation of this discussion it may be concluded, taking into account the erection by the State of New York of the Adirondack park, as well as the tendency to abandon stony farms, that on the whole the conditions governing the runoff of streams on Black river are improving. The same thing is true of the Hudson and Mohawk rivers or of any other stream issuing from the State forests. Deductions, therefore, based on what has happened in the past may be expected to be realized in the future.

The main water power developments of New York. In the State of New York there are seven large towns, at all of which the original basis of the development was water power, namely, Lockport, Rochester, Oswego, Watertown, Little Falls, Glens Falls and Cohoes. The recent development of the city of Niagara Falls is also due purely to the water power of Niagara river, but this was not the original basis of growth. The attraction of the falls as a great natural curiosity gave this place its original impulse. There are also a number of smaller places in the State where water power has developed towns, but the foregoing are the larger ones. Moreover, so strong has been the impulse of the water power that several of these towns have developed at locations where there were serious adverse conditions. At Lockport there is no water supply within reasonable distance. Even in 1904, aside from a few polluted wells, the water supply for the town is still taken from Erie canal, which receives the sewage of over

70,000 people at Buffalo.[1] Lockport is a specially interesting case, because the original water power at that place was artificially created by the construction of the Erie canal.

At Rochester the conditions were also somewhat forbidding. An extensive black ash swamp occupied the area now covered by the original first, second and third wards of that city, and which is now largely the business part of the town.

Because of its location on Lake Ontario, and at the mouth of Oswego river, Oswego may be possibly considered a natural town site, although considerable amounts of money have been expended to construct a harbor there, while not very far away the fine harbors of Sodus bays are still practically unutilized. By way of comparing the Sodus bays harbors with Oswego, we may refer to the annual report of the Chief of Engineers for the fiscal year ending June 30, 1898, from which it appears that the total amount expended for the harbor at Great Sodus bay from May 23, 1828, to June 3, 1896, inclusive, was $475,646.80; at Little Sodus bay from August 20, 1852, to June 3, 1896, the total amount expended was $332,941.77, and at Oswego from March 20, 1826, to June 3, 1896, the total amount expended was $1,902,612.87. Had it not been for the water power at Oswego it is quite possible that the chief town of the east end of Lake Ontario might have been located at some place other than the mouth of the Oswego river, although in considering these figures as to the cost of harbor we may properly take into account that Oswego has become a large town, while there are still only very small towns on Sodus bays.

At Watertown the conditions for building a city may be considered fairly favorable and the advantage of the Black river water power has been accentuated by the admirable site.

At Little Falls rocky ledges in a narrow river gorge have operated to make the cost of building a town expensive, and the

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[1] For account of water supply of Lockport, see the following reports: (1) Report on the Water Supply of the Western Division of Erie Canal, dated April 15, 1896. (2), Report on a System of Domestic Water Supply in the Vicinity of Lockport, N. Y., dated Nov. 27, 1903.

location of the water power at that point has been the governing condition.

Cohoes would not be selected as the site of a city aside from the location of extensive water power there.

Glens Falls may be considered a good site, and small towns like the neighboring villages of Fort Edward and Sandy Hill would probably in any event have grown up at this point.

Economic statistics of the city of Watertown. Generally, we may say that had it not been for the water power, these seven chief manufacturing towns of New York would either never have come into existence, or at any rate would not have developed to any such extent as we now find them. In taking this view, however, it is not overlooked that with the towns once started other causes have contributed, in some cases, very materially to their advancement. What may be fairly assumed is that the water power was not only the determining cause for the location of all these towns, but that they have grown much larger on account of possessing the water power than they would otherwise have grown. It is also assumed that some of the locations are so unsatisfactory as to have prevented the growth of any town except there were some strong, predetermining cause like the possession of water power. It appears proper, therefore, to examine, in the present connection, the economic value of the water powers of the Black river valley to the State of New York.

TABLE No. 38—ECONOMIC STATISTICS OF THE CITY OF WATERTOWN

YEAR	Area, in acres	Assessed valuation	Rate on the dollar	STATE TAX			Total State tax on an equal area of farming land in the adjoining township of Watertown	Annual net profit to the State on account of the city of Watertown. Column (7)—column (8)	Present value of the annual net profit, being total increase in wealth in the State by reason of the values created at Watertown
				For schools	Exclusive of school tax	Total Column (5)+column (6)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1869	3,237	$3,171,702	$0.0059	$4,123 98	$14,433 88	$18,557 86	$449 14	$18,108 72	$130,937 73
1870	3,237	3,143,391	0.0073	3,911 01	19,059 16	22,970 17	555 14	22,415 03	124,289 74
1871	3,237	3,315,210	0.0054	3,992 10	14,078 82	18,070 92	404 78	17,666 14	90,303 96
1872	3,237	3,426,873	0.0090	4,130 52	26,848 37	30,978 89	680 23	30,298 66	146,110 94
1873	3,237	3,638,820	0.0068	4,481 77	20,408 85	24,890 62	511 14	24,379 48	110,911 81
1874	3,237	4,285,012	0.0063	4,727 17	22,437 45	27,164 62	553 60	26,611 02	114,211 29
1875	3,237	7,838,424	0.0031	5,057 00	19,219 00	24,276 00	496 82	23,779 18	96,280 53
1876	3,237	7,857,258	0.0017	4,974 12	8,784 42	13,758 54	308 88	13,449 66	51,374 43
1877	3,237	7,267,536	0.0023	5,214 85	9,540 96	14,755 81	341 04	14,414 77	51,944 25
1878	3,237	4,490,122	0.0027	4,553 68	7,779 57	12,333 25	296 62	12,036 63	40,919 36
1879	3,237	6,196,145	0.0020	4,764 80	7,796 55	12,561 35	307 84	12,253 51	39,298 73
1880	3,237	5,737,927	0.0025	4,431 39	9,800 24	14,231 63	370 52	13,861 11	41,938 24
1881	3,237	5,099,394	0.0017	4,509 22	4,390 55	8,899 77	235 17	8,664 60	24,731 74
1882	3,237	5,612,152	0.0017	4,396 55	5,395 76	9,792 31	260 69	9,531 62	25,666 51
1883	3,237	5,360,216	0.0024	4,219 60	8,490 07	12,709 67	333 47	12,376 20	31,439 94
1884	3,237	5,338,693	0.0019	4,108 08	5,918 74	10,026 82	253 68	9,773 14	23,421 92
1885	3,237	5,345,960	0.0021	3,777 82	7,403 86	11,181 68	268 52	10,913 16	24,673 64
1886	3,237	5,300,001	0.0022	4,490 84	7,029 15	11,519 99	283 67	11,236 32	23,966 29
1887	3,237	5,363,697	0.0020	4,389 54	6,384 79	10,774 33	264 63	10,509 70	21,147 60
1888	3,237	5,483,851	0.0018	4,085 09	6,617 82	10,702 91	258 24	10,444 67	19,827 12
1889	3,237	5,653,686	0.0027	4,101 99	10,783 60	14,885 59	349 54	14,536 05	26,031 87
1890	3,237	5,744,195	0.0018	4,546 29	5,682 84	10,229 13	235 10	9,994 03	16,884 67
1891	3,237	6,230,433	0.0010	4,725 66	1,772 09	6,497 75	135 67	6,362 08	10,140 08
1892	3,237	7,329,440	0.0015	5,569 14	5,457 56	11,026 70	193 64	10,833 06	16,288 92
1893	3,237	8,010,611	0.0021	6,191 02	10,534 46	16,725 48	262 43	16,463 05	23,353 15
1894	3,237	8,201,452	0.0017	6,078 89	8,240 96	14,319 85	216 34	14,103 51	18,873 68
1895	3,237	8,481,123	0.0026	6,197 09	15,544 31	21,741 40	312 63	21,428 77	27,053 34
1896	3,237	8,816,620	0.0023	6,816 57	13,448 81	20,265 38	279 30	19,986 08	23,803 75
1897	3,237	9,287,426	0.0021	6,452 72	13,117 03	19,569 75	270 44	19,299 31	21,684 71
1898	3,237	9,359,612	0.0017	6,605 50	10,306 49	16,911 99	229 50	16,682 49	17,683 44
Total	....	....	....	$145,624 00	$326,706 16	$472,330 16	$9,918 41	$462,411 75	$1,435,193 38

In order to make such showing we may consider the statistics of the city of Watertown, as given by table No. 38, showing the amount raised for State tax since 1869, in which year Watertown became a city, to 1898, inclusive. In this table column (1) shows the years in sequence; column (2) the area, which has remained fixed during the whole period at 3237 acres; column (3) the assessed valuation each year; column (4) the rate on the dollar of the State tax; columns (5), (6) and (7) the State taxes for each year; column (8) the total State tax on an equal area of farming land in the adjoining township of Watertown; colunm (9) the annual net profit to the State on account of the city of Watertown—that is to say, the difference of columns (7) and (8); and column (10) the present value (amount) of the annual net profit, being the total increase in wealth in the State by reason of the values created at Watertown. The rate of 6 per cent has been used in computing column (10). Referring to the footings of the table, it appears that the total State tax from 1869 to 1898, inclusive, was $472,330.16, and that the total State tax on an equal area in the adjoining township of Watertown has been, for the same period, $9,918.41. A comparison of these two columns shows forcibly the economic value to the State of municipal developments. The footing of column (9), which is the difference of columns (7) and (8), is $462,411.75. The total value (amount) in 1898 was $1,435,193.38. These figures, it will be remembered, represent merely State taxation—they do not represent the increment to the county, the municipality itself, or to the private wealth of citizens.

Inasmuch as Lockport is a town of about the same size as Watertown, it is of interest to compare the statistics of the two places. Lockport was made a city in 1865, and the statistics have been brought up to and including the year 1896. The assessed valuation in 1865 was $2,929,130, while the assessed valuation of Watertown in 1869 was $3,171,702. The assessed valuation of Lockport in 1896 was $6,785,100, and of Watertown in 1898, $9,359,612. The total State tax at Lockport from 1865 to 1896, inclusive, was $511,861.59; the total State tax on an equivalent area of farming land in the adjoining township of Lockport was $17,692.88; the total annual net profit to the State on account of the city of Lockport for the whole period from 1865 to 1896, inclusive, was $494,169.16, and the present value (amount) is found to be $1,584,765.17.[1]

Streams flowing into St Lawrence river. Proceeding along the St Lawrence river we find a number of streams, such as the Oswegatchie, which flows into the St Lawrence at Ogdensburg; the Grasse, which enters the St Lawrence near the north line of the State; the Raquette and St Regis, flowing into the St Lawrence a short distance below the Grasse, and finally the Chateaugay, which flows from this State into the Dominion of Canada and thence into the St Lawrence. These streams all head in and about the Adirondack plateau and, as a rule, fall rapidly from their sources to near their mouths, affording large water powers, which thus far have been chiefly utilized for pulp grinding, paper making, and sawing lumber.

There is a lack of definite information in regard to all the streams of the northern part of the State. No detailed surveys of this region have been made. Partial reservoir systems have been constructed on the Oswegatchie, Grasse, and Raquette rivers. Some of the economic questions involved in the construction of these reservoirs have been discussed on another page.

Until within a year or two, no measurements had been made of any of the streams tributary to the St Lawrence river proper. It is probable, however, that several of them are the best water-yielding streams of the State, because they flow from the great northern forest, and because their headwaters are in the extensive lake region which lies immediately west of the main Adirondack mountains, and which extends westward from the base of the main range to the borders of the forest, a distance of nearly 50 miles. This portion of the Adirondack plateau is comparatively level. As regards geographic distribution, these lakes are most numerous in the northern parts of Herkimer and Hamilton

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[1] Abstract from Report to the Board of Engineers on Deep Waterways.

counties and the southern parts of St Lawrence and Franklin counties. Those in Herkimer county flow into the Moose and Beaver rivers, tributaries of Black river. The following are the elevations of a few of the more important lakes of Hamilton, St Lawrence, and Franklin counties, which are tributary to streams flowing northward into the St Lawrence:

Lake	Feet
Cranberry	1,540
Raquette	1,774
Forked	1,753
Long	1,630
Little Tupper	1,728
Big Tupper	1,552

Oswegatchie river. This stream has its source in several lakes and swamps on the Adirondack plateau, in the southern portion of St Lawrence county. The main stream is the outlet of Cranberry lake and flows in a general northwesterly direction, entering the St Lawrence river at Ogdensburg. Indian river, one of the principal tributaries of the Oswegatchie, rises in Indian and Bonaparte lakes, flows to and through Black lake and joins the Oswegatchie a few miles above Ogdensburg. The following are the catchment areas of the Oswegatchie river and its main tributaries:

	Square miles
East Branch Oswegatchie river above mouth	358
West Branch Oswegatchie river above mouth	272
Oswegatchie river below junction of two branches	630
Oswegatchie river above Gouverneur	727
Oswegatchie river above Galilee	1,033
Indian river above Philadelphia	216
Black lake above Galilee	544
Oswegatchie river below Black lake junction	1,577
Oswegatchie river above Ogdensburg	1,609

The flow of the Oswegatchie at Ogdensburg varies from 614 cubic feet per second at low water to 15,500 cubic feet per second during the spring floods.

Water power of Oswegatchie river. Water power is developed by twenty-six dams on the Oswegatchie and its branches, and is used mainly in lumber and paper industries at various points, as shown by the following tabulation:

Number of dam	Number of mills at dam	Location	Use	Average head, in feet	Number of employees
(1)	(2)	(3)	(4)	(5)	(6)
1	17	Ogdensburg.	General manufacturing.	8	336
2	2	Heuvelton	Woodworking and gristmill. .	8	5
3	3	Rensselaer Falls.	Sawmills and custom mills. . .	7½	31
4	1	Coopers Falls . . .	Sawmill privileges	8	. . . . . .
5	4	Wegatchie	Abandoned woolen mill. Sawmill; runs in winter.	11	. . . . . .
6	1	Natural Dam. . . .	Saw and paper mills.	19½	150
7	7	Gouverneur	General manufacturing.	7	82
8	1	Hailsboro	Talc pulp.	. . . . . .	. . . . . .
9	1	Hailsboro	Talc pulp.	. . . . . .	. . . . . .
10	2	Hailsboro	Woodworking mills. Custom grinding	12	4
11	1	Hailsboro	Talc pulp.	18	. . . . . .
12	1	Hailsboro	Oswegatchie Light & Power Co	20	1
13	1	Emeryville.	Gouverneur Wood Pulp Co. . .	31	33
14	1	Dolgeville.	U. S. Talc & Pulp Co.	16	11
15	1	Talcville	Talc mine	12	1
16	2	Edwards	Grist and sawmills.	12	10
17	. . . . . .	South Edwards. .	. . . .	. . . . . .	. . . . . .
18	1	Fine	Saw and paper mills.	. . . . . .	. . . . . .
19	1	Oswegatchie	Standard Pulp Co.	34	. . . . . .
20	1	Newton Falls. . . .	Wood pulp.	20	150
21	1	Newton Falls. . . .	Wood pulp paper	38	
		Water Power on the West Branch.			
22	1	Below Fullerville	Talc pulp.	13	5
23	1	Fullerville	Iron works (abandoned)	12	. . . . . .
24	1	Fullerville	Wood and talc pulp.	19½	20
25	1	Gears Corners. . .	Sawmill (abandoned)	9	. . . . . .
26	1	Harrisville	Gristmill	13	3

Cranberry lake, with a water surface area of 12.8 square miles, could furnish additional storage if the present dam were raised a few feet. Black lake, with a water surface of 17.2 square miles, is virtually an enlargement of Indian river and greatly aids in regulating the flow at Ogdensburg, offering a chance for additional storage at a reasonable cost.

Grasse river. The next stream is Grasse river, which drains a long, narrow catchment area lying between Oswegatchie and Raquette rivers. The channel of Grasse river is parallel to the St Lawrence throughout the whole eighteen miles of its course. For several miles it is separated from the St Lawrence by a neck of land about four miles in width. The Long Sault rapids of the St Lawrence river, comprising a fall of about 50 feet, occur within this reach. This fact has been taken advantage of for the construction of an hydraulic power plant by the St Lawrence Power Company. A canal, three and one-half miles in length, has been cut across the divide, by which water is diverted from near the head of the rapids to a power plant on the bank of Grasse river. After using, the water is turned into Grasse river for a tail-race; 35,000 horsepower is developed under a head of 42 feet. The catchment area of Grasse river above Canton is 113 square miles and 637 square miles above its mouth.

Water power of Grasse river. The following shows the principal developed water powers on Grasse river, but not including the large power plant at Massena:

Number of dam	Number of mills at dam	Location	Use	Average head, in feet	Number of employees
(1)	(2)	(3)	(4)	(5)	(6)
1	3	Massena	Grist and planing mills	8	8
2	2	Lewisville	Grist and sawmills	7	6
3	1	Chase Mills	Custom sawmill	8	2
4	5	Madrid	Clothing, feed and sawmills	7	57
5	1	Bucks Bridge	Sawmill	8½	50
6	4	Morley	Woodworking and feed mills	6	8
7	4	Canton	Grist, sawmills, foundries, etc.	9	......
8	1	Canton	Sawmill	......	......
9	1	Pyrites	Sulphite pulp mill	65	......
10	2	Russell	Woodworking and grist mills	8	8
		Water power on Little river.			
11	1	Little River	Sawmill	12	......
12	1	Little River	Woodworking and grist mills	14	3
13	1	Little River	Grist mill	14	......
14	1	Little River	......	12	......

Raquette river. This river flows northerly through St Lawrence county, entering the St Lawrence river near the Canadian line. It drains a long, narrow catchment area, extending from the north part of Hamilton county to the St Lawrence river. The upper portion of the catchment is a flat plateau, with many lakes, furnishing opportunities for storage at reasonable cost. After leaving this plateau, the stream descends rapidly, forming many excellent sites for water-power developments.

The following are the main divisions of the catchment area of Raquette river:

	Square miles
Above Piercefield	695
Above Hannawa Falls	967
Above Massena Springs	1,188
Above mouth	1,240

The following gives the water-surface areas and the catchment areas of some of the lakes on the upper plateau tributary to Raquette river:

	Surface area, square miles	Catchment area, square miles
Blue Mountain lake	2.0	39
Raquette lake	10.0	94
Forked lake	2.3	40
Long lake	8.7	152
Little Tupper lake	4.0	59
Big Tupper lake	7.5	....

Storage can be secured in Big Tupper, Little Tupper, Long and Raquette lakes at a reasonable cost, owing to their being bordered by cheap flatland, a great portion of which is a part of the State Forest preserve.[1]

Storage reservoirs can be built at other points on the Raquette, notably at Moosehead in township 6 on Cold river, and on Moose creek.

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[1] This statement does not take into account that there is at present a constitutional provision against the cutting of forests.

Water power of Raquette river. The following water powers on Raquette river are either fully or partially developed:

Owners and location	Present head in feet	If fully developed, head in feet
1 Kent's mills, in Norfolk	5	5
2 Raymondville (State dam)	5	5
3 Raymondville Paper Company	14	14
4 Remington-Martin Company, Norfolk	44	44
5 Remington-Martin Company, Yaleville	12	20
6 Frost Paper Company, Norwood	10	20
7 Raquette River Paper Company, Union Mills	18	22
8 Raquette River Paper Company, Dewittville	16	22
9 A. Sherman Lumber Company, Sissonville	12	14
10 Potsdam Village Power, Potsdam	8	10
11 Hannawa Falls Water Power Company	90	90
12 Raquette River Pulp Company, Colton	28	28
13 Piercefield Paper Company, Piercefield	34	34
	296	328

The following water powers on Raquette river are undeveloped:

	Number of feet fall
Sols Island	22
Starks falls	40
Leonard falls	75
Gain-Twist falls	75
Rainbow falls	70
Five falls	70
South Colton falls (undeveloped)	40
Higley falls	25
Colton falls (undeveloped)	250
Norfolk (undeveloped)	30
Comprising	697

The foregoing undeveloped powers may be considered as either vertical falls or as rapids of sharp descents. In addition, the following with smaller catchment areas and less rapid descent, may be enumerated: Buttermilk falls, above Long lake; Raquette falls, below Long lake; Jamestown falls and Moody falls. There is about 70 feet fall per mile at all these places. There are also numerous small falls and rapids, capable, when the country is settled and lines of communication established, of furnishing valuable power, although at present such water powers have less value than they otherwise would have because there is no way of utilizing them. The discussion on a later page of this report, however, as to the developing of mountain powers and transmitting them electrically may be taken into account in estimating the value of undeveloped water powers. With efficient water storage on the many fine lakes at the headwaters of Raquette river, it is perhaps possible to keep the stream in its lower reaches (at Piercefield and below) up at all times to at least 1000 cubic feet per second. Assuming that it is practical to develop 900 feet out of the possible total of 1025, we would have about 100,000 gross horsepower from this stream alone, and this estimate does not take into account a number of the smaller water powers.[1]

St Regis river. This stream rises in various Adirondack lakes in the southern part of Franklin county, flows northerly into and through St Lawrence county and enters the St Lawrence river at St Regis village. Like most of the streams flowing north from the Adirondacks, its catchment consists of a high plateau, then a steep, rocky portion, followed by a low plateau near its mouth.

The catchment areas of the St Regis river and its principal branches are as follows:

	Square miles
West Branch of St Regis	280
East Branch of St Regis	347
St Regis below junction	627
Deer river	212
St Regis at mouth	910

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[1] In a paper, the Future Water Supply of the Adirondack Mountain Region and its Relations to Enlarged Canals in the State of New York, the writer has estimated the water power on Raquette river at 70,000 horsepower. It is evident that that estimate is very conservative.

Water powers have been developed at Parishville, West Stockholm, Skinnerville, Brashers Falls, Brasher Center and Hogansburg. There are undeveloped power sites at Sylvan Falls, High Falls, Kerr Falls, Whittaker Falls and Allens Falls.

Considerable storage can be secured by raising the dams on several of the larger lakes at the headwaters of the east and west branches of the river.

The chief tributary of St Regis river is Deer river, which, like the St Regis, flows generally in a northerly direction. Deer river joins the St Regis river about seven miles from the St Lawrence river.

Salmon river north. The next stream is Salmon river north, which flows northerly into the St Lawrence a short distance over the Canadian line. Its chief tributary, the Little Salmon river, enters the stream at Fort Covington, on the New York State line, about four miles from the St Lawrence river.

The following are the catchment areas of this stream:

	Square miles
Little Salmon river, above junction with Salmon river	103
Salmon river, above Malone	179
Salmon river, above Little Salmon river	273
Salmon river, below junction with Little Salmon river	452
Salmon river, above mouth	480

Trout river. The next stream flowing to the north is Trout river, the catchment area of which, above the New York State line, is 129 square miles.

Chateaugay river. The next stream is Chateaugay river, with a catchment area above the New York State line of 199 square miles. Very little is known about the water power of this stream any further than that Chateaugay river heads in Upper Chateaugay lake and flows through Lower Chateaugay lake. The elevation of Chateaugay lake is unknown.

Lake Champlain System

Lake Champlain has a water area of 400 square miles. The area of its catchment in New York State amounts to 2950 square miles; in Vermont to 4270 square miles; and in the Province of

Quebec to 740 square miles. The total area of the catchment, not including water surface, is 7960 square miles, or the total area of the catchment basin, including water surface, is 8360 square miles. Lake Champlain is considered as beginning at Whitehall and terminating at St Johns, on the Richelieu. Its length is 125 miles and its breadth in the northern portion is about 13 miles. The standard low-water elevation is given at 95.03 feet, and the standard high water at 103.78 feet, above tide.

The streams tributary to Lake Champlain are Big Chazy, Little Chazy, Saranac, Salmon river east, Little Ausable, Big Ausable, and Bouquet rivers and the outlet of Lake George. There are also a few small streams of no special importance.

Big Chazy river. This stream rises in the western part of Clinton county, and flows in an easterly direction into Lake Champlain, at King bay, five miles south of the village of Rouse Point. The main branch issues from Chazy lake, of which the elevation is 1500 feet above tidewater. The headwaters of the north branch probably are at a somewhat greater elevation than this. The catchment area is 300 square miles.

Little Chazy river. This river enters Lake Champlain two miles south of the Big Chazy.

Saranac river. The streams tributary to Lake Champlain are, as a rule, not of great length, but rising, as they nearly all do, in or near the high mountains of the northern plateau, they have a rapid descent with an abundant fall. Saranac river has its head chiefly in Upper Saranac lake,[1] at an elevation of 1577 feet above tide and flows northeasterly, entering Lake Champlain at the village of Plattsburg. The length of the river, according to Bien's atlas, is 55 miles from its mouth to Lower Saranac lake. The elevation of Lake Champlain above tidewater is 101 feet, while that of Lower Saranac lake is 1539 feet; hence, the fall in 55 miles of river course is 1438 feet. Middle Saranac lake lies at an elevation of 1542 feet and Upper Saranac, as already given, at 1577 feet.

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[1] There are a number of lakes and ponds tributary to Upper Saranac lake which are not here specially considered.

The catchment of the Saranac river has an area of 628 square miles, about one-half being wooded. The lakes on its headwaters have a water surface of 21 square miles, and afford an opportunity for considerable storage. This storage could be largely increased at comparatively small cost for construction, but the land damages on the Saranac lakes would be considerable owing to the large private residences and summer hotels on their banks.

The quantity of merchantable timber likely to be cut on the catchment of Saranac river is small, owing to the large area owned by the State or by private parties as forest preserves.

There are a few developed powers on Saranac river, the principal ones being at Saranac Lake village, Cadyville and Plattsburg. There is an undeveloped power at Franklin Falls with a possible fall of 60 feet.

Salmon river east. This river rises in the western part of Clinton county and flows easterly into Lake Champlain near the village of South Plattsburg. Its catchment area is 480 square miles.

Little Ausable river. This stream rises in the south part of Clinton county and flows northeasterly to the village of Lapham, then southeast, entering Lake Champlain about four miles south of the mouth of Salmon river east.

Ausable river. This stream has its source in the central part of Essex county in Upper Ausable lake, which lies in a valley in the midst of the highest mountains of the State, at an elevation of 1993 feet above tidewater. It flows in a northeasterly direction to Ausable Forks, from near which it is the boundary line between Clinton and Essex counties. It then flows a little north of east, entering Lake Champlain three miles above the village of Port Kent. The length of the stream from its mouth to Lower Ausable lake, the elevation of which is 1961 feet above tide, is about 42 miles; hence we have a fall of 1860 feet in a little over 40 miles. For several miles of its course the stream flows through Ausable Chasm. The catchment has an area of 519 square miles of partly wooded, mountainous territory. There are only a few small developed powers on the Ausable. The merchantable timber has mostly been cut, and the original dams used by the lumbermen for floating logs have decayed. There is a large undeveloped water power at Wilmington notch, where there is a fall of 100 feet. There is also a fall of 100 feet at High Falls. From the upper end of Wilmington notch to two miles above the village of Wilmington there is a fall of 600 feet in a distance of four miles. This part of the stream is as yet entirely undeveloped. These water powers are on the west branch of the Ausable which heads in Lake Placid.

Bouquet river. The Bouquet river rises in the eastern part of Essex county and flows northerly to the village of Willsboro and thence southeasterly for two miles, when it enters Lake Champlain.

Outlet of Lake George. The most southerly tributary of Lake Champlain of any great importance for water purposes is the outlet of Lake George, which in about 2 miles has a fall of 222 feet. The greater portion of this is concentrated in the first mile from the lake. The elevation of Lake George above tidewater is 323 feet. The area of the lake surface is 43 square miles, and the tributary catchment area about the foot of the lake is 229 square miles.

The streams in eastern New York can not be depended on to furnish a natural flow of more than about 0.2 cubic foot per second per square mile as a minimum in a dry year. On account of the large water surface of Lake George in proportion to the catchment area, it is possible, by utilizing the storage on the lake surface, to realize in an average year a much larger quantity. From 0.7 to 0.8 cubic foot per second per square mile may be assumed as a conservative estimate, the results being based on allowing the water to flow out of the lake 24 hours per day for only 310 days in the year. On this basis we may assume a mean flow for minimum dry years of about 200 cubic feet per second. Since the entire 222-foot fall of the Lake George outlet is now utilized, we may place the permanent power in a dry year at about 5000 gross horsepower. The village of Ticonderoga, at which this power is utilized, had a population in 1900 of 1911.

Wood creek, the most southerly tributary of Lake Champlain, is of interest in a study of the water resources of New York, chiefly because of its relations to the Champlain canal, its channel being utilized for several miles as part of the canal. At Fort Ann there is considerable power developed on one of its tributaries, used at present for grinding pulp.[1]

Hudson River System

Hudson river. The Hudson river rises in the high mountains of the Adirondack plateau, in the western part of Essex county, and flows with some turnings in a generally south direction to a short distance below Palmers Falls, where it flows from 15 to 20 miles mostly in a northeasterly direction to Sandy Hill. It then turns again, and for the balance of its course is nearly due south. It enters New York bay at New York. Its headwaters may be taken to issue from Lakes Henderson and Catlin, which are at elevations above tide respectively of 1889 feet and 1570 feet. Lake Colden, at an elevation of 2764 feet, is the extreme source of the Hudson river, but as this lake is small and the stream issuing therefrom is also small, in a discussion of water power the larger lakes at lower elevations are preferably taken. The length of the stream, measured roughly along its course, is something like 285 miles.

Hudson river, with its principal tributary, the Mohawk, is the most important river of the State. From its mouth to Troy, a distance of over 150 miles, it is a great inland estuary subject to tidal action, and because of its great length and the large fresh-water inflow, it is unique among inland estuaries. From the first landing of the Dutch on Manhattan Island to the present time it has been an important channel of commerce. On his voyage of discovery in 1609 Hendrik Hudson ascended to the head of tidewater, and doubtless discerned the possibilities of future

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Partially abstracted from the Report of the Water Storage Commission on the Fourth or Northern Division.

settlement which were soon realized at Albany, Waterford and Schenectady.

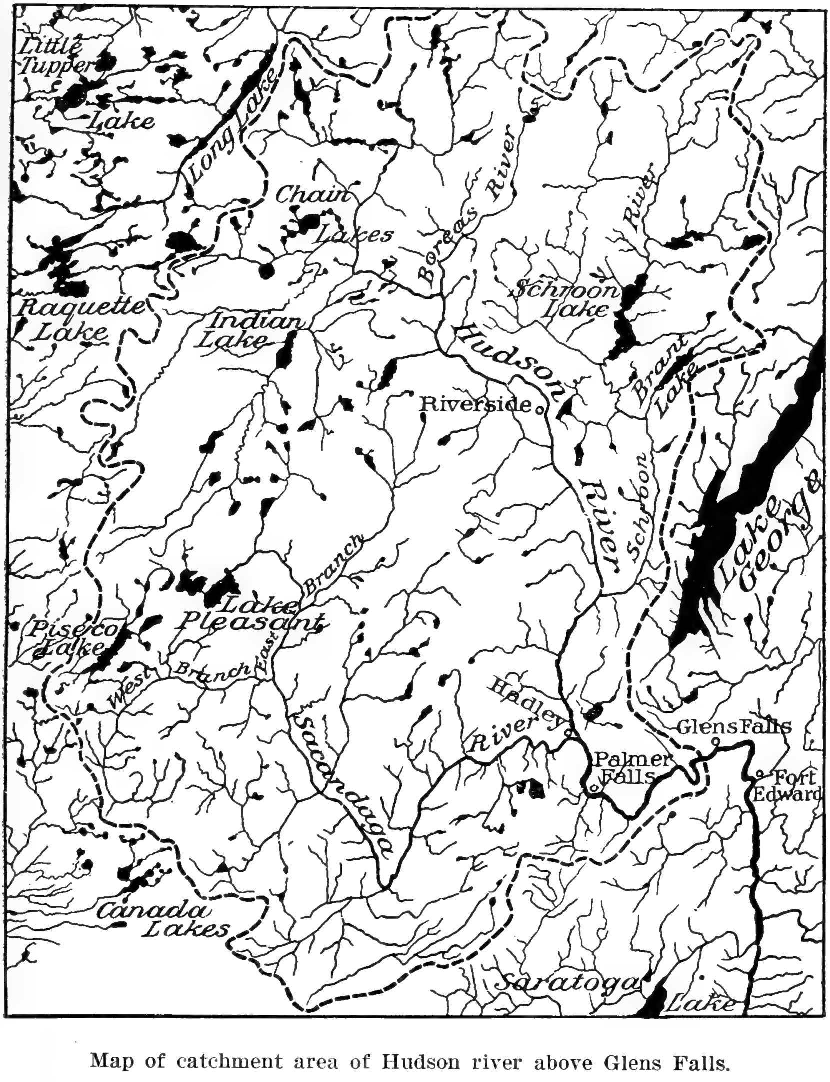
When the great Dutch navigator sailed up the river, no doubt as he passed on from day to day, penetrating farther and farther inland, the conviction grew upon him that he had discovered a passage through the continent leading to India, nor could he have overlooked the vast possibilities of trade and commerce opened up, even when he finally reached the head of navigation and found that the East Indian passage was after all a myth. Indeed, one can imagine him saying to his companions, "What a great place for navigation!" We can imagine a company standing upon the deck of his ship, gazing in silent wonder over the panorama at either side, and saying to one another, " here, indeed, is the seat of future empire."

The tidal action of the Hudson river originally terminated at the rapids above Troy, but its present termination is a few miles below, at the Troy dam, a structure erected about 1820 as a part of the State canal system. There is a lock at the east end of this dam through which canal boats pass into the pool above, thus enabling them to reach Lansingburg on the east side of the river, or Waterford, on the west side, where they may enter the Champlain canal.

In ascending the river the principal streams on the east side are Harlem river, Croton river, Fishkill creek, Wappinger creek, Roeliff Jansen kill, Claverack creek, Kinderhook creek, Hoosic river, Battenkill, Schroon river and Boreas river. On the west side, the principal streams are Murderers creek, Rondout creek, Wallkill river, Esopus creek, Catskill creek, Normanskill, Mohawk river, Fish creek, Sacandaga river, Indian river and Cedar river.

The principal tributaries of the Mohawk from the north are Chuctenunda creek, Cayadutta creek, Garoga creek, East Canada creek and West Canada creek. From the south, Schoharie creek, Sauquoit creek and Oriskany creek, and from the west the Lansing kill. There are tributary to both the Hudson and Mohawk rivers a considerable number of smaller streams, some of which have

Plate 3.



Map of catchment area of Hudson river above Glens Falls.

power development upon them, but which are not specifically mentioned here.

Below Troy the tributaries of the Hudson river are mostly small and generally not of very great importance, although some of them have considerable power development. One of them, Croton river, is the principal source of water supply of the City of New York. On this part of the river, the catchment basin is rather narrow, and many of the streams issuing from the highlands at either side have such small catchment areas as to carry only moderate quantities of water.

Tides in Hudson river. The following are the elevations of mean tide, mean low tide and mean high tide above mean sea level at New York, and the mean rise and fall of tides at various points along the tidal estuary between New York bay and the Troy dam:

Locality	Mean tide	Mean low tide	Mean high tide	Mean rise and fall
Sandy Hook	....	....	....	4.70
Governors Island	0.00	2.20	2.20	4.40
Dobbs Ferry	0.18	1.62	1.98	3.60
Coxsackie light-house	1.68	0.17	3.53	3.70
New Baltimore	1.73	0.02	3.44	3.42
Coeymans	1.88	0.44	3.31	2.87
Castleton	2.09	0.82	3.35	2.53
Van Wies	2.13	0.82	3.29	2.33
Albany	2.43	1.27	3.59	2.32
Nail works	2.78	1.81	3.75	1.94
Troy dam	3.77	3.37	4.17	0.80

The following gives the hight above tidewater at New York of a number of points on the Hudson river:

	Feet
New York (at mouth)	0.0
Troy	3.8
Saratoga dam (crest)	102.0
Fort Edward (below dam)	118.0
Glens Falls (crest of feeder dam)	284.0

	Feet
Mouth of Sacandaga river	556.0
Mouth of Stony creek	584.0
Mouth of Schroon river	608.0
At Glen bridge	728.0
At Riverside bridge	875.0
At North Creek bridge	998.0
At North River	1,050.0
Mouth of Boreas river	1,140.0
Mouth of Indian river	1,415.0
Mouth of Cedar river	1,460.0
Lake Sanford	1,723.0

Water power of Hudson river. There is a large amount of power on the Hudson river at Troy, Mechanicville, Stillwater, Northumberland, Fort Miller, Fort Edward, Bakers Falls, Sandy Hill, Glens Falls, Feeder Dam, Spier Falls, Palmers Falls and Hadley; on Sacandaga river at Conklinville, and on Schroon river at Warrensburg. A canvass of the Hudson river powers was made in 1895 and appears in detail in table No. 12, Showing Water Power in Use on the Hudson River in 1895, of the Report on Upper Hudson Storage Surveys, December 31, 1895. The detail is too extensive for insertion here, but may be obtained by reference to the said report.

According to this table, the total power in use on the Hudson river in 1895 was 43,481 net horsepower. This power remains substantially the same in 1904 as in 1895, except that the Hudson River Power & Transmission Company has built a new plant of a stated minimum capacity of 5000 horsepower three miles below Mechanicville. There has also been some increase in the power in use at Bakers Falls, but just how much, the writer is unable to state. The new plant of the Hudson River Water Power Company at Spier Falls has also been built. The total power in use on the Hudson river in 1904 is perhaps 75,000 to 80,000 net horsepower.

Harlem river and Spuyten Duyvil creek. This river and creek are an arm of the Hudson, extending from Hudson river to East river. For two miles they flow in an easterly direction and then southerly, for a total distance of about 7 miles. These streams have been canalized by the Federal government and are rapidly becoming an important artery of commerce. They form the northern and, for a portion of the way, the eastern boundary of Manhattan island. The two streams join at Kings Bridge, New York.

Before improvement the Harlem river had an available depth of 10 feet from the East river to Morris dock, except at Highbridge, where it was only 6 feet. From Morris dock to Fordham landing there was a crooked channel 7 feet deep, and above the latter place the river could be used only by the smallest class of vessels.

Spuyten Duyvil creek from Kings Bridge to the Hudson had a depth of 4 feet.

The original project for improvement, adopted in 1874, provided for the removal of old bridge piers, Candle factory reef, and boulders at various places near the East river to a depth of 12 feet, the cost of the work being estimated at $167,875.56. In furtherance of this project $21,000 was expended.

The existing project, adopted June 18, 1878, and modified October 7, 1886, provides for a continuous channel, 400 feet wide and 15 feet deep, from the East river to the Hudson river, except just north of Highbridge, where the width was made 375 feet, and the rock cut through Dyckman's meadow, where the width was reduced to 350 feet and the depth increased to 18 feet. The cost of the work was estimated at $2,700,000.

The amount expended in carrying on work under the existing project to the close of the fiscal year ending June 30, 1903, was $1,244,851.90.

The maximum draft that could be carried June 30, 1903, over the shoalest part of the channel was 12 feet.

The commerce of this river is very large. In 1895, the tonnage amounted to over 7,500,000 tons.[1]

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[1] Report of the Chief of Engineers for the year ending June 30, 1903.

Croton river. The Croton river is formed by the uniting of three branches, known as the East, the Middle and the West branch, which rise in the southern part of Dutchess county, flowing in a southerly direction through Putnam county and uniting near its southern boundary. From this point the river continues in a southwesterly course across Westchester county to the Hudson river, into which it enters at Croton point thirty miles northerly from the City of New York. The principal tributaries of the Croton are the Titicus, Cross, Kisco and Muscoot rivers.

The catchment of the Croton, extending about thirty-three miles north and south and eleven miles east and west, lies almost entirely in New York, only a small portion being in Connecticut. Its area is 339 square miles above the old Croton dam and 360 square miles above the new Croton dam now being constructed. The catchment is hilly. The surface soil is composed principally of sand and gravel—clay, hardpan and peat are found to a limited extent in a few localities. The rock formation consists largely of gneiss. Limestone, micaceous and talcose slate, granite, serpentine and iron ore occur in a few places.[1] This stream is of very great importance because its runoff is completely utilized for the water supply of the City of New York and it is accordingly extensively discussed in this report.

Fishkill creek. This stream rises in the central part of Dutchess county and flows southwesterly into the Hudson, one mile south of Fishkill station. Its headwaters drain the western slope of Chestnut Ridge mountains. In its upper reaches the stream receives the drainage from extensive swamp and flatlands. The lower reaches of the stream flow along the foot of the Fishkill range. From Fishkill village to Fishkill landing it falls over slate and limestone ledges, making a descent of 200 feet in five miles. This fall is largely utilized to provide water power for manufactories on its banks. As a result, the stream becomes greatly polluted from manufacturing waste and other impurities which it receives.

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[1] Wegman's Water Supply of the City of New York. (1896).

Water power of Fishkill creek. The extent of the manufactures of Fishkill creek is shown in the following tabulation, which gives the principal developed water powers on the stream in 1901:

Number of dam	Location	Name of mill and of owner or operator	Average working head, in feet	Rated horsepower of wheels at average head	Horsepower of engines
(1)	(2)	(3)	(4)	(5))	(6)
1	Fishkill	Tironda Hat Works	.....	......	......
2	Fishkill	New York Rubber Co.	17	430	250
3	Fishkill	Rockwell Silk Mills	.....	......	......
4	Matteawan	Matteawan Mfg. Co	26	168	225
5	Matteawan	William Carroll & Co	29	283	140
6	Matteawan	Carroll Electric Co	20	......	525
7	Glenham	Glenham Carpet Mill, Hilton estate	32½	460	1,500

The catchment area of Fishkill creek above Groveville dam is 200 square miles and the total catchment area above the mouth, 204 square miles.

Wappinger creek. This stream rises in the extreme northern part of Dutchess county and flows in a southerly direction into the Hudson river, near the village of New Hamburg. The catchment area of that portion of the stream above Hibernia and Clinton Hollow dam is 116 square miles. During the last year the New York Water Supply Commission has extensively considered this stream, with Fishkill creek and others, as a partial source of a water supply for the City of New York.

Considerable opposition, however has developed to this project. There are large manufacturing interests at Wappinger Falls and other points which depend wholly upon the water power of the stream, and a bill has accordingly been introduced at the session of the Legislature for 1904 prohibiting the taking of any stream for a water supply for any municipality in the State where any number of people depend upon the water power of the stream for their livelihood.

The headwaters of Wappinger creek are at an elevation of 700 to 1000 feet above tidewater.

Murderers creek. This creek rises in the central part of Orange county and flows easterly into the Hudson at Cornwall. Its chief tributaries are Otter creek and Cromiline creek. It is not an important stream.

Rondout creek. This stream has its source in the timber-covered mountain group forming Wittemberg chain. It flows southeasterly to Napanoch, where it encounters the foot of the Shawangunk range, turns abruptly to the northeast and enters the Hudson river at Rondout. Its catchment on the south is very restricted, as it is separated from the Wallkill river only by the narrow Shawangunk mountains. Notable waterfalls occur at Honk falls and Napanoch over the Hudson river shale, and on Good Beer kill above Ellenville. On Good Beer kill there is a total fall of 870 feet from the Cape, three miles above Ellenville, to Ellenville. Of this about 200 feet are concentrated in a series of cascades called Hanging Rock falls.

Water power was orginally developed at Napanoch in 1754. At present there are five dams utilizing a total fall of 115 feet. A series of cascades with a descent of about 50 feet occurs at High Falls, where the water flows over Rosendale cement rock.

The following are the catchment areas of Rondout creek:

	Square miles
Above Honk falls	88
Above High Falls	339
Above Rosendale	365
Above Wallkill river	369
Below Wallkill river	1,148
Above Rondout village	1,164

Formerly the Delaware and Hudson canal utilized slack water from the mouth of Rondout creek to Eddyville. From the head of the pond above Eddyville dam, the canal runs parallel to Rondout creek as far as Napanoch. In 1898 the canal was abandoned from Honesdale, Pa., to Ellenville, and in August, 1901, the remaining canal, with the exception of that from High Falls feeder to Rondout, was abandoned.

Above its junction with Sandberg creek, at Napanoch, Rondout creek is a mountain stream. At Honk falls a natural declivity affords a fall of 125 feet over tilted strata of Hudson river shale. There is a dam at the head of this fall of 22½ feet, making the total head 147½ feet.

Water power of Rondout creek. The following is a list of the principal developed water powers on Rondout creek in 1901:

Number of dam	Location	Name of mill and of owner and operator	Average working head, in feet	Rated horsepower of wheels at average head	Horsepower of engines
(1)	(2)	(3)	(4)	(5)	(6)
1	Eddyville	D. & H. Canal Co.	......	None	None
2	Lawrenceville	Lawrenceville Cement Co.	10	......	......
3	Below High Falls	W. I. Vandermark, J. H. Vandermark estate	......	80	125
4	High Falls	Hasbrook & Hopper, Ulster County Savings Banks	12	......	......
5	High Falls	......	31	......	......
6	Port Hickson	D. & H. Canal	10	......	......
7	Napanoch	E. C. Shook & Son	6	60	None
8	Napanoch	M. M. Pillsbury	7	......	......
9	Napanoch, R. H.	Humphrey & Young	30	481	......
10	Napanoch, L. H.	J. C. & S. E. D. Hornbeck	30	......	......
11	Napanoch	Pittsburg Ax Factory	......	......	......
12	Napanoch, L. H.	Napanoch Knife Co.	15½	12	None
13	Napanoch, L. H.	......	......	......	......
14	Napanoch, R. H.	Young & Humphrey, John Russell estate	......	......	......
15	Napanoch, L. H.	M. M. Pillsbury Paper Mill	56	593	......
16	Napanoch	Honk Falls Power Co.	147½	1,500	None
17	Lackawack	C. N. Morse	10	140	None
18	Grahamville	......	......	......	......
19	Bull River	......	......	50–100	......

Wallkill river. Wallkill river is the chief tributary of Rondout creek. It has its source on Sparta mountain, New Jersey, about twenty-one miles from the point where it enters New York State. From its source to the head of the Drowned Lands it is essentially a highland stream.

The Drowned Lands are an extensive Pleistocene lake bottom situated mainly in New York. They comprise an area of 28 square miles. A dam of drift at the north end of this tract holds back the water of the Wallkill, causing an overflowing of this entire flood plain. Formerly, this area formed a shallow lake or undrained swamp. An artificial canal, cut through the drift at the foot, has enabled a large part of the downstream portion to be reclaimed for agricultural purposes.

Below the foot of the Drowned Lands, fifteen miles from the New Jersey line, the Wallkill flows in a broad, shallow valley, averaging about one half mile in width. This valley has been eroded from the drift, leaving a stream-bed of cobble and small boulders too heavy for stream transport. The river terraces are not abrupt, often curving gracefully to the uplands 30 to 60 feet above the stream, and leaving a narrow plain submerged only during freshets. At frequent intervals the stream cuts through the overlying drift to the Hudson river slate, and passing over ledges of this slate produces waterfalls.

At Gardiner the Wallkill receives its principal tributary, the Shawangunk kill. The divide between the two streams is formed by vertical strata of a blue shale fold, making a definite ridge between the catchment areas.

The following are the catchment areas on Wallkill river:

	Square miles
Wallkill above Franklin Furnace, N. J.	31
Wallkill at New York and New Jersey State line	210
Wallkill above foot of Drowned Lands	393
Wallkill above Freeman's proposed dam site	464
Wallkill at mouth of Shawangunk kill	563
Shawangunk kill above mouth	149
Wallkill below Shawangunk kill	712
Wallkill above Rifton Glen	761
Wallkill at junction with Rondout creek	779
Wallkill total catchment in New York	567

Water power of Wallkill river. The following is a list of the water powers developed on Wallkill river in 1901:

Number of dam (1)	Location (2)	Name of mill and of owner or operator (3)	Average working head, in feet (4)	Rated horsepower of water wheels at average head (5)	Horsepower of engines (6)
1	Creek Locks	Empire Powder Mill, Laffin & Rand Powder Co	14	288	100
2	Rifton	Rifton Gristmill, J. W. Dimick, Jr	16	119	......
3	Rifton	J. W. Dimick Co	......	679	......
4	Dashville	......	......	......	......
5	Galeville	......	10	......	......
6	Wallkill	J. C. Hedden	......	......	......
7	Waldon	Waldon Knife Co	8	150	75
8	Waldon	N. Y. Knife Works	32	300	None
9	Montgomery	Crabtree & Patchett	9	160	75
10	Red Mills	Red Mill[1]	10	......	None

[1] On Shawangunk kill.

There are a number of tributaries of Rondout creek and Wallkill river, but none of them are at present important as power streams, although some have been considered as water supplies for the City of New York.

Esopus creek. The source of Esopus creek is in Winnissook lake on the northwestern slope of Slide mountain. From Big Indian to Olive Bridge the stream flows through a valley with timber-covered mountains on either side. A number of sites for storage reservoirs are offered at points where the valley broadens out to receive the inflowing water of tributaries. Some of these are at Big Indian, where Birch creek enters; at the mouth of Bush kill at Shandaken; at the mouth of Stony Clove creek at Phoenicia; at Cold Brook at the mouth of the Little Beaver kill, and at Olive Bridge.

The descent of the stream is rapid, although not precipitous above Olive Bridge. At this point the stream flows over a rocky ledge, 22 feet in hight, forming Bishops falls. Below Bishops falls the stream flows through a narrow gorge for some distance, after which the valley broadens with a decrease of slope. The general course of the stream is mostly southeasterly, until Marbletown is reached. At this point it turns and flows northeasterly to near Kingston. From Kingston it flows northerly, entering the Hudson river at Saugerties. A second water fall occurs at Glen Erie, where there is a cascade with a fall of 56 feet. The final descent to tidewater at Saugerties is made over a fall of 42 feet.

The following are the catchment areas on this creek:

	Square miles
Above mouth at Saugerties	417
Above Glen Erie falls	409
Above gaging station, Kingston	312
Above Bishop's falls, Olive Bridge	234

Water power of Esopus creek. The following gives the principal water powers developed on Esopus creek:

Number of dam	Location	Name of mill and of owner or operator	Average working head, in feet	Rated horsepower of water wheels at average head	Horsepower of engines
(1)	(2)	(3)	(4)	(5)	(6)
1	Saugerties	Diamond Paper Co., Sheffield estate	35	607	425
2	Saugerties	Saugerties Mfg. Co., Sheffield estate	21	90	......
3	4 miles above Saugerties	Legg's Mill	......	......	......
4	Glen Erie	Ulster White Lead Co	56	......	None
5	Olive Bridge	Boice Gristmill	22	......	None
6	Olive Bridge	DeWett's mill, leased to Hudson River Pulp Co	22	......	None
7	Brown Station	Hudson River Pulp Co	......	......	......
8	Boiceville	J. C. Hornbeck	9	90	20
9	Phoenicia	Mrs. De Mott	6	......	......
10	Big Indian	R. and T. C. Wey	18	60	None
11	Pine Hill[1]	Geo. Rose Turning Mill	10	......	None

[1] On Birch creek.

Catskill creek. This stream rises on the northern slope of the Catskill mountains, lying for the most part in the timbered highlands of Greene county. It flows in a southeasterly direction, entering the Hudson river at the village of Catskill. For the last two miles of its course, below the mouth of Kaaterskill creek, there is slack water. From Kaaterskill creek to Leeds, a distance of three miles, it flows through a bluestone gorge, the fall for this distance being 180 feet. The stream flows over a rock bed through most of its course and is subject to wide variations in flow. The slopes of the catchment area are precipitous and there are no lakes or other artificial storage. The catchment area at the mouth is 394 square miles.

Water power of Catskill creek. The following tabulation shows the principal developed water powers on Catskill creek:

Number of dam	Location	Name of mill and of owner or operator	Average working head, in feet	Rated horsepower of water wheels at average head	Horsepower of engines
(1)	(2)	(3)	(4)	(5)	(6)
1	Leeds	Catskill Woolen Mill	18	200	60
2	Leeds	Waterville Woolen Mill	14	200	80
3	Lake's mills	Lake's Mills	......	......	......
4	Woodstock	Woodstock Paper Mill	......	......	......
1	Freehold	Brown's Mill	11	15–20	None
2	Greenville	Reed's Mills	22	22	8
1	East Durham	Not reported	16	......	......
2	East Durham	Atter Bros.	......	30	......
3	East Durham	......	10	......	......

Fishkill creek, Rondout creek, Wallkill river, Esopus creek and Catskill creek have all been considered as water supplies for the City of New York. The following tabulation gives the catchment areas above the reservoir proposed, as well as above the mouth, for each of these streams:

	Catchment area in square miles	
	Above proposed reservoir	Above mouth
Fishkill creek	158	204
Rondout creek	184	[1]369
Wallkill river	464	779
Esopus creek	242	417
Catskill creek	140	394

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[1] Above junction with Wallkill river.

Normans kill. This stream enters the Hudson river at Kenwood, a suburb of Albany. It drains a narrow area of 168 square miles, lying between the lower Mohawk catchment and the northern drainage slope of the Helderberg mountains. It rises in Schenectady county, about fifteen miles a little south of west of the city of Schenectady. The headwaters are at an elevation of 700 to 800 feet above tide. At French Mills the stream is 200 feet above tidewater. The catchment area at French Mills is 111 square miles and at the mouth of the stream 168 square miles.

Roeliff Jansen kill. This stream flows into the Hudson river from the east about six miles south of Hudson. It rises in the extreme southwestern part of Columbia county and flows first southwest to about the village of Silvernail, thence a little north of west to Elizaville, thence northwest to its mouth in the Hudson river. The headwaters of this stream have been proposed as a water supply for the City of New York by the Water Supply Commission of 1903. The catchment above Silvernail dam is 149 square miles.

Claverack creek. This stream rises in the western part of Columbia county and joins the Kinderhook creek at Stockport, a few miles north of Hudson. From the village of West Taghkanick it flows in a generally northerly direction to its junction with Kinderhook creek. Above West Taghkanick, the Taghkanick creek, a branch of the Claverack, flows southeasterly. The catchment area of Claverack creek at its mouth is about 100 square miles.

Kinderhook creek. This stream rises in the Hancock mountains in western Massachusetts. It flows in a southwesterly direction across Rensselaer and Columbia counties, emptying into the Hudson river at Stockport. The following are the catchment areas:

	Square miles
In New York	305
In Massachusetts	29
Above mouth	334

This stream is of interest as having been proposed as a water supply for the city of Albany.

Hoosic river. An important tributary of the Hudson from the east is Hoosic river, which rises in the mountains of Berkshire county, Massachusetts. It first runs northwesterly, passing from Massachusetts into the extreme southwestern corner of Vermont and thence into Rensselaer county, in New York. At the northern boundary of Rensselaer county it turns and pursues a westerly course to the Hudson opposite the village of Stillwater. Its catchment area at the mouth is taken at 730 square miles. Its principal tributaries are Little Hoosic river, Walloomsac river, and Tomhannock creek. The country drained is mainly mountainous, the summits attaining an elevation of from 1000 to 2000 feet above tide. The principal water powers developed on Hoosic river, in New York, are at Schaghticoke and Hoosic Falls, with a few at intermediate points. At Schaghticoke there is from 97 to 98 feet fall, broken into falls of 8, 7.5, 24.5, 34.5, and 23 feet. The available statements as to the power at Hoosic Falls are so conflicting that it is thought best to omit them.

Hoosic river is of considerable interest to persons concerned in waterpower development on the Hudson below its mouth, because there are two reservoirs on its headwaters which have been constructed by manufacturers in Massachusetts in order to maintain a more equable summer flow. The first of these is the Clarksburg reservoir, on the north branch of Hoosic river, and at a distance of about 2½ miles above North Adams. The second reservoir is on the south branch, and is known as the Cheshire reservoir, being situated in the town of that name. The Clarksburg reservoir is stated to flow 156 acres and to have a depth of 22 feet. The Cheshire reservoir flows about 650 acres and can be drawn down about 8 feet. These reservoirs are controlled by an association of mill owners on the Hoosic and its branches in Massachusetts.

Battenkill river. Battenkill river, another important tributary of the Hudson from the east, rises in the southwestern part of Vermont, in Bennington county. It first flows southwesterly and then westerly irregularly across Washington county, New York, to the Hudson at a point about a mile above Schuylerville. The catchment area is taken at 460 square miles. The elevation above tide at the mouth of the river is 82 feet, and at the Delaware & Hudson railway crossing, a little south of Shushan, the elevation is 437 feet. This gives a descent of 355 feet in 22 miles, about one-half of which is concentrated within the last 4 or 5 miles of the river's course.

The following is a brief statement of the water powers on the lower section of the Battenkill, in ascending order from the mouth, as they stood in 1897:

At Clark Mills, the American Woodboard Company, 24 feet head.

At Big Falls, the dam at the head of the falls gives 106 feet head, divided into Bennington Falls Pulp Company, 32 feet; Ondawa Pulp and Paper Company, 30 feet; not utilized, 44 feet.

At Middle Falls, the dam at the head of the falls gives 55 feet head. Here there are a leather-board mill, shank mill, sawmill, plaster mill, gristmill, and electric-light station.

At Greenwich, Dunbar, McMaster & Co., 8 feet head; Palmer's lower dam, 9 feet head, furnishes power for gristmill, paint works, shirt manufacturing, scale manufacturing, and plow works; Palmer's upper dam, 6 feet head, furnishes power for a cotton mill and a paper mill.

At Center Falls, Angel & Langdon Paper Mill, 25 feet head.

At Battenville, Phoenix Paper Company, 10 feet head.

At Rexleigh there is a cotton mill with 6 feet head; at Shushan a gristmill, shirt factory, electric-light station and foundry, all receiving power from about 14 feet head.

In addition to the foregoing there are stated to be undeveloped water powers on the Battenkill as follows: Between Clark Mills and Big Falls, 27 feet; between Greenwich and Center Falls, 8 feet; between Center Falls and Battenkill, 10 feet.

It is stated that the utilized powers on the Battenkill are developed up to about 30 horsepower per foot fall. They are, however, sometimes short of water in dry weather. With a catchment area of 460 square miles, a minimum flow of 0.3 of a cubic foot per second per square mile would give only about 15.3 gross horsepower per foot of fall. If this is true, the Battenkill is an exceedingly good water yielder, although definite data derived from stream measurements are entirely lacking. It is understood that gagings have been kept for the last two or three years by private parties, but the results have not yet been published.

Fish creek. This stream, which flows into the Hudson at Schuylerville, is the outlet of Saratoga lake. Its chief tributary is the Kayaderosseras creek, which drains the central part of Saratoga county. The catchment area of Fish creek at its mouth is estimated at 253 square miles. Both Fish creek and Kayaderosseras creek are extensively utilized for water power.

Sacandaga river. This stream is the next important tributary of the Hudson in the ascending order. It has three principal branches, which unite to form the main river in the southeastern part of Hamilton county. The west branch is the outlet of Piseco lake; the middle branch is the outlet of Sacandaga and Pleasant lakes, while the east branch issues from a series of small ponds and lakes in the southwestern part of Warren county, not far from Bakers Mills. The east and middle branches unite a few miles to the north of Wellstown, and the west branch joins a few miles south of Wellstown. The river then flows southeasterly to about 5 miles below Northville, where it turns rather more than a right angle and flows irregularly northeast to the main Hudson at Hadley. The principal tributary of the Sacandaga, aside from its several branches, is East Stony creek.

The following are the several subdivisions of the catchment area of Sacandaga river:

	Square miles
At mouth	1,040
South branch	240
Middle branch	115
East branch	124
Stony creek	212
Main river below Stony creek	223

The following are elevations above tide at a number of principal points on Sacandaga river:

	Feet
At mouth of river	556
Above dam at Conklinville	697
Northville	732
Hope Center	763
Wellstown	902
East branch at old tannery	958
East branch at foot of High falls	1,205
East branch at head of High falls	1,337
East branch at Brighams pond	1,706
Piseco lake	1,648
Lake Pleasant	1,706
Sacandaga lake	1,706

From Conklinville to the mouth of the river, a distance of a little over 5 miles, the river falls 141 feet. At present this section of the river is entirely unutilized except by two powers, one at Conklinville and the other about 2 miles from Hadley.

Thus far there are no detailed measurements of the Sacandaga, but since the catchment area is still largely in primeval forest it is without doubt an excellent water yielder.

Schroon river. This stream rises in Essex county, along the southern slopes of the highest mountains of the Adirondack group. As shown by the map, it flows in a general southerly direction for about forty-five miles through Essex and Warren counties, and joins the Hudson just above Thurman. On the boundary between Essex and Warren counties the river flows through Schroon lake, a body of water nearly 9 miles long and from a little less than 0.5 to 1.5 miles in width.

The following are some of the important subdivisions of the catchment area of Schroon river:

	Square miles
At mouth	550
Warrensburg	535
Tumblehead falls	502
Foot of Schroon lake	479

Some of the elevations on Schroon river are as follows:

	Feet
At mouth	610
Schroon lake	807
Paradox lake	820
Schroon Falls	840
Elk lake	1,986

Water power of Schroon river. There is no developed water power on Schroon river except at Warrensburg. The Schroon River Pulp & Paper Company at that place use something over 1000 horsepower, while at several other dams there is 450 to 500 horsepower in use, making a total in use at Warrensburg of about 1500 horsepower. The detail of this power may be obtained from the writer's first Report on the Upper Hudson Storage Surveys, in a table facing p. 150.[1]

Boreas river. This stream rises on the south slope of the extreme high Adirondack mountains, at an elevation of over 2000 feet above tidewater. It flows through Boreas pond, in a southerly direction, entering the Hudson river five miles north of North River village. The country through which Boreas river flows is mountainous and there are no power developments. There is, however, a fine opportunity to make storage at Cheney pond, Boreas pond, etc. and undoubtedly this stream will be ultimately utilized for water storage as part of the Hudson river system of storage reservoirs.

Indian river. The Indian river issues from a precipitous, forested mountain area in the eastern part of Hamilton county. It rises in Indian lake and flows in a northeasterly direction into the Hudson river. In 1898 the writer constructed for the Indian River Company a masonry storage dam at the foot of Indian lake, replacing the lumberman's dam which was formerly at this location, and raising the level of the artificial lake twenty-three feet, or about thirty-four feet above the original water level. The length of the reservoir is about twelve miles and it stores

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[1] In An. Rept. of State Engineer and Surveyor of New York for 1895.

5,000,000,000 cubic feet of water, the area of water surface being 5035 acres and the elevation of the spillway crest 1650 feet. The Indian River Company were the owners of the original rights of flowage of Indian lake as held in the timber dam since 1845.

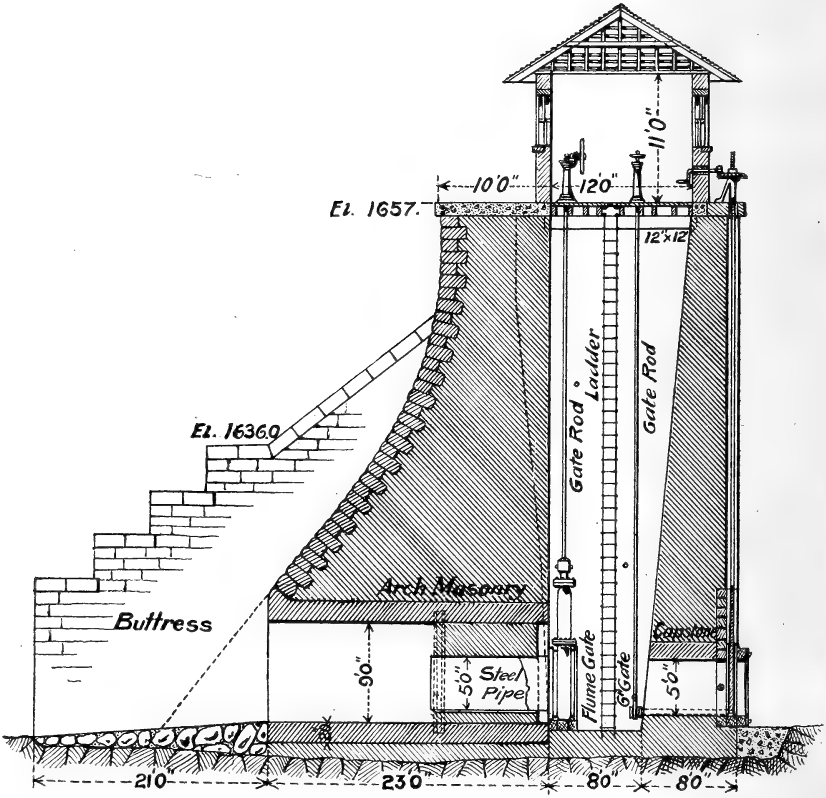

Fig. 19 Cross-section of main dam and gate house at Indian river.

This company deeded to the State of New York about 18,000 acres of land in township 32 and 24,000 acres in township 15, or 42,000 acres in all. The price paid for this land, including the present structures thereon, as well as the structures contracted for and in process of construction by the company (the masonry dam), together with any damages which might accrue from the appropriation of land and structures, was $164,000, or a little less than $4 per acre. The total cost of the dam, including engineering, was about $100,000. The operation of this dam is under the control of the Superintendent of Public Works. The object of constructing it was to store flood water to be turned into the Hudson river during the low-water period of each year, thereby equalizing the flow. The fact that the Champlain canal takes water from the Hudson river through the Glens Falls feeder was the reason why the State considered it necessary to control this dam. The catchment area above the dam is 146 square miles. The storage cost is at the rate of $20 per million cubic feet stored.[1]

Cedar river. This river rises in Cedar lake in the central part of Hamilton county at an elevation of about 2530 feet above tide, and flows northeasterly, generally parallel to Indian lake and river, entering the Hudson river two miles north of Indian river. There is no water-power development upon this stream, but there is a reservoir of considerable capacity at Wakeley, at an elevation of about 2000 feet above tide.

Mohawk River

Mohawk river, the largest tributary of the Hudson, rises in the western central part of the State, near the Lewis and Oneida county line. It flows in a southerly direction to the city of Rome, from which it takes an easterly course across the State, emptying into the Hudson a little above Troy. The principal tributaries are Schoharie, East Canada, West Canada and Oriskany creeks, while less important tributaries are Chuctenunda, Cayadutta, Garoga and Sauquoit creeks and Lansing kill. There are a number of small streams, several of which are utilized as water supplies for the villages of the Mohawk valley.

The following are the elevations above tidewater of a number of points along the Mohawk river:

	Feet.
At mouth	12
Lower Mohawk aqueduct	162
Schenectady	214
Mouth of Schoharie creek	270
At Rome, above feeder dam	431

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[1] For complete account of Indian river dam, see Engineering News for May 18, 1899.

There are two principal falls of the Mohawk river, the Great falls at Cohoes and the Little falls at the city of the same name, where are found the only important water powers developed on this stream. At the Great falls at Cohoes there is a fall of 105 feet over Hudson river shale, which has been extensively utilized by the Cohoes Company for power. Cohoes is a city of 25,000 inhabitants, entirely devoted to manufacturing.

According to the statement of David Van Auken, Engineer of the Cohoes Company, there are about 10,000 horsepower developed. At Little Falls there is a total fall of about 45 feet, occurring in about one-half mile, of which 40 feet are utilized by three dams. The population of Little Falls is 12,000, extensively devoted to manufacturing. There is stated to be about 3000 horsepower developed at this place. Aside from a small amount of power developed below Cohoes, just above the "sprouts" of the Mohawk, there are no water-power developments on the stream other than those of Cohoes and Little Falls, except a few unimportant mills on the extreme headwaters. The waterworks of the city of Rome are at Ridge Mills, 2 miles north of Rome, where a water power pumping system is in use.

The following are the principal subdivisions of the catchment area of the Mohawk river:

	Square miles
At mouth	3,400
Below mouth of Schoharie creek	3,100
At Little Falls	1,275
At Utica	524
At Rome	184

Chuctenunda creek. This stream rises in Saratoga county and flows southerly into the Mohawk river at Amsterdam. There is a small amount of power on this stream, at Rockton and Hagaman. The city of Amsterdam, with a population of 21,000, is a manufacturing city on the Mohawk river at its mouth, but most of its manufacturing is by steam power. It offers a good opportunity for the sale of power from an electrical power plant on

Schoharie creek. Chuctenunda creek itself has too small a catchment area to be of much value.

Cayadutta creek is another small stream which rises in the central part of Fulton county, and flows south through the cities of Gloversville and Johnstown into the Mohawk river at Fonda. There is considerable water power developed upon it, but statements in reference to the quantity are not at hand. The catchment area above its mouth is 62 square miles. The catchment at Johnstown is 40 square miles.

Schoharie creek. This stream rises in the southern part of Greene county, whence it flows 18 miles northwesterly, and then northerly about 50 miles to the Mohawk. Its catchment comprises the greater part of Schoharie county and portions of Greene, Albany, Delaware, Otsego, Montgomery and Schenectady counties. Its headwaters, which lie at an elevation of about 1800 feet above tidewater, drain the western and northern slopes of the Catskill mountains. The lower reaches of the creek flow through a long, flat valley in a channel largely covered with flat boulders. At Central Bridge, about 19 miles from the mouth of the creek, the water surface is 560 feet above tidewater; at the mouth the elevation is 274 feet. Notwithstanding this large fall, Schoharie creek is not considered specially valuable for water-power development. It is subject to great extremes of flood and low-water flow. This is largely explainable by the nearly complete cutting off of the forests from the catchment area many years ago. The impervious character of the soil may also be taken into account. The principal subdivisions of the catchment area of Schoharie creek are as follows:

	Square miles
At mouth	947
Central Bridge	684
Gilboa	308

Water power of Schoharie creek. With one exception the water powers thus far developed in the Schoharie creek catchment are nearly all small and unimportant. The principal tributaries of the stream are the Cobles kill and the Batavia kill, but neither of these streams is important from the waterpower point of view. The headwaters of the Batavia kill have been proposed to be taken by a tunnel through the Catskill mountains as part of the water supply of New York city.

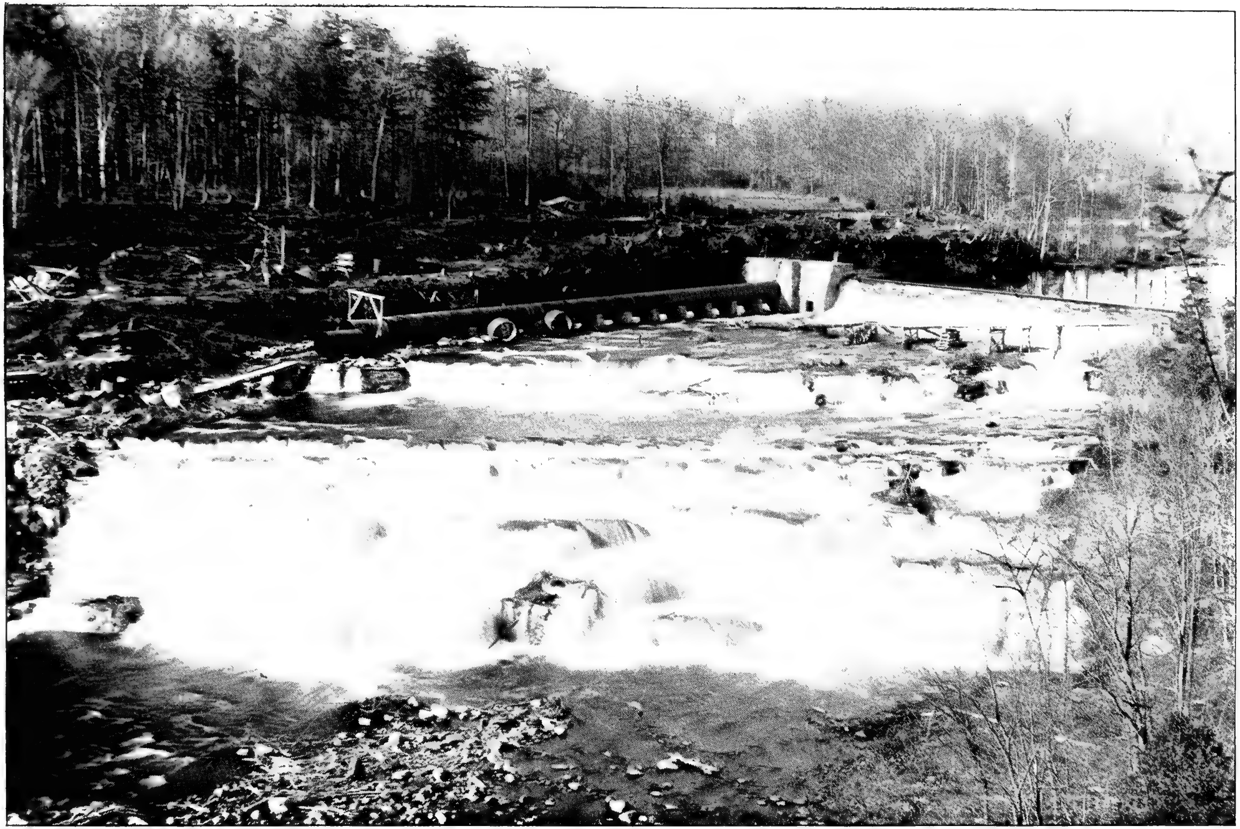
In 1899 and 1900 the Empire State Power Company developed an extensive water power on Schoharie creek at Schoharie falls a few miles south of its mouth. Their dam, however, has been twice injured by floods and it is understood that at present (spring of 1904) they are out of business. There are however negotiations in progress looking toward a consolidation with the Hudson River Power Company, but until these are completed it is uncertain whether the dam will be repaired or not.

Garoga creek. This stream rises in the Garoga lakes and Peck pond. It flows southerly into the Mohawk river two miles above Fort Plain. The catchment area above its mouth is 89 square miles.

East Canada creek. This creek, which is one of the important tributaries of the Mohawk river, rises in the southwestern part of Hamilton county and flows southerly, joining the Mohawk at East creek, about 7 miles from Little Falls. According to a map furnished by Stephen E. Babcock, of Little Falls, the total catchment area of East Canada creek is 285.7 square miles, of which 58.2 square miles are in Hamilton county, 98.4 square miles in Herkimer county, 128 square miles in Fulton county, and 1.1 square miles in Montgomery county. Following are the elevations of principal points on East Canada creek:

	Feet
Bottom of Beardslee falls near mouth	0
Top of Beardslee falls	105
Bottom of High falls	327
Top of High falls	379
Crest of dam at Dolgeville	445
Mouth of Spruce creek	477
Mouth of Fish creek	559
Emmonsburg	646
Stratford	720
Oregon	1,140

Plate 4.



Power dam at the High Falls of the East Canada creek. Constructed by the Dolgeville Electric Light and Power Company in 1897.

The distance from the mouth of the stream to Oregon is about 25 miles.

The principal tributary of East Canada creek is Fish creek, which is the outlet of the Canada lakes. The distance from its point of junction with East Canada creek to the mouth of the Canada lakes outlet is about 9 miles, and the total rise in this distance 635 feet. The outlet of the lakes, which is nearly level, is about 3.5 miles long. There are no falls of any magnitude on this creek. For the first 5 miles from its mouth Fish creek rises 245 feet, and from that point to the mouth of the outlet of the Canada lakes, a distance of 4 miles, the rise is 390 feet.

The second tributary of East Canada creek is Spruce creek, which has a total length from its mouth to its head in the Eaton millpond of about 8.7 miles, the total rise in this distance being about 550 feet. Just below the Eaton millpond there is a fall of 180 feet in 2000 feet. At Salisbury Center, Spruce creek falls 85 feet in about 900 feet.

Water power of East Canada creek. In 1904 there are twelve dams on Spruce creek. The water supply of Dolgeville is taken from Cold brook, a tributary of East Canada creek. Aside from the development at Dolgeville, and small developments at Beardslee falls and at one or two other points, very little use has thus far been made of the water power of East Canada creek. It is probable, however, that within a few years the water power of this stream will be nearly all utilized.

According to a manuscript report on the water power of East Canada creek, by S. E. Babcock, the fall in this stream for the first 1500 feet from its junction with Mohawk river is very slight. At this point the first rapids are encountered, where it has been proposed to develop a water power, with a head of about 60 to 70 feet. About 1000 to 1200 feet farther upstream there is an additional fall of from 30 to 40 feet. This takes one to the top of the so-called Beardslee falls, referred to in the foregoing.

It has also been proposed to construct an extensive system of power development by a series of dams on East Canada creek, some of the details of which may be gathered from the following tabulation:

Plan of power development on East Canada creek

Location	Head in feet	Horse-power	Estimated cost	Cost per horse-power
Twin Bridges	43	1,172	$108,427	$92.51
Green street	26	1,023	73,667	72.01
Factory	29	1,141	30,910	27.10
Intermediate	22	865	46,090	53.28
High falls	72	2,700	56,320	20.86
No. 1 (below High falls)	74	2,956	125,092	42.40
No. 2 (below High falls)	34	1,360	56,408	41.40
No. 1 (Ingham's mill)	44	1,778	135,410	76.16
No. 2 (Ingham's mill)	44	1,778	129,800	73.00
Beardslee falls	105	5,112	128,326	25.10
Totals and mean	423	19,885	$890,450	$44.80

This plan of power development further includes the construction of a storage of 1,250,000,000 cubic feet, which is estimated to cost $148,000, making a total for the whole development of $1,038,450. With these figures the final cost per net horsepower becomes $52.22. The estimates leading to this result include cost of land to be flooded, masonry of dams and head works, turbine water wheels, flumes and head feeders, tail raceways, waste gates, power stations, racks, engineering and superintendence, etc. So far as the actual power developments are concerned, the work can probably be constructed for the estimates, but the cost of the storage is, in the writer's opinion, somewhat too low. The total number of dams which it is proposed to build is stated at 40, thus giving an average of only $3700 per dam. This sum would only build timber dams of the most temporary character. The proper operation and repairs of this number of dams, scattered over an area of 200 square miles, would entail in the end an annual expense of $30,000, which is the annual interest at 5 per cent on $600,000. To obtain the real capitalized cost we need then to add $600,000, which gives an amended total of $1,638,450, whence the cost per net horsepower for the entire system would become $82.40.

In 1897 an electric-power station was in process of installation by the Dolgeville Electric Light & Power Company at the high falls just below Dolgeville, capable of developing 1200 net horsepower. The wheels set are two twin horizontal 36-inch Victor special wheels, to work under a 72-foot head, and which are claimed by the manufacturers to yield, at full capacity, 600 net horsepower each. A portion of the power generated at this station is used at Dolgeville for manufacturing, and the balance is transmitted to Little Falls, 8 miles distant.

Dolgeville is the seat of the piano-felt and other industries originally established by Alfred Dolge & Son. The power for the establishments now in operation is derived from two 35-inch Victor turbines, working under a 25-foot head, and rated by the manufacturers to furnish, when running at full capacity, 229 net horsepower each, or a total of 458 horsepower. According to the manufacturer's catalogue, these wheels will consume 197 cubic feet per second when working at full capacity, and the statement was made in 1897 that they were ordinarily so worked. The catchment area of East Canada creek above Dolgeville is about 250 square miles; hence the present development is based upon a minimum flow of 0.79 cubic feet per second per square mile. As there is very little pondage at Dolgeville, it may be assumed that the power is sometimes short in a dry season, although the effect of the pondage of the large number of lakes and ponds on the head waters of East Canada creek will undoubtedly be to increase considerably the minimum flow.

There is a power development at Beardslee falls, near the mouth of East Canada creek, which is stated to be capable of developing 1000 horsepower, but owing to deficiencies in the design it is uncertain whether or not this amount of power can be produced continuously.

The following tabulation gives the principal water powers developed on East Canada creek, substantially as they exist in 1904:

Number of dam	Location	Effective head, in feet
1	Beardslee falls	120
2	Ingham's mills	10
3	High falls	72
4	Dolgeville	20
5	Stratford	...

West Canada creek. This creek, another important tributary of the Mohawk, rises near the center of Hamilton county and flows southwesterly about forty miles, by general course, to the eastern edge of the town of Trenton in Oneida county, where it turns and first runs southeasterly and then southerly for a total distance of twenty miles, finally emptying into the Mohawk at Herkimer. The following tabulation gives the catchment areas on this stream:

	Square miles
At mouth	569
Middleville	519
Trenton Falls	375
One-half mile below Hinckley	372
Prospect	370 (?)
Twin Rock bridge	352
Below mouth of Black creek	349 (?)

This creek has its source in the Canada lakes, which are about forty miles northeast from Prospect. These lakes are known separately as the West, Middle and East Canada. The principal lake of this series has an elevation of 2348 feet above tidewater. The catchment area at the village of Prospect, where there is a natural fall of about 60 feet, is approximately 370 square miles. At Trenton Falls, three miles below, the stream descends about 200 feet in half a mile. Ascending the stream the principal falls in order are: Sherman falls, 24 feet; High falls, 105 feet; Mill dam falls, 14 feet; Suydam falls, 12 feet.

In a report made by Wallace C. Johnson, under date of March 17, 1896, to the Trenton Falls Power Company, it appears that of the 370 square miles of catchment area above Prospect, about

175 square miles lie at an elevation of between 2000 and 3000 feet above tidewater, the average elevation of this portion being about 2500 feet. Of the remaining 200 square miles above Prospect the average elevation is placed at not less than 1600 feet. The Trenton Falls Power Company has been reported as intending to develop an extensive storage on the headwaters of this stream, thus enabling it to produce several thousand electrical horsepower at Trenton Falls for transmission to Utica, Rome, and other towns in the vicinity. General plans were prepared by Mr Johnson, but the details of the project are not at hand. Judging from the data at hand, the writer is disposed to place the minimum flow of West Canada creek at from 0.25 to 0.30 of a cubic foot per second per square mile.

Water power of West Canada creek. However, these developments were not made by the Trenton Falls Power Company, and the property at Trenton Falls has passed into the hands of the Utica Gas & Electric Company, who have developed an electric power plant which presents a number of points of interest. It is estimated that 4000 horsepower can be furnished from this station. Water powers are also in use on West Canada creek at Herkimer, Middleville, Newport, Prospect and Hinckley, as well as at a few points higher up.

Parties interested in the development of an extensive power project at Trenton Falls have claimed that a very large storage reservoir could be constructed in the main valley of West Canada creek a short distance above Prospect, and at very low cost per unit volume stored. The data are not at hand for accurately determining the cost of a reservoir at this place. However, casual inspection of the Remsen sheet of the topographic map of the State, made in 1897, shows that such a reservoir would probably be expensive in proportion to the storage gained. A trial estimate shows that with a dam from 80 to 100 feet in hight a storage of about 2,000,000,000 cubic feet may be obtained. The cost of the dam necessary to store this quantity of water can hardly be placed as an experimental figure at less than $1,000,000, whence the cost per 1,000,000 cubic feet stored would become $500. This approximate estimate has no other significance than to indicate the importance of studying large reservoir projects in detail before deciding as to their feasibility.

In connection with the barge canal surveys of 1900, a reservoir was surveyed on this stream near Hinckley, with a capacity of 2,742,400,000 cubic feet. This reservoir was estimated to cost $1,855,000, or $676.40 per million cubic feet of water stored. It is evident, therefore, that the preceding estimate was under, rather than above, the cost. The hight of the dam to store 2,742,400,000 cubic feet is 90 feet above the rock foundation.

Sauquoit creek. This stream rises in Oneida county and flows in a northerly direction, emptying into the Mohawk river at Whitestown. Its headwaters lie at an elevation of about 1200 feet above tidewater.

Water power of Sauquoit creek. There is a large amount of power development on this stream, as shown by the following tabulation:

Number of dam (1)	Location (2)	Name of mill or of owner or operator (3)	Average working head, in feet (4)	Number of employees (5)	Horsepower of water wheels (6)
1	New York Mills..	The New York Mills No. 4....	28	......	266
1	New York Mills..	The New York Mills No. 2....	29	......	500
2	New York Mills..	The New York Mills No. 3....	18	......	300
3	Capron..........	Utica Cotton Company.......	21	250	100
[1]4	New Hartford....	Divine Brothers..............	6	50	25
[1]4	New Hartford....	New Hartford Knitting Mill..	9	None	......
[1]4	New Hartford....	New Hartford Mills..........	12	3	......
[1]4	New Hartford....	New Hartford Cotton Mfg. Co.	20	140	120
5	Washington Mills	Utica Tool Company..........	13	90	150
6	Washington Mills	Washington Mills............	11	None	100
7	Willowvale	Utica Willowvale Bleaching Co.	9.5	270	None
8	Willowvale	J. C. Dewhurst..............	10	None	......
8	Willowvale	J. H. Rehm...................	10	2	80
9	Chadwicks	Chadwicks Mills Cotton Co...	22	125	......
10	Sauquoit.........	Lewis Knitting Co...........	20	100	65
11	Sauquoit.........	Sauquoit Valley Mills.........	15	4	101
12	Sauquoit.........	Polk's Knife Factory..........	20	2	87
13	Sauquoit.........	Adolph Seigel, Lower Mill....	20	None	None
14	Sauquoit.........	Adolph Seigel, Upper Mill....	22	15	None
15	Clayville.........	Alfred King..................	15	......	50
16	Clayville.........	Empire Woolen Company.....	25	55	80
17	Clayville.........	Empire Woolen Company.....	15	None	None
18	Clayville.........	First National Bank, Utica...	15	None	None
19	Clayville.........	Babbitt's Wire Works........	30	......	114

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[1] Water used in four levels; total fall in power canal 48 feet.

The catchment area of Sauquoit creek above its mouth is 67 square miles.

Oriskany creek. This stream rises in the northern part of Madison county, flowing northerly across Oneida county into the Mohawk river at Oriskany. The catchment area above its mouth is 146 square miles. There is considerable water power developed on Oriskany creek.

Comparison of the flow over two dams on Oriskany creek. This creek is of slight interest because, in connection with the work done for the Board of Engineers on Deep Waterways, two gaging stations were established at widely varying types of dams and it was found that even in winter fairly comparable results could be obtained by gagings over such dams. The first station was established at the State dam at Oriskany, where water is diverted for the use of the Erie canal. The catchment area at this point is 144 square miles. During the navigation months, a record was kept of the gate openings, together with daily observations of the difference in water surface above and below gates. Outside of the navigation months, the feeder gates were entirely closed and the record is for flow over the dam only. The second station was established at Coleman, a couple of miles above the first, where the catchment area is 141 square miles.

The object of establishing two stations on Oriskany creek was to determine whether on dams of somewhat different forms, but with nearly the same catchment area, the flows could be gaged close enough to give comparable figures. Space will not be taken to give the method of computation used in detail, but those interested can refer to the report to the Board of Engineers on Deep Waterways for an extended account of the method used. For present purposes it is sufficient to refer to the accompanying tabulation, in which are given the flows at the two stations for the months from October, 1898, to February, 1899, inclusive. During the winter months, December to February, the ice was kept clear from the crest of both dams. The results show good agreement and indicate that even when one of the cases is complicated by discharge through a number of water wheels, as at the second station, comparable results may still be obtained. The following are the flows at the two stations in cubic feet per second. The apparent discrepancy at the upper station in October is explained by the fact that the figures for that month are the means of only the last sixteen days.

Month	Station No. 1, Oriskany	Station No. 2, Coleman
October, 1898	325	246
November, 1898	327	306
December, 1898	327	335
January, 1899	295	297
February, 1899	291	283

Lansing kill. This stream rises in the extreme northern part of Oneida county, near Booneville, and flows southerly to the village of Leila, where it enters the Mohawk river. The Lansing kill has rapid descent, but thus far there is not much power developed upon it.

Allegheny River System

Allegheny river. The Allegheny river enters the State of New York from Pennsylvania in the southeastern corner of Cattaraugus county. It rises in McKean and Potter counties, Pennsylvania, and flows thence northwesterly to Salamanca, about thirty miles in the State of New York; thence southwesterly for twenty miles, crossing into Pennsylvania again near the western boundary of Cattaraugus county. The catchment area of Allegheny river and its tributaries within New York, at the point of leaving the State, including Conewango creek, which joins the Allegheny river in the State of Pennsylvania, is about 2100 square miles. Its principal tributary from the north is Conewango creek, which receives the outlet of Chautauqua lake and Cassadaga creek as tributaries. Little Valley, Great Valley and Olean creeks are also tributaries in New York, but none of these streams is of special importance for water power.

Chautauqua lake outlet. Chautauqua lake outlet receives drainage from Chautauqua lake, which is twenty miles in length and from one to two miles in width. The northern extremity of this lake is only eight miles distant from Lake Erie. Its elevation above tidewater is 1,297 feet, while that of Lake Erie is 573 feet. This stream flows into the Conewango creek about five miles north of the Pennsylvania line, where the elevation above tidewater is 1243 feet. The fall from Chautauqua lake to the southern boundary of the State along the drainage line is therefore only 54 feet. The catchment area of Chautauqua lake outlet at the foot of Chautauqua lake is 178 square miles and of Chautauqua lake outlet below Cassadaga creek, its chief tributary, 343 square miles.

Cassadaga creek. This creek rises in Cassadaga lake at an elevation of over 1300 feet above tidewater, and flows south into Chautauqua lake outlet.

Conewango creek. One branch of this creek rises in the extreme northern part of Cattaraugus county and the other in the northern part of Chautauqua county. It flows south for part of the way near the county line between these two counties, and enters Pennsylvania four miles west of the west line of Chautauqua county.

The territory drained by Conewango creek is, in general, hilly and rolling, although the northern portion of the stream has slight descent with swampy valley. From Markham, in the town of Dayton, to Clear creek, in the town of Conewango, the fall is only 25 feet. Throughout this whole section the channel is quite irregular, and probably the average stream slope does not exceed one foot per mile. The elevation of the headwaters is 1500 to 1600 feet above tide, while at the Pennsylvania line this stream is about 1200 feet above tide. The catchment area in the State of New York is 770 square miles.

Little Valley creek. This creek rises in the central part of Cattaraugus county and flows southerly into the Allegheny river at Salamanca. The headwaters are at an elevation of about 1700 feet above tide, while the elevation at its mouth is about 1380 feet. The catchment area is 42 square miles.

Great Valley creek. This creek rises in the north central part of Chautauqua county and flows southerly into the Allegheny river, three miles east of Salamanca. The country at the headwaters is 1600 to 1700 feet above tide. The catchment area is 145 square miles.

Olean creek. The principal tributary of this stream is the Ischua creek, which rises in the northern part of Chautauqua county and, with the main Olean creek, flows south, entering the Allegheny river at Olean. The elevation at its mouth is 1433 feet, while the headwaters lie at an elevation of about 1800 feet above tide. None of these streams is important for water power.

The topography of the catchment areas of all these streams tributary to Allegheny river is rugged. With the exception of a portion of the Allegheny river itself, and some of its main tributaries, the slopes are several feet to the mile. The slope of the main Allegheny river is slight.

The Tunungnant creek enters the Allegheny river four miles south of Carrollton, from Pennsylvania.

Susquehanna River System

Susquehanna river. The headwaters of the north branch of the Susquehanna lie chiefly in the State of New York, the catchment area in this State being taken at 6267 square miles. The main stream may be considered as rising in Otsego lake, from which it flows first southwesterly, then westerly with a short portion of its course south of the Pennsylvania line. It finally leaves New York State in Tioga county at Waverly. The Susquehanna, while one of the large rivers of New York, is not at all important as regards water power. The main river and most of its tributaries in New York flow through a rolling country with fairly uniform declivity. While utilized for small powers in many places, thus far there are no extensive developments on either the main stream or its branches, except at Binghamton, where considerable water power is utilized. The slope of the stream in and near New York State is shown by the following elevations, in feet, above tidewater:

	Feet
At Towanda, a few miles south of the State line........	700
At Athens, on Chemung river, near the State line........	744
At Otsego lake..	1,193

Chemung river. This river is formed by the confluence of the Cohocton, Canisteo and Tioga rivers, at Painted Post. The Tioga river receives the Canisteo at Erwin, a few miles southwest of Painted Post. The elevation at Painted Post is 947 feet above tidewater. From Painted Post the Chemung river pursues a southeasterly course, crossing the State line at Waverly and joining the Susquehanna near Athens, in Bradford county, Pennsylvania, a short distance south of the State line.

Tioga river. This stream rises in Tioga county, Pennsylvania, and flows north to join the Cohocton at Painted Post.

Canisteo river. This stream is the principal tributary in New York of the Tioga river, joining it five miles south of Painted Post. It rises in the extreme northeastern part of Allegany county and flows southeasterly to its junction with the Tioga at Erwin.

Cohocton river. The Cohocton river rises in the town of Springwater in Livingston county and flows southeast to join the Tioga at Painted Post. There are several small powers on this stream at Bath and other places. The area drained by the Cohocton and Canisteo rivers is almost entirely denuded of forests, and these streams are in consequence less valuable for water power than formerly. For a considerable length of time in the fall of 1895 the natural yield of these streams was probably not more than 0.05 of a cubic foot per second per square mile. At an early date the Cohocton, Canisteo and Tioga rivers were extensively utilized for floating logs to market, but this business has, of course, long since ceased for lack of material.

The topography of the country from which these streams issue may all be classed as semi-mountainous. The parts remote from the main streams are roughly rolling, while in their vicinity the topography is more rugged, with valleys flanked by high and steep hills, in many cases precipitous and bluff-like at their bases. The main valleys are at elevations ranging from 800 to 1200 feet above tidewater, while the hills rise to an altitude of 2500 feet.

Cayuta creek. This creek rises in the central part of Chemung county and flows south through Waverly into the Susquehanna river just south of the Pennsylvania line. Its headwaters are at an elevation of about 1200 feet, with hills in the vicinity rising several hundred feet higher than this.

Owego creek. This stream flows into the Susquehanna river at Owego. The east branch rises in Cortland county, flowing first westerly, thence southerly to its junction with the west branch at Flemingville. The west branch of Owego creek rises in the southeastern part of Tompkins county and flows south to its junction with Catatonk creek, the principal tributary of Owego creek. Catatonk creek rises in the northern part of Tioga county and flows south to its junction with Owego creek, two miles north of Owego. These streams all have characteristics in common. The headwaters are at an elevation of about 1000 feet to 1200 feet above tide and they flow through valleys of similar character with long ridges between. There is very little power on any of them.

Chenango river. This stream rises in the central part of Madison county in the towns of Eaton and Madison, and flows south, across Chenango and Broome counties, into the Susquehanna at Binghamton. About two miles south of Earlville the east branch joins the main stream. The elevation of the valleys on the headwaters is about 1200 feet above tide.

Tioughnioga river. This stream is the chief tributary of Chenango river. The east branch rises in Madison county and flows southwesterly to Cortland, where it joins the west branch. The west branch rises in the extreme south part of Onondaga county and flows south to Cortland, from which point the general course of the Tioughnioga river is southeast to its junction with Chenango river at Chenango Forks.

Otselic river. This stream is the chief tributary of the Tioughnioga river. It rises in the town of Nelson in the south central part of Madison county and flows generally southwest, joining the Tioughnioga river at Whitney Point. The valleys at its headwaters are at an elevation above tide of 1450 feet.

Unadilla river. The Unadilla river rises in the town of Bridgewater in the extreme southeastern part of Oneida county and flows southerly, joining the main Susquehanna near Sidney. The elevation of the valleys at its headwaters is about 1200 feet, while the elevation of the Susquehanna river at Sidney is somewhat less than 1000 feet.

Charlotte river. This river rises in the western part of Schoharie county and flows west into the main Susquehanna a few miles east of Oneonta.

Oak creek. This stream rises in Schuyler lake and flows south, joining the main Susquehanna three miles south of Otsego lake. Richfield Springs is at the north end of this lake, with an elevation above tide of 1450 feet.

The streams of the Susquehanna catchment area largely issue from the region of Chemung sandstones and shales. The country is deforested and they are all flashy and uncertain in their flow. While there are no measurements verifying the statement, the writer considers it probable that all, or nearly all of them, have a minimum flow not exceeding 0.1 of a cubic foot per second per square mile, and several of them, in an extremely dry time, sink to about 0.05 of a cubic foot per second per square mile. The flood flows, on the contrary, are universally large. The valleys at the headwaters, as we have seen, usually lie at elevations of from 1200 to 1400 feet above tide.

In regard to the following tabulation of the catchment areas of the Susquehanna river and its tributaries in New York, it must be stated that they are approximate only. Some of them are from the Report on Water Power in the Tenth Census, and were taken by planimeter measurements from French's Map of the State of New York, published in 1860. Undoubtedly when topographic maps of the region are prepared, they will be modified somewhat, but they are the best available at the present time.

The following are the approximate catchment areas of the Susquehanna and its tributaries in the State of New York:

	Square miles
Main river below mouth of Chemung river (south of Pennsylvania line)	7,463
Total area north of Pennsylvania line	6,267
Above mouth of Chemung river	4,945
Below mouth of Chenango river	3,982

	Square miles
At Binghamton	2,400
At Susquehanna	2,024
At Nineveh	1,789
Above Oneonta	686
Below mouth of Unadilla river	1,638
Below mouth of Oak creek	212
Above mouth of Oak creek	97
Oak creek	115
Cherry Valley creek	121
Schenevus creek	127
Charlotte river	178
Otego creek	106
Ouleout creek	115
Unadilla river	561
Butternut creek	123
Chenango river at mouth	1,582
Chenango river above Tioughnioga	685
Chenango river below Tioughnioga	1,438
Chenango river above Canasawacta creek	297
Tioughnioga river at mouth	753
Tioughnioga river above mouth of Otselic river	428
Otselic river	259
West branch of Tioughnioga river	103
East branch of Tioughnioga river	164
Owego creek	391
Cayuta creek	148
Chemung river at junction of Canisteo and Cohocton rivers	1,941
Chemung river at Elmira	2,055
Chemung river at mouth	2,518
Cohocton river at mouth	425
Tioga river at mouth	1,530
Tioga above mouth of Canisteo	750
Canisteo at mouth	780
Tuscarora creek at mouth	120

Delaware River System

Delaware river. The main Delaware river drains the western slopes of the Catskill mountains, originating on the slope of Mine mountain near the southwestern line of Schoharie county. It flows southwesterly across Delaware county to Deposit, where it is joined by Oquaga creek, a large tributary draining eastern Broome county. The upper catchment area is long and narrow, with numerous short lateral tributaries. It is precipitous and to a considerable extent covered with a not very dense second-growth forest. At Deposit the stream turns abruptly to the southeast, forming the boundary line between New York and Pennsylvania until Port Jervis is reached. At this point it encounters the foot of the Shawangunk range and its direction of flow is again turned to the southwest. It leaves New York State at this point. Above Hancock the main stream is known as the West branch of the Delaware river in order to distinguish it from the East or Pepacton branch of the river. It is also sometimes called "Mohawk," but should not be confused with Mohawk river, a tributary of the Hudson.

The declivity of Delaware river in New York State is shown by the following elevations above tidewater:

	Feet
At Lackawaxen	600
At Deposit	984
At headwaters	1,886

East branch or Pepacton river. The principal tributary of Delaware river in New York State is the East branch of the Delaware or Pepacton river, which rises in the eastern part of Delaware and Greene counties, flowing southwest in a course generally parallel to the main stream. The catchment area is broader and more branching than in the case of the West branch. Several of the tributaries head in small lakes and ponds.

Neversink river. This river rises in the foothills of the Catskill mountains in the southwestern part of Ulster county. The east and west branches unite to form the main stream near the south line of Ulster county, from which point the main stream flows nearly due south, across Sullivan and Orange counties, entering the main Delaware river at Port Jervis. The catchment area of this stream is long and narrow, and with the exception of the Basher kill and Bush kill, is practically without tributaries for its whole length of about 50 miles.

Mongaup river. This stream rises in the north central part of Sullivan county and flows due south, entering the Delaware river at Mongaup.

There are a number of other streams tributary to Delaware river, but none of them is of enough importance for extended mention. Very little water power is developed throughout this region, although there are a number of places where powers could be developed. The location of railways near the water level has interfered with such developments. The removal of forests has further undoubtedly considerably injured the tributary streams for mill purposes.

The following gives the more important catchment areas of the Delaware river and its tributaries in New York State:

	Square miles
Total area in New York State	2,580
Main stream below mouth of Neversink river	3,600
Main stream below Port Jervis	3,252
Main stream below junction of East and West branches	1,604
West branch at mouth	685
West branch at Deposit, below Oquaga creek	519
Pepacton river at mouth	919
Above mouth of Beaverkill	520
Beaverkill creek	322
Oquaga creek	82
Little Delaware creek	53
Neversink river at mouth	346

By way of concluding the general discussion of the Allegheny, Susquehanna, and Delaware river systems in the State of New York, it may be remarked that these have all been extensively used, either for floating logs or for propelling sawmills, or for both.

The clearing up of the catchment areas has, however, long since reduced the lumbering business to nothing. These streams are therefore much less extensively utilized than formerly. At present, aside from one or two points, their use is chiefly for propelling small sawmills and flour mills and for other moderate-sized industries. With one or two exceptions, there are no large power developments, throughout the whole region, but undoubtedly a number of developments could be made on the Susquehanna and Delaware rivers, although owing to high flood flows, developments should be made of a very permanent character. But this condition, it may be premised, implies large expenditure, and whether large permanent developments can be made to pay on streams where there are no facilities for water storage is an unsettled question.

In a paper on the History of the Lumber Industry in the State of New York, Col. Wm. F. Fox, Superintendent of Forests, has given many interesting facts relating to the early use of the streams for floating logs, etc., to which the reader is referred for an extended account under these heads.[1]

Streams of Long Island

The sand areas of Long Island present conditions of water yield different from those of the other catchment areas of the State. We have here an extended region of course, deep sand, into which the rainfall sinks easily, there being almost no surface runoff. These sand areas form subterranean reservoirs, from which from 0.7 to 0.8 cubic foot per second per square mile may be drawn, the same as from artificial reservoirs on the earth's surface, these natural underground reservoirs possessing the advantage of furnishing a filtered water of a high degree of purity.

The taking of the water supply of Brooklyn from the sand areas of Long Island has led to the development of legal principles relating to rights in underground water somewhat different from those derived from the common law of England. The decision in a test case, tried several years ago, was in effect, that when sub-

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[1] Published by the Department of Agriculture, Washington, 1902.

terranean water is taken in large quantity for the supply of cities or for manufacturing purposes the party taking it is liable to the adjacent landowners the same as in the case of diverting surface water.

Long Island is chiefly a sandy plain, about 120 miles in length, with a total area of 1682 square miles. A considerable portion is below an elevation of 100 feet above tidewater, although in places it rises to elevations of 300 feet and more. The streams are all small and only a few miles in length, running down from the high land of the middle section to the Atlantic ocean on the south and to Long Island sound on the north. As regards water power, the water resources of Long Island have little significance, although there are many places where small powers are utilized for gristmills and other similar uses. The chief value of the inland water of Long Island is for the water supply of the city of Brooklyn.

East river, which connects Long Island sound with New York bay, may also be referred to for convenience as a Long Island water resource. The great value of the stream to the commerce of New York is so obvious as to hardly require mention.

The foregoing description of the river systems of New York has been made brief, because very complete descriptions have been given in the several monographs relating to New York State which appear in the report on the Water Power of the United States, Tenth Census, 1880. In these reports may be found the detail of the several river valleys, with statements as to agricultural production, population, geology, climatology, and many other subjects either not at all touched on, or only briefly, here.

RUNOFF OF NIAGARA AND ST LAWRENCE RIVERS

In view of the size of the streams and their importance the runoffs of Niagara and St Lawrence rivers are discussed separately from the balance of the streams of New York.

Niagara river. The great developments of the Niagara Falls Power Company authorized by the laws of 1886 have been in part completed, while at the same time the original Niagara Falls power development, now owned by the Niagara Falls Hydraulic Power &

Manufacturing Company, has increased greatly in capacity. The laws of 1886, and amendments thereto, have also authorized the taking from Niagara river of large quantities of water for the purpose of creating a water power near the city of Lockport. A ship canal is projected connecting Lakes Erie and Ontario, and the Canadian government has made a concession for extensive power developments on the Canadian side of the river, which are in progress in 1904. Hence it is evident that the future demands for water to be taken from Niagara river and delivered either into the lower river below the falls or into Lake Ontario independent of the river are very large, and the interest which the people of the State of New York have in the runoff of Niagara river becomes exceedingly important.

A recent determination of the area of the basin drained by the Great Lakes and of the water surfaces of the lakes themselves is that given in the report of the United States Deep Waterways Commission, from which the following general summary is taken. This determination was made in 1896. In 1898 the Board of Engineers on Deep Waterways redetermined these areas but without changing any except that of Lake Erie, which was taken at 9932 square miles.

Lake	Area of water surface, square miles	Area of catchment, square miles	Total area of basin, square miles
Superior	31,800	48,600	80,400
Michigan	22,400	45,700	68,100
Huron	23,200	52,100	75,300
St Clair	495	6,320	6,815
Erie	10,000	24,480	34,480
Total	87,895	177,200	265,095

That portion of the catchment area of Lake Erie lying within the State of New York is given as 2210 square miles. The area of islands in Niagara river is given as 29 square miles. That portion of the catchment area of Niagara river lying within the State of

New York has an area of 789 square miles. The area of the river itself from its head at Lake Erie to the falls, is 21 square miles.[1]

The accompanying table gives the precipitation within and in the vicinity of the catchment area of the Great Lakes for the years from 1892 to 1895, inclusive. In this table a few only of the many precipitation records which are now available have been used. The records here appearing are, it is believed, sufficient to show the mean precipitation of the basin of the Great Lakes for the years indicated. In this table the monthly precipitation has been omitted, as it can readily be found in the annual reports of the United States Weather Bureau, and the data have been condensed to show the total quantities for the storage, growing and replenishing periods, together with the total annual quantity.

TABLE NO. 39—PRECIPITATION (IN INCHES) WITHIN AND IN THE VICINITY OF THE CATCHMENT AREA OF THE GREAT LAKES, 1892 TO 1895, INCLUSIVE.

Locality and year	December to May	June to August	September to November	Annual
Pokegama Falls, Minn.:				
1892	11.76	6.99	2.86	21.61
1893	9.64	13.06	2.84	25.54
1894	14.72	8.04	9.01	31.77
1895	9.14	12.49	5.70	27.33
Mean				*26.56*

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[1] Report of the United States Deep Waterways Commission, by the Commissioners, James B. Angell, John E. Russell, Lyman E. Cooley, accompanied by the report on technical work and the several topical reports and drawings pertaining thereto. Printed as House Document No. 192, Fifty-Fifth Congress, Second Session, Washington, 1897, pp. 146, 147.

For the catchment area of the Great Lakes in detail reference may be made to an excellent map of the basin of the Great Lakes and of the St Lawrence and Hudson rivers in relation to the surrounding drainage systems accompanying the report of the Deep Waterways Commission. Also see map on page 318.

TABLE No. 39—*Continued.*

Locality and year	December to May	June to August	September to November	Annual
Duluth, Minn.:				
1892	17.96	11.78	2.39	32.13
1893	11.08	6.86	3.64	21.58
1894	19.44	3.80	8.51	31.75
1895	6.44	9.32	7.70	23.46
Mean				*27.23*
Minneapolis, Minn.:				
1892	13.78	23.32	2.33	39.43
1893	12.80	9.79	5.68	28.27
1894	15.66	1.73	6.46	23.85
1895	7.72	9.96	5.01	22.69
Mean				*28.56*
Green Bay, Wis.:				
1892	14.95	12.47	7.95	35.37
1893	14.85	8.12	7.15	30.12
1894	19.65	8.52	10.46	38 63
1895	10.06	7.52	3.14	20.72
Mean				*31.21*
Madison, Wis.:				
1892	18.89	13.34	4.89	37.12
1893	13.37	12.75	5.82	31.94
1894	10.96	6.23	7.61	24.80
1895	5.54	3.88	2.57	11.99
Mean				*26.46*
Milwaukee, Wis.:				
1892	18.17	11.00	5.71	34.88
1893	15.69	10.14	6.06	31.89
1894	15.94	4.81	8.79	29.54
1895	10.34	7.45	5.33	23.12
Mean				*29.86*

TABLE NO. 39—*Continued.*

Locality and year	December to May	June to August	September to November	Annual
Chicago, Ill.:				
1892	16.03	14.66	5.56	36.25
1893	13.93	6.85	6.18	26.96
1894	14.48	3.16	10.30	27.94
1895	9.58	10.70	7.00	27.28
Mean				*26.61*
Logansport, Ind.:				
1892	27.26	10.91	6.97	45.14
1893	24.45	4.52	8.92	37.89
1894	21.11	4.58	7.82	33.51
1895	9.08	6.40	8.56	24.04
Mean				*35.15*
Ann Arbor, Mich.:				
1892	14.52	8.18	7.70	30.38
1893	20.54	7.18	10.33	38.05
1894	16.63	2.76	7.21	26.60
1895	8.92	5.40	4.70	19.02
Mean				*28.51*
Grand Haven, Mich.:				
1892	16.57	8.93	4.97	30.47
1893	19.02	6.79	8.68	34.49
1894	19.84	4.07	11.08	34.99
1895	10.89	4.88	6.17	21.94
Mean				*30.47*
Marquette, Mich.:				
1892	16.03	3.53	8.89	28.45
1893	14.81	9.16	7.41	31.38
1894	24.65	5.25	9.31	39.21
1895	16.35	7.04	8.89	32.28
Mean				*32.83*

TABLE No. 39—*Continued.*

Locality and year	December to May	June to August	September to November	Annual
St. Ignace, Mich.:				
1892	12.39	10.30	6.43	29.12
1893	15.61	7.94	8.31	31.86
1894	17.80	6.83	9.80	34.43
1895	11.66	4.59	8.98	25.23
Mean				*30.16*
Traverse City, Mich.:				
1892	17.65	10.87	8.61	37.13
1893	17.88	7.07	11.41	36.36
1894	20.62	5.61	9.72	35.95
1895	16.69	4.53	7.85	29.07
Mean				*34.63*
Cleveland, Ohio:				
1892	19.84	11.91	5.90	37.65
1893	19.09	5.46	7.45	32.00
1894	15.28	5.55	7.77	28.60
1895	9.29	7.59	7.91	24.79
Mean				*30.76*
Toledo, Ohio:				
1892	17.77	12.76	6.47	37.00
1893	10.17	4.81	6.92	21.90
1894	14.93	2.78	5.23	22.94
1895	9.23	6.24	7.11	22.58
Mean				*26.10*
Buffalo, N. Y.:				
1892	22.62	16.93	8.32	47.87
1893	20.65	8.00	7.87	36.52
1894	22.47	5.82	12.50	40.79
1895	14.17	6.23	8.85	29.25
Mean				*38.61*

TABLE NO. 39—*Concluded.*

Locality and year	December to May	June to August	September to November	Annual
Rochester, N. Y.:				
1892	17.75	13.41	5.94	37.10
1893	18.05	9.36	6.02	33.43
1894	21.26	7.05	7.14	35.45
1895	16.16	6.84	7.15	30.15
Mean				*34.03*
Oswego, N. Y.:				
1892	15.22	15.33	6.82	37.37
1893	14.63	9.83	8.01	32.47
1894	19.55	6.46	11.13	37.14
1895	15.06	6.25	9.08	30.39
Mean				*34.34*
Winnipeg, Manitoba:				
1892	6.65	8.70	3.96	19.31
1893	8.25	10.81	4.35	23.41
1894	8.55	3.80	5.84	18.19
1895	8.18	6.62	2.42	17.22
Mean				*19.53*
Port Arthur, Ontario:				
1892	8.84	7.35	5.31	21.50
1893	8.48	7.39	6.50	22.37
1894	8.20	5.57	8.30	22.07
1895	8.76	7.86	6.05	22.67
Mean				*22.15*
Toronto, Ontario:				
1892	12.21	12.29	6.65	31.15
1893	18.64	9.85	7.86	36.35
1894	19.90	3.07	8.44	31.41
1895	11.93	6.24	7.76	25.93
Mean				*31.21*

These precipitation data are of special interest because the year 1895 was the culmination of a period of exceedingly low water. They show that for a period of four years the precipitation of this basin was low, and in consequence the runoff of the tributary streams must have been exceedingly small. As illustrating this proposition, we will refer to the runoff of the Upper Mississippi,[1] where there is a reservoir system controlling a catchment area of 3265 square miles, first operated about 1885. The rainfall of the area tributary to these reservoirs, as indicated by records kept at Leech lake, Lake Winibigoshish, and Pokegama Falls from 1885 until the present time is, on an average, from 24 to 26 inches per year. The highest recorded yearly precipitation is 31.87 inches, at Pokegama Falls in 1894. The rainfall of the area tributary to the Upper Mississippi reservoirs is found to be quite similar to that of the region tributary to Lake Superior. Hence the runoff of this reservoir system may be considered as representing the runoff of the catchment area of Lake Superior and the northern portion of Lakes Michigan and Huron. The following gives the discharge from these reservoirs for the years 1892 to 1895, inclusive, corresponding with the years of precipitation shown in table No. 39.

Water year.	Mean rainfall on catchment area. Inches	Runoff of catchment area. Inches	Proportion of runoff to rainfall. Per cent
1892	21.33	4.43	20.8
1893	25.42	3.61	14.2
1894	26.63	3.62	13.6
1895	25.11	2.79	11.1
Total	98.49	14.45	....
Mean	24.62	3.61	14.7

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[1] Annual report of Chief of Engineers U. S. Army for 1896, part III, p. 1843; also for 1897, part III, p. 2169.

The tabulation shows that during the years 1892 to 1895, inclusive, the mean runoff of the Upper Mississippi area was only 3.61 inches on the total catchment. These figures, however, are subject to correction because the state of the reservoirs at the beginning and ending of the four-year period is not given in the report of the United States engineers, from which these data are taken. This correction, however, can not be very large, because the reservoirs are so operated as to be emptied, generally speaking, each year. In considering the runoff of these Upper Mississippi reservoirs, due consideration should be given to the fact that the water area of the reservoirs is 585 square miles, or nearly 18 per cent of the whole. For Lakes Superior, Michigan, Huron, St Clair, and Erie we have a total water surface of 87,895 square miles, with a total catchment area, including the surface of the lakes, of 265,095 square miles. The water surface of these several lakes is, therefore, about 33 per cent of the entire area of the basin, or nearly double the relative area of water surface and catchment area for the Upper Mississippi reservoirs. With other conditions the same, this fact would probably lead to a somewhat greater proportion of runoff from the Great Lakes. The Upper Mississippi reservoirs are in a forested region, and it is interesting to consider what the runoff will be after the forests are removed. Taking into account results in other places, it is probable that the runoff, under conditions of deforestation, will not exceed an average of about 2 inches per year.

Runoff of Desplaines river. By way of further illustrating the yield of streams in the vicinity of the Great Lakes area, we will refer to the runoff of the Desplaines river, as given in table No. 40. This stream has been measured by the Chicago Drainage Commission, with certain intermissions as shown since January, 1886, the catchment area above the point of measurement being 633 square miles. The catchment comprises a long and narrow flat region extending from near Chicago to a few miles north of

Milwaukee, the eastern line being for the entire distance nearly parallel to Lake Michigan and in places only 2 or 3 miles distant therefrom. The area drained by the Desplaines river is large enough to give a fair idea of the average yield of streams tributary to Lake Michigan in northern Illinois and Indiana, western Michigan, and southern and central Wisconsin. In 1893, with a mean rainfall on the catchment area of 39.96 inches, the total runoff was 10.14 inches, of which 8.61 inches occurred during the storage period from December to May, inclusive. In 1894, with a total rainfall of 27.94 inches, the total runoff was 7.70 inches, of which 7.54 inches occurred in the storage period. For the year 1895 the total rainfall was 27.28 inches. The runoff data of this year are incomplete, but taking into account the sequence of the rainfall it is clear that the total runoff for that year did not exceed about 2.0 to 2.5 inches. The effect of the three dry years 1893, 1894, and 1895 in the Desplaines catchment area is shown by the record of 1896, where, with a total rainfall of 39.58 inches, the total runoff was only 6.69 inches, of which 5.39 inches occurred in the storage period. These figures indicate that the ground water of the Desplaines area must have been so low at the end of 1895 as to absorb a large portion of the heavier rainfall of 1896 before any great amount could appear as runoff.[1]

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[1] For details of the measurements of the Desplaines river see Data Pertaining to Rainfall and Stream Flow, by Thomas T. Johnston, Journal Western Soc. C. E., Vol. I (June, 1896).

TABLE NO. 40—RAINFALL AND RUNOFF OF DESPLAINES RIVER, AS DETERMINED BY THE CHICAGO DRAINAGE COMMISSION, FROM 1886 TO 1897, INCLUSIVE

[Inches on the catchment]

MONTH	1886		1887		1888		1889		1890		1891	
	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff
(1)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)
December	.....	.....	1.76	0.00	3.67	.....	1.94	0.00	1.90	.....	.....	.....
January	.....	.....	3.13	0.89	1.56	1.37	1.64	0.29	.....	.....	.....	.....
February	.....	.....	5.10	5.59	1.51	2.50	1.31	0.01	.....	.....	.....	.....
March	.....	.....	0.89	2.64	2.99	4.84	1.43	0.43	.....	.....	.....	.....
April	.....	.....	0.46	0.52	.....	.....	2.35	1.13	.....	.....	.....	.....
May	.....	.....	1.38	0.13	.....	.....	5.38	0.39	.....	.....	.....	.....
Storage period	.....	.....	12.72	9.77	.....	.....	14.05	2.25	.....	.....	.....	.....
June	0.94	0.16	1.63	0.02	.....	.....	2.98	1.26	.....	.....	.....	.....
July	1.53	0.14	1.05	0.33	.....	.....	9.56	1.09	2.57	.....	.....	.....
August	3.38	0.01	3.35	0.18	.....	.....	0.39	0.45	2.58	0.02	.....	.....
Growing period	5.85	0.31	6.03	0.53	.....	.....	12.88	2.80	.....	.....	.....	.....
September	6.93	0.03	4.03	0.22	0.98	.....	2.75	0.00	1.39	0.01	.....	.....
October	1.42	0.01	2.03	0.63	2.95	0.00	1.82	0.00	4.20	0.02	.....	.....
November	1.66	0.00	2.41	0.07	2.89	0.00	3.49	0.01	1.59	0.04	.....	.....
Replenishing period	10.01	0.04	8.47	.....	6.82	.....	8.06	0.01	7.18	0.07	.....	.....
Yearly total	.....	.....	27.22	.....	.....	.....	34.99	5.06	.....	.....	.....	.....

TABLE NO. 40—RAINFALL AND RUNOFF OF DESPLAINES RIVER, AS DETERMINED BY THE CHICAGO DRAINAGE COMMISSION, FROM 1886 TO 1897, INCLUSIVE (*concluded*)

[Inches on the catchment]

MONTH.	1892		1893		1894		1895		1896		1897	
	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff
(1)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)
December	......	......	1.63	0.04	2.14	0.27	1.66	......	6.76	1.80	0.16	0.19
January	......	......	2.08	0.01	1.55	0.50	2.15	......	1.12	6.26	4.53	......
February	......	......	2.44	0.31	2.13	1.06	1.60	0.21	3.48	1.06	2.22	1.39
March	......	......	1.69	5.15	2.66	3.05	1.32	0.71	1.26	1.11	3.56	4.61
April	......	......	4.16	1.79	2.65	0.76	0.86	0.29	2.79	0.77	2.23	1.88
May	6.77	4.24	1.93	1.31	3.35	1.90	1.99	0.11	4.16	0.39	0.84	0.60
Storage period	......	......	13.93	8.61	14.48	7.54	9.58	......	19.57	5.39	13.54	......
June	10.58	6.04	3.59	1.37	1.96	0.08	1.79	0.00	2.82	0.09	......	......
July	2.23	0.79	3.08	0.14	0.60	0.01	2.42	0.00	3.61	0.02	......	......
August	1.35	0.03	0.18	0.00	0.60	0.00	6.49	0.01	3.52	0.06	......	......
Growing period	14.66	6.86	6.85	1.51	3.16	0.09	10.70	0.01	9.95	0.17	......	......
September	1.34	0.02	1.98	0.00	8.28	0.06	0.89	0.06	6.54	0.32	......	......
October	1.54	0.00	1.75	0.02	0.84	0.00	0.51	0.00	1.36	0.33	......	......
November	2.68	0.02	2.45	0.00	1.18	0.01	5.60	0.00	2.16	0.48	......	......
Replenishing period	5.56	0.04	6.18	0.02	10.30	0.07	7.00	0.06	10.06	1.13	......	......
Yearly total	......	......	26.96	10.14	27.94	7.70	27.28	......	39.58	6.69	......	......

TABLE No. 41.—EVAPORATION FROM THE DESPLAINES CATCHMENT, AS GIVEN BY DIFFERENCES BETWEEN RAINFALL AND RUNOFF IN THE PRECEDING TABLE.

[Inches on the catchment.]

Water year.	December to May.	June to August.	September to November.	Total.
1886	......	5.54	9.97	....
1887	2.95	5.50	....	....
1889	11.80	10.08	8.05	29.93
1890	......	....	7.11	....
1892	......	7.80	5.52	....
1893	5.32	5.34	6.16	16.82
1894	6.94	3.07	10.23	20.24
1895	......	10.69	6.94	....
1896	14.18	9.78	8.93	32.89

Runoff of Muskingum river. In table No. 42 is given the rainfall and runoff record for Muskingum river, Ohio, as measured at Zanesville,[1] for the years 1888 to 1895, inclusive, the area of the catchment above the point of measurement being 5828 square miles. The headwaters of the stream are not far from Lake Erie and on the dividing line between the hill country of the east and the prairie country of the Mississippi valley. Hence this stream represents conditions applicable to the runoff of the Ohio streams tributary to Lake Erie. The rainfall record as used in this table is the mean of the records kept at Akron, Canton, Newcomerstown and Wooster, and may be considered to represent fairly well the mean precipitation of the Muskingum catchment area. For the year 1892 the total rainfall was 41.74 inches and the total runoff 13.38 inches, of which 9.06 occurred in the storage period. In 1893 the total rainfall was 42.36 inches, with a total runoff of 16.20 inches, the runoff of the storage period being 14.13 inches.

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[1] Survey of the Miami and Erie canal, the Ohio canal, etc. Report of Capt. Hiram M. Chittenden, Corps of Engineers, U. S. Army, January 20, 1896, printed as House Document No. 278, Fifty-fourth Congress, First Session, p. 42.

TABLE NO. 42 — RAINFALL, RUNOFF, EVAPORATION, AND MEAN TEMPERATURE OF MUSKINGUM RIVER, AS MEASURED BY THE UNITED STATES ENGINEERS, FROM 1888 TO 1895, INCLUSIVE

[In inches on the catchment area]

MONTH	1888				1889				1890			
	Rainfall	Runoff	Evaporation	Temperature	Rainfall	Runoff	Evaporation	Temperature	Rainfall	Runoff	Evaporation	Temperature
(1)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)
				°				°				°
December	1.94	0.18	......	30.8	1.50	0.84	......	31.5	3.01	1.48	......	41.1
January	3.96	1.24	......	23.5	3.63	1.89	......	31.7	4.52	3.53	......	37.0
February	1.91	1.12	......	29.4	1.55	1.42	......	24.0	5.84	3.73	......	37.5
March	4.05	1.38	......	32.5	1.71	0.71	......	39.0	4.38	4.23	......	32.0
April	1.75	0.80	......	46.9	2.23	0.88	......	47.9	3.41	2.00	......	48.8
May	3.55	0.45	......	58.4	2.90	0.28	......	59.1	6.61	3.10	......	56.9
Storage period	17.16	5.17	11.99	36.9	13.52	6.02	7.50	38.9	27.77	18.07	9.70	42.2
June	2.66	0.29	......	68.4	4.79	0.47	......	65.7	5.27	1.64	......	70.7
July	5.81	0.81	......	70.4	5.35	0.55	......	71.7	3.06	0.51	......	70.9
August	5.84	0.67	......	68.8	1.98	0.22	......	67.0	5.35	0.49	......	66.6
Growing period	14.31	1.77	12.54	69.2	12.12	1.24	10.88	68.1	13.68	2.64	11.04	69.4
September	3.28	0.61	......	58.0	4.17	0.14	......	61.3	6.86	2.28	......	60.6
October	3.25	0.77	......	45.6	2.35	0.14	......	46.5	6.20	2.01	......	51.1
November	4.61	2.01	......	41.1	3.72	0.68	......	40.2	2.46	1.84	......	42.0
Replenishing period	11.14	3.39	7.75	48.2	10.24	0.96	9.28	49.3	15.52	6.13	9.39	51.2
Yearly mean or total	42.61	10.33	32.28	47.8	35.88	8.22	27.66	48.8	56.97	26.84	30.13	51.3

TABLE NO. 42 — RAINFALL, RUNOFF, EVAPORATION, AND MEAN TEMPERATURE OF MUSKINGUM RIVER, AS MEASURED BY THE UNITED STATES ENGINEERS, FROM 1888 TO 1895, INCLUSIVE (*continued*)

[In inches on the catchment area]

MONTH	1891				1892				1893			
	Rainfall	Runoff	Evaporation	Temperature	Rainfall	Runoff	Evaporation	Temperature	Rainfall	Runoff	Evaporation	Temperature
(1)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)
				°				°				°
December	2.45	0.91	......	29.3	2.62	1.03	......	37.8	1.62	0.24	......	28.1
January	2.52	2.40	......	31.2	2.40	0.74	......	22.8	3.01	0.37	......	18.0
February	4.43	4.56	......	34.8	2.76	2.40	......	33.0	6.38	4.70	......	28.3
March	3.19	2.52	......	33.5	3.10	1.26	......	32.7	2.31	2.55	......	36.9
April	1.74	1.58	......	49.8	2.24	1.38	......	46.0	5.94	2.22	......	49.6
May	2.39	0.45	......	55.8	7.27	2.25	......	57.9	5.78	4.05	......	57.0
Storage period	16.72	12.42	4.30	39.1	20.39	9.06	11.33	38.4	25.04	14.13	10.91	36.3
June	7.56	0.91	......	69.0	7.05	2.30	......	71.6	3.08	0.78	......	70.2
July	3.92	0.51	......	67.6	5.44	0.75	......	70.9	2.92	0.28	......	73.6
August	2.08	0.35	......	68.7	4.05	0.60	......	70.0	2.31	0.16	......	69.5
Growing period	13.56	1.77	11.79	68.4	16.54	3.65	12.89	70.8	8.31	1.22	7.09	71.1
September	1.08	0.17	......	66.5	2.33	0.28	......	62.2	1.56	0.14	......	63.4
October	1.25	0.26	......	49.7	0.80	0.20	......	50.1	5.51	0.46	......	52.4
November	4.75	0.94	......	38.6	1.68	0.19	......	37.8	1.94	0.25	......	38.4
Replenishing period	7.08	1.37	5.71	51.6	4.81	0.67	4.14	50.0	9.01	0.85	8.16	51.4
Yearly mean or total	37.36	15.56	21.80	49.5	41.74	13.38	28.36	49.4	42.36	16.20	26.16	48.8

TABLE NO. 42 — RAINFALL, RUNOFF, EVAPORATION, AND MEAN TEMPERATURE OF MUSKINGUM RIVER, AS MEASURED BY THE UNITED STATES ENGINEERS, FROM 1888 TO 1895, INCLUSIVE (*concluded*)

[In inches on the catchment area]

MONTH	1894				1895				MEAN			
	Rainfall	Runoff	Evaporation	Temperature	Rainfall	Runoff	Evaporation	Temperature	Rainfall	Runoff	Evaporation	Temperature
(1)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)
				°				°				°
December	2.59	1.54		31.7	3.01	0.36		33.2				
January	2.11	1.00		33.2	3.99	1.67		22.4				
February	2.95	2.19		27.6	0.89	0.12		19.1				
March	2.20	1.41		43.9	1.87	1.20		23.2				
April	2.45	0.75		49.8	1.76	0.59		50.6				
May	4.63	0.74		58.3	1.52	0.10		60.5				
Storage period	16.93	7.63	9.30	40.7	13.04	4.04	9.00	36.5	18.82	9.57	9.25	38.6
June	2.12	0.42		70.6	2.87	0.17		71.6				
July	1.77	0.13		73.1	2.52	0.21		69.6				
August	0.67	0.11		70.1	3.75	0.11		71.7				
Growing period	4.56	0.66	3.90	71.3	9.14	0.49	8.65	71.0	11.53	1.68	9.85	69.9
September	4.12	0.15		67.2	2.39	0.13		67.2				
October	2.19	0.10		53.3	1.38	0.08		45.3				
November	2.71	0.16		36.8	3.89	0.16		40.8				
Replenishing period	9.02	0.41	8.61	52.4	7.66	0.37	7.29	51.1	9.31	1.77	7.54	50.7
Yearly mean or total	30.51	8.70	21.81	51.3	29.84	4.90	24.94	48.8	39.66	13.02	26.64	49.5

In 1894 the rainfall dropped to a total of 30.51 inches and the runoff to a total of 8.70 inches, of which 7.63 inches occurred in the storage period. In 1895 the total rainfall was 29.84 inches and the total runoff 4.90 inches, of which 4.04 inches occurred during the storage period.

Runoff of Genesee river. Genesee river, while not tributary to the Great Lakes above Niagara river, may still be cited as showing that at times the runoff of streams tributary to the Great Lakes is very low. Referring to table No. 43, which, for the years 1890, 1891 and 1892, gives the rainfall and runoff of Oatka creek, a tributary of the Genesee, we learn that in the water year 1891, with a rainfall of 38.12 inches, the runoff was 14.05 inches. In 1892, with a rainfall of 41.69 inches, the runoff was 15.42 inches.

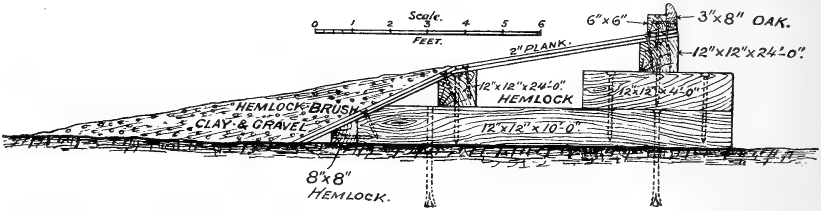

Fig. 20 Section of weir erected on Genesee river in 1896.

Taking the record of Genesee river proper, for the years 1893–1898, inclusive, as given in table No. 43, we learn that for the water year 1894, with a mean precipitation above the point of measurement of 47.79 inches, the runoff was 19.38 inches, of which 15.73 inches occurred in the storage period. In 1895 the rainfall dropped to 31 inches and the total runoff to 6.67 inches. In 1880 Hemlock lake, a tributary of Genesee river, with a catchment area of 43 square miles and a total rainfall of 21.99 inches, gave a runoff of only about 3.4 inches.

TABLE No. 43—RUNOFF DATA OF GENESEE RIVER FOR WATER YEARS 1890–1898, INCLUSIVE
(In inches)

MONTH	1890			1891			1892			1893			1894		
	Rainfall *	Runoff	Evapo-ration	Rainfall *	Runoff	Evapo-ration	Rainfall *	Runoff	Evapo-ration	Rainfall	Runoff	Evapo-ration	Rainfall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	3.33	1.00†	......	2.61	0.97	......	3.80	1.04	......	1.23	......	......	3.39	2.34	......
January	4.36	1.70†	......	4.12	2.62	......	3.82	0.78	......	2.68	......	......	3.91	1.40	......
February	3.63	2.53†	......	4.67	3.40	......	3.71	1.66	......	4.49	......	......	2.93	0.86	......
March	2.72	2.40†	......	3.70	2.87	......	1.73	1.94	......	2.85	......	......	1.62	3.31	......
April	2.82	2.17	......	1.52	1.39	......	1.04	2.21	......	3.65	......	......	7.22	3.39	......
May	6.15	3.16	......	1.60	0.63	......	5.74	1.75	......	5.75	......	......	8.64	4.43	......
Storage period	23.01	12.96	10.05	18.22	11.88	6.34	19.84	9.38	10.46	20.65	11.10†	9.55†	27.71	15.73	11.98
June	4.12	1.85	......	4.01	0.44	......	6.67	1.41	......	2.11	......	......	2.51	1.10	......
July	3.18	0.38	......	4.52	0.37	......	4.18	2.06	......	2.27	......	......	3.70	0.14	......
August	3.22	0.28	......	4.25	0.25	......	4.45	1.43	......	5.17	......	......	1.74	0.22	......
Growing period	10.52	2.51	8.01	12.78	1.06	11.72	15.30	4.90	10.40	9.55	1.00†	8.55†	7.95	1.46	6.49
September	6.59	1.35	......	1.72	0.46	......	1.62	0.24	......	3.74	0.33	......	6.97	0.93	......
October	4.52	2.27	......	2.49	0.24	......	2.19	0.33	......	2.95	0.38	......	3.50	0.44	......
November	2.90	2.13	......	2.91	0.41	......	2.74	0.57	......	2.41	0.54	......	1.66	0.82	......
Replenishing period	14.01	5.75	8.26	7.12	1.11	6.01	6.55	1.14	5.41	9.10	1.25	7.85	12.13	2.19	9.94
Yearly total	47.54	21.22	26.32	38.12	14.05	24.07	41.69	15.42	26.27	39.30	13.35	25.95	47.79	19.38	28.41

* For the years 1890–92, inclusive, the rainfall of the Oatka creek catchment area has been used rather than that of the entire upper Genesee area, as per Table No. 11 of 1896 Report of State Engineer and Surveyor of New York, p. 669. † Approximate.

TABLE No. 43—RUNOFF DATA OF GENESEE RIVER FOR WATER YEARS 1890–1898, INCLUSIVE (*concluded*)
(In inches)

MONTH	1895			1896			1897			1898			MEAN		
	Rainfall	Runoff	Evapo-ration	Rainfall	Runoff	Evapo-ration	Rainfall	Runoff	Evapo-ration	Rainfall	Runoff	Evapo-ration	Rainfall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	2.47	0.61	......	3.80	1.32	......	1.41	0.79	......	2.94	0.95	......	......	......	......
January	3.26	0.66	......	2.29	0.47	......	2.92	0.78	......	3.66	1.95	......	......	......	......
February	1.22	0.22	......	3.56	0.91	......	1.56	0.79	......	1.75	1.85	......	......	......	......
March	1.72	1.94	......	4.00	3.00	......	3.61	2.65	......	4.19	2.75	......	......	......	......
April	2.10	2.01	......	1.62	3.38	......	2.77	1.31	......	2.71	1.65	......	......	......	......
May	2.43	0.19	......	2.57	0.17	......	3.41	0.99	......	3.41	1.25	......	......	......	......
Storage period	13.20	5.63	7.57	17.84	9.25	8.59	15.68	7.31	8.37	18.66	10.40	8.26	19.4	10.5	8.9
June	4.57	0.13	......	3.52	0.39	......	3.99	0.44	......	4.73	0.80	......	......	......	......
July	2.57	0.11	......	4.90	0.24	......	5.66	0.46	......	2.30	0.45	......	......	......	......
August	3.99	0.12	......	1.86	0.20	......	2.27	0.44	......	7.12	0.80	......	......	......	......
Growing period	11.13	0.36	10.77	10.28	0.83	9.45	11.92	1.34	10.58	14.15	2.05	12.10	11.5	1.7	9.8
September	1.96	0.10	......	5.22	0.16	......	2.23	0.18	......	1.44	0.50	......	......	......	......
October	1.30	0.11	......	4.08	1.74	......	0.79	0.18	......	5.12	0.78	......	......	......	......
November	3.41	0.47	......	3.26	0.82	......	3.77	0.37	......	3.13	1.40	......	......	......	......
Replenishing period	6.67	0.68	5.99	12.56	2.72	9.84	6.79	0.73	6.06	9.69	2.68	7.01	9.4	2.0	7.4
Yearly total	31.00	6.67	24.33	40.68	12.80	27.88	34.39	9.38	25.01	42.50	15.13	27.37	40.3	14.2	26.1

These figures are cited to show that in years of low rainfall the runoff of streams tributary to the Great Lakes is low, and as a consequence the runoff of Niagara river will necessarily be affected thereby.

Aside from the measurements made by the Board of Engineers on Deep Waterways in 1898, the most elaborate measurements thus far made are those of the Lake Survey in 1867 and 1869 which are, however, extremely unsatisfactory. According to these measurements the mean discharge, rainfall and evaporation from the Great Lakes for the year 1868, in cubic feet per second, were as follows:[1]

Lake	Mean discharge	Total rainfall on basin	Evaporation from surface
Superior	86,000	171,430	27,690
Huron and Michigan	225,000	251,450	59,890
Erie	265,000	100,540	14,310
Total	....	523,420	101,890

According to the Deep Waterways Commission's tabulation of records of hights of the Great Lakes, it appears that the water level fluctuated through a series of years to the extent of about 3.8 feet. In the present discussion we are chiefly concerned with the fluctuations of Lake Erie, which control the discharge of Niagara river. From table No. 44, which gives the mean monthly elevations of Lake Erie at Buffalo for the years 1865–1898, inclusive, it appears that the highest mean monthly elevation during these years was for June, 1876, when the mean lake surface was 574.31 feet. The lowest mean monthly elevation for the period was for November, 1895, when the mean for the month was 570.49 feet. The range in the mean monthly elevations for this period was therefore 3.82 feet.

In regard to table No. 44 it is stated in the Report of the Board of Engineers on Deep Waterways that the uncertainty concerning the stability of the Buffalo gage previous to 1896, together with the excessive fluctuations of the lake level at Buffalo, appear to make the Cleveland gage record more reliable, and it has therefore been used in determining the mean monthly elevations of the lake.

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[1] These figures are derived from Mr Cooley's Lakes and Gulf Waterways, as corrected and given in the Journal of the Assoc. of Eng. Soc., Vol. VIII (March, 1889), p. 132.

TABLE NO. 44 — MEAN MONTHLY ELEVATIONS OF LAKE ERIE, 1865–1898, INCLUSIVE

YEAR	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1865	571.80	571.22	571.54	572.26	572.84	572.82	572.78	572.70	572.66	572.36	571.98	571.84	572.23
1866	571.57	571.41	571.80	572.38	572.60	572.86	572.97	572.72	572.66	572.65	572.41	572.42	572.37
1867	572.13	571.81	572.21	572.53	573.05	573.36	573.17	572.86	572.47	572.13	571.63	571.41	572.40
1868	571.21	570.83	571.42	572.25	572.70	573.09	573.06	572.54	572.27	571.82	571.66	571.45	572.02
1869	571.44	571.37	571.85	572.15	572.70	573.09	573.37	573.27	573.00	572.55	572.09	572.44	572.44
1870	572.68	572.91	572.68	573.33	573.54	573.51	573.55	573.50	573.25	572.87	572.57	572.45	573.07
1871	572.24	571.91	572.36	572.84	573.11	573.14	573.12	572.91	572.74	572.07	571.89	571.45	572.48
1872	571.37	571.13	571.04	571.24	571.68	572.05	572.04	572.01	571.78	571.61	571.28	571.05	571.52
1873	570.95	570.96	571.03	572.31	572.98	573.06	573.04	572.98	572.58	572.28	572.08	572.45	572.23
1874	572.84	572.89	572.92	573.09	573.18	573.25	573.28	573.12	572.66	572.22	571.80	571.59	572.74
1875	571.36	571.19	571.33	571.73	572.20	572.63	572.76	572.75	572.61	572.12	571.97	572.19	572.07
1876	572.15	572.71	573.36	573.88	574.20	574.31	574.20	573.90	573.73	573.20	573.28	572.94	573.49
1877	572.54	572.38	572.15	572.58	572.83	572.91	573.15	573.01	572.93	572.53	572.45	572.53	572.67
1878	572.61	572.75	572.88	573.30	573.56	573.56	573.56	573.32	573.19	572.84	572.64	572.72	573.08
1879	572.30	572.16	572.19	572.55	572.70	572.79	572.82	572.60	572.27	572.04	571.57	571.83	572.32
1880	572.33	572.37	572.51	572.67	572.94	573.05	573.14	572.90	572.67	572.23	572.15	571.81	572.56
1881	571.40	571.51	571.83	572.53	572.93	573.17	573.12	572.80	572.45	572.40	572.22	572.43	572.40
1882	572.90	572.90	573.35	573.57	573.77	573.92	573.85	573.71	573.44	572.99	572.67	572.16	573.27
1883	572.07	572.28	572.47	572.59	573.05	573.75	573.95	573.89	573.58	573.26	572.88	572.91	573.06
1884	572.58	572.84	573.03	573.58	573.85	573.93	573.71	573.55	573.12	572.79	572.31	572.24	573.13
1885	572.06	571.85	571.71	572.53	573.26	573.77	573.73	573.74	573.59	573.49	573.37	573.32	573.04
1886	573.34	572.61	572.42	573.30	573.60	573.70	573.68	573.47	573.23	573.00	572.59	572.64	573.13
1887	572.41	572.83	573.64	573.66	573.84	573.87	573.63	573.31	573.08	572.49	572.22	572.24	573.10
1888	572.06	571.79	571.89	572.52	572.77	572.90	573.05	572.95	572.51	572.14	572.20	572.08	572.40
1889	572.10	571.94	571.78	572.13	572.31	572.74	572.94	572.63	572.24	571.82	571.55	571.81	572.17
1890	572.17	572.46	572.58	573.07	573.41	573.78	573.40	572.96	572.77	572.58	572.55	572.32	572.84
1891	572.10	572.08	572.54	572.41	572.23	572.37	572.27	572.00	571.82	571.44	571.00	571.07	571.94
1892	571.10	570.89	570.93	571.49	572.29	573.05	573.17	572.82	572.50	571.94	571.61	571.34	571.93
1893	570.96	571.04	571.26	571.99	572.83	573.02	572.74	573.40	572.02	571.67	571.27	571.35	571.88
1894	571.63	571.51	571.54	571.94	572.33	572.63	572.52	572.15	571.98	571.66	571.42	571.35	571.89
1895	571.02	570.79	570.80	571.05	571.27	571.36	571.25	571.17	571.07	570.59	570.49	570.65	570.96
1896	570.75	570.67	570.62	571.07	571.45	571.72	571.60	571.81	571.49	571.25	570.88	570.91	571.19
1897	570.88	571.08	571.45	572.00	572.33	572.43	572.42	572.26	571.98	571.49	571.36	571.33	571.75
1898	571.38	571.58	571.84	572.42	572.57	572.60	572.38	572.18	571.80	571.60	571.48	571.31	571.93
Mean, 1865–1898, incl.	....	....	....	....	....	....	....	....	....	....	....	....	572.40

Temporarily, much greater fluctuations than indicated in the foregoing table have been experienced, due largely to wind action, to which Lake Erie, on account of its shallowness, and the fact that its general direction is favorable for the sweep of the prevailing winds, is peculiarly subject. In regard to the measurements of the Lake Survey, it may be remarked that they indicate large variations in discharge from all of the lakes, from the effects of winds and other disturbing causes, but give little clew to the quantities at either of the extremes of high or low water. According to Lyman E. Cooley the extreme low-water discharge is probably 20 to 30 per cent less than the Lake Survey figures, and extreme high water 20 to 30 per cent more.

Measurements of the amount of water flowing in Niagara river were begun in December, 1891, at a time when the water in Lake Erie was very low and the conditions were considered specially favorable for minimum discharge. The results are given in the Annual Report of the Chief of Engineers for 1893, part VI, pp. 4364–4371. The point selected was about 1000 feet below the International bridge at Black Rock, near the foot of Squaw island, at which point the river is free from eddies. Niagara river, on leaving Lake Erie, has a nearly straight channel about 2000 feet wide for the first 2 miles. The fall in this section is from 4 to 5 feet, and the velocity ranges from 7 miles per hour at the upper end to about 5 miles at the lower end. The point was chosen, after careful consideration, as the point in that vicinity least subject to disturbance. In taking the cross sections, the width, which varies slightly with different stages of the river, was accurately determined for gage readings 1 foot apart, and for extreme points the width was determined by interpolating values derived from the known slope of the river banks. A local gage was established at the draw pier of the International bridge by setting gage boards on each side of the pier, with the zeros of the gages on the same level. The local gage was read at the beginning and close of all velocity observations, and the gage at Buffalo was read at 7 a. m. and 1 and 7 p. m. The zero of this latter gage is at the mean level of Lake Erie, or 572.23 feet above mean tide at New York in the Erie canal levels, or as used by the government engineers, 572.96 feet. During the velocity observations in December, 1891, Lake Erie was about 1.5 feet below its mean level, and is stated not to have been seriously affected by strong winds. Still the daily record shows that there must have been some wind action. The current velocities were obtained after the methods used by the Mississippi River Commission and described in their reports, all velocity observations being taken with a current meter, with electrical appliances for recording the number of revolutions. The following are some of the results obtained:[1]

Date	Mean hight on local gage	Mean hight on Buffalo gage	Discharge per second
1891	Feet	Feet	Cu. feet
December 24	0.05	—2.95	164,648
December 14	0.65	—1.85	191,822
December 21	0.735	—1.75	193,522
December 20	0.835	—1.75	201,433
December 22	1.125	—1.45	208,597
December 10	1.33	—0.50	218,353
1892			
May 19	1.562	—0.80	213,180
May 7	1.750	—0.85	218,988
May 24	2.292	+0.15	236,762

The tabulation shows (1) a variation in lake elevations, as indicated in the Buffalo gage, from —2.95 on December 24, 1891, to +0.15 on May 24, 1892, a range of 3.10 feet; (2) a variation in discharge of 72,114 cubic feet per second. There are some discrepancies in the results which it is not necessary to discuss at length; but in the absence of more satisfactory data we may safely assume, in view of the foregoing evidence as to the small runoff of streams tributary to and in the vicinity of the Great Lakes, that the figures obtained in the fall of 1891 and spring of 1892, are more nearly correct than the larger figures of the Lake Survey. By plotting the observed discharges a mean discharge curve has been obtained, from which the discharge of the river at points within the range of the observation can be taken off, when one has the tabulated hights of the Buffalo gage before him. At present these measurements are, on the whole, not considered sufficiently

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[1] Annual Report of Chief of Engineers, United States Army, 1893, part VI, p. 4367.

exact to justify the labor of preparing a tabulation of this character.[1]

Referring to the tabulation on page 311, it is learned that the rainfall in that portion of the basin of the Great Lakes tributary to Niagara river was, for 1868, 523,420 cubic feet per second, and the evaporation from the water surface of the lakes tributary to Niagara river was 101,890 cubic feet per second. Hence the evaporation from the lake surfaces was nearly 20 per cent of the rainfall on the whole basin. Assuming for the moment the truth of these figures, we have 80 per cent of the total rainfall from which the land evaporation must be deducted before anything can run off. Again assuming the land evaporation at 1.70 feet, there results a loss from this source alone of 298,000 cubic feet per second; adding to this the evaporation loss from the water surfaces gives a total evaporation loss of 399,890 cubic feet per second. The runoff is the difference between rainfall and total evaporation losses. If, therefore, the land evaporation was 1.7 feet for the year 1868, the runoff would have been in reality only

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[1] There have been a number of independent measurements of volume of the Niagara, and though the results differ widely, they probably do not differ more than the actual volume of the river at various stages of Lake Erie.

Lyell (1841 ?) quotes Ruggles as authority for a volume of 250,000 cubic feet per second.

E. R. Blackwell, computed by Allen (Am. Jour. Sci., 1841), obtains 374,000 cubic feet per second. His work was afterwards recomputed by D. F. Henry, who obtained 244,797 cubic feet per second.

In the Annual Report of the Chief of Engineers, United States Army, for 1867-68, D. F. Henry gives as a result of observations in August and September, 1867, 242,494 cubic feet per second. A year later he recomputed from the same data, and obtained 240,192 cubic feet per second. He also made a new measurement by a different method (see report for 1868-69) from which he obtained two results, 304,307 and 258,586 cubic feet per second.

W. F. Reynolds (Annual Report of the Chief of Engineers, United States Army, 1870?), gives the result of observations from June to September, 1869, 212,860 cubic feet per second.

In the Annual Report of the Chief of Engineers, United States Army, for 1871, there is a mention of a result, without date of measurement, 245,296 cubic feet per second.

In the Annual Report of the Chief of Engineers, United States Army, for 1891-92, Quintus, as a result of gaging, gives the volume, reduced to mean stage, as 232,800 cubic feet per second.

Sir Casimir S. Gzowski, from continuous observations at the International bridge, 1870-1873, gives an average discharge for that period of 246,000 cubic feet per second.

123,330 cubic feet per second instead of 265,000 cubic feet per second, as determined by the Lake Survey. These figures, while not conclusive, are suggestive, so much so, indeed, that taking into account all the conditions it seems clear that in a series of years of minimum rainfall the runoff of the Great Lakes, tributary to Niagara river, may be as low as from 6 to 9 inches a year on the catchment. At the former figure the mean discharge would be about 177,700 cubic feet per second.[1]

As an additional source of loss from the Great Lakes the diversion of 10,000 cubic feet per second through the Chicago drainage canal to the headwaters of Illinois river may be referred to. Thus far the discussion of such loss has been mainly conducted on the supposition that the mean discharge of the Great Lakes at Niagara was about 265,000 cubic feet per second. If this were true the injurious effect of such diversion could only appear during a series of extremely dry years. The writer can not but think that this whole question of the runoff of Niagara river has become fogged by a discussion based thus far purely on averages. What we really want to know is the runoff of a cycle of dry years. With such data we can compute the effect of a given diversion more satisfactorily than when dealing with means.

With a cycle of rainfall years, either high or about the average very little effect from such diversion will be observed, the consensus of opinion at the present time apparently being that it will not exceed about 0.3 to 0.4 foot in depth over the areas affected. Owing to the balancing of conditions due to the pondage of the Great Lakes, and which requires years in order to complete a cycle, it is uncertain whether the abstraction of 10,000 cubic feet per second at Chicago would be specially detrimental at Niagara

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[1] By way of illustrating further the probable inaccuracy of the Lake Survey figures, it may be pointed out that if the determination of evaporation from the water surfaces at 101,890 cubic feet per second and runoff at 265,000 cubic feet per second for the year 1868 is correct, the total outgo from these two sources was 368,890 cubic feet per second, leaving the land evaporation for that year at 156,330 cubic feet per second, or at 0.9 foot over the catchment.

By studying the evaporation of the Upper Mississippi reservoirs, the Desplaines and Muskingum rivers, and other streams herein referred to, it will readily be seen that it is exceedingly improbable that a land evaporation as low as 0.9 foot ever occurred over the whole catchment of the Great Lakes.

Falls, although in years of extreme low flow it is probable that it would be apparent. If, however, the minimum flow of Niagara river is really as low as 150,000 to 180,000 cubic feet per second, it is clear that the loss of 10,000 cubic feet per second will be a matter worth taking into account.

In a paper on The Reservoir System of the Great Lakes of the St Lawrence Basin,[1] Col. Hiram M. Chittenden discusses many of the questions in regard to the runoff of the Great Lakes. This paper is accompanied by a Mathematical Analysis of the Influence of Reservoirs Upon Stream Flow, by Jas. A. Seddon, which elucidates many of the more pertinent facts affecting such flow.

In the discussion of the effect of diverting 10,000 cubic feet per second at Chicago on the levels of the Great Lakes, by Lyman E. Cooley, which appears in the Proceedings of the Annual Convention of the International Deep Waterways Association, held at Cleveland in September, 1895, it is stated that assuming the correctness of the figures derived from the Lake Survey placing the mean discharge of St Clair river at 225,000 cubic feet per second, the abstraction of 10,000 cubic feet per second would diminish the mean outflow in St Clair river by nearly 4.5 per cent and in Niagara river by about 3.75 per cent. Mr. Cooley says that, reasoning on lines obvious to those unacquainted with hydraulic principles, it is apparent that the ruling depth in the rivers at mean level can not be lessened by an amount greater than the percentages just stated; but if we consider the question as an hydraulic proposition, taking into account the relation of mean radius to area and perimeter, it is apparent that the effect on lake levels would be only a fraction of that indicated by the reduction in volume.

From September, 1897, to September, 1898, the Board of Engineers on Deep Waterways made an extended series of current meter measurements of the outflow of Niagara river. These measurements were made at the International railway bridge at Buffalo, and are the best thus far made. The minimum flow occurred in November, 1895, when the mean for the month was 177,852 cubic feet per second, and the mean for the whole year

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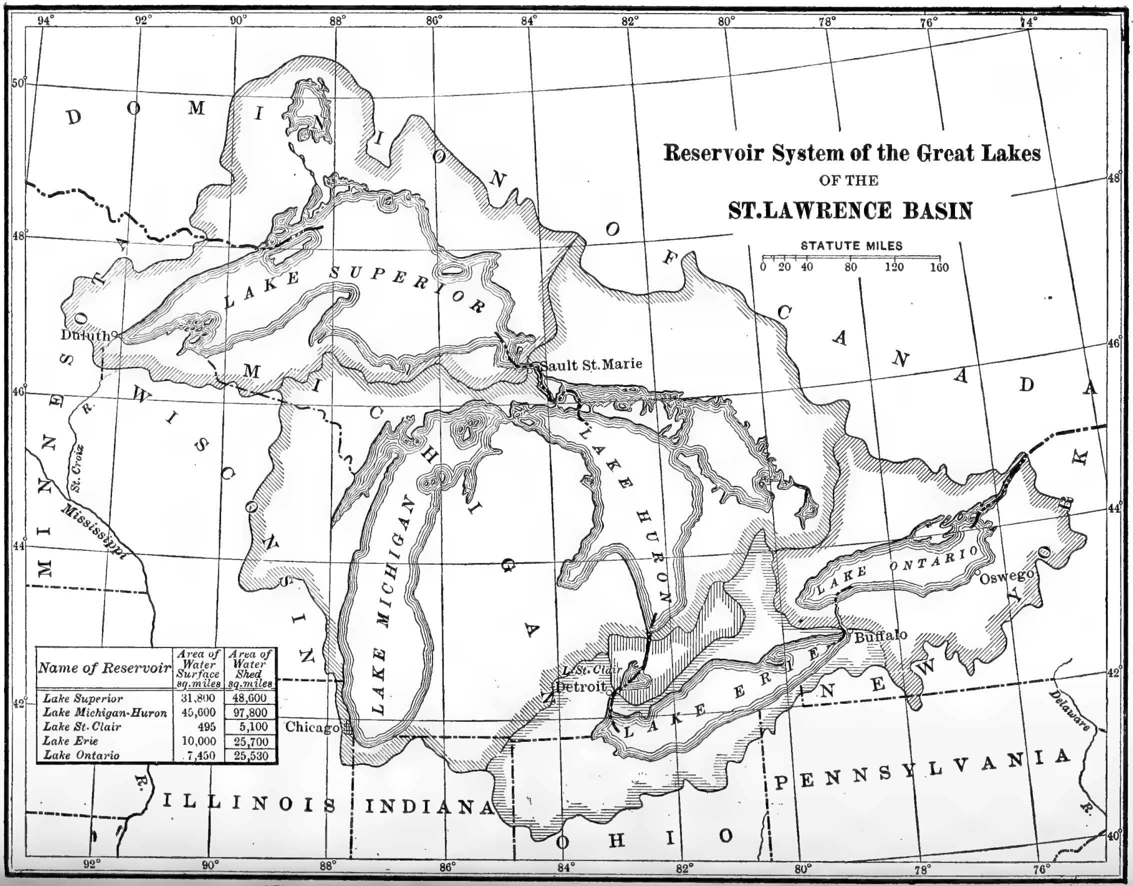
[1] Trans. Am. Soc. C. E., Vol. XL (Dec. 1898), pp. 355–448, inclusive.



Name of Reservoir	Area of Water Surface sq. miles	Area of Water Shed sq. miles
Lake Superior	31,800	48,600
Lake Michigan-Huron	45,600	97,800
Lake St. Clair	495	5,100
Lake Erie	10,000	25,700
Lake Ontario	7,450	25,530

Fig. 21 Map of the reservoir system of the Great Lakes.

was 187,255 cubic feet per second. Table No. 45, giving these discharges, has been constructed by substituting the mean monthly elevations of Lake Erie from the preceding table in the formula for discharge of Niagara river. It extends from 1865-1898, inclusive.

It will be noticed that on a preceding page the writer states that the mean discharge for a year may be as low as 177,700 cubic feet per second, or not exceeding about 6 inches in depth over the entire catchment area. For the year 1895 the mean discharge for the entire year was only 10,000 cubic feet per second in excess of this figure, but it is certain that 1895, while a low year, was not absolutely the minimum year. In view of the foregoing, it is believed that when properly used, intelligent analysis of rainfall, runoff and evaporation may be sufficient to settle such a question.

The literature of the discharge of Niagara river and of the probable effect on the lake levels of abstracting 10,000 cubic feet per second at Chicago has grown so extensive as to preclude further discussion here. Those wishing to pursue the subject may consult the references given in the footnote.

The following is a summary of the matter:

1) The studies of the Lake Survey indicate a mean discharge of Niagara river of about 265,000 cubic feet per second, with a range above and below the mean of from 20 per cent to 30 per cent.

2) The measurements made from December to May, 1891-92, indicate a minimum discharge as low, or even lower, than 141,000 cubic feet per second.

3) The measurements of the Board of Engineers on Deep Waterways, made in 1898-99, indicate a mean discharge from 1865-1898, inclusive, of 220,000 cubic feet per second, while for the year 1895 the mean for the whole year is only 187,000 cubic feet per second.

4) Based on theoretical considerations purely, the writer in 1897 estimated the minimum mean discharge for a series of dry years at 178,000 cubic feet per second, or at the rate of 6 inches in depth over the entire catchment area. The writer considers that this latter figure is more nearly right than any estimate

TABLE NO. 45.—MONTHLY DISCHARGES OF LAKE ERIE AT BUFFALO, 1865–1898, INCLUSIVE

YEAR (1)	Jan. (2)	Feb. (3)	Mar. (4)	Apr. (5)	May (6)	June (7)	July (8)	Aug. (9)	Sept. (10)	Oct. (11)	Nov. (12)	Dec. (13)	Mean for year (14)
	Cu. feet per sec'd	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*	*Cu. feet per sec'd*
1865	205,349	192,581	199,510	216,154	230,624	230,108	229,082	227,041	226,032	218,580	209,507	206,266	215,903
1866	200,174	196,659	205,349	219,068	224,518	231,139	233,997	227,551	226,032	225,780	219,803	220,049	219,176
1867	213,040	205,577	214,949	222,772	236,097	244,403	239,280	231,139	221,283	213,040	201,510	196,659	219,971
1868	192,368	184,528	196,877	215,912	227,041	237,151	236,361	223,021	216,395	205,806	202,182	197,533	211,229
1869	197,314	195,793	206,496	213,516	227,041	237,151	244,675	241,963	234,779	223,271	212,090	220,543	221,063
1870	226,536	232,432	226,536	243,587	249,349	248,517	249,627	248,239	241,425	231,397	223,770	220,790	236,850
1871	215,672	207,879	218,580	230,624	237,681	238,481	237,948	232,432	228,061	211,619	207,414	197,533	221,994
1872	195,793	190,685	188,812	193,007	202,632	211,149	210,913	210,207	204,894	201,062	193,858	189,019	199,336
1873	186,961	187,165	188,605	217,361	234,257	236,361	235,833	234,257	224,019	216,635	211,854	220,790	216,175
1874	230,624	231,913	232,692	237,151	239,813	241,425	242,233	237,948	226,032	215,190	205,349	200,617	228,416
1875	195,578	191,945	194,931	203,760	214,708	225,275	228,572	228,317	224,770	212,801	209,274	214,469	211,200
1876	213,516	227,296	244,403	258,942	268,268	271,542	268,268	259,514	254,670	240,079	242,233	233,214	248,495
1877	223,021	219,068	213,516	224,019	230,366	232,432	238,747	235,043	232,953	222,772	220,790	222,772	226,291
1878	224,770	228,317	231,655	242,771	249,905	249,905	249,905	243,315	240,079	230,624	225,527	227,551	237,044
1879	217,118	213,754	214,469	223,271	227,041	229,337	230,108	224,518	216,395	210,913	200,174	206,036	217,762
1880	217,849	218,824	222,273	226,284	233,214	236,097	238,481	232,171	226,284	215,431	213,516	205,577	223,833
1881	196,440	198,846	206,036	222,772	232,953	239,280	237,948	229,592	220,790	219,556	215,190	220,296	219,975
1882	232,171	232,171	244,131	250,182	255,803	260,092	258,084	254,103	246,590	234,518	226,284	213,754	242,324
1883	211,619	216,636	221,283	224,269	236,097	255,237	260,959	259,228	250,460	241,694	231,655	232,432	236,797
1884	224,019	230,624	235,570	250,460	258,084	260,381	254,103	249,627	237,948	229,337	217,361	215,672	238,599
1885	211,384	206,496	203,306	222,772	241,694	255,803	254,670	254,953	250,737	247,964	244,675	243,315	236,481
1886	243,859	224,770	220,049	242,771	251,015	253,820	253,259	247,415	240,887	234,779	224,269	225,527	238,535
1887	219,803	230,366	252,137	252,698	257,797	258,656	251,857	243,043	236,888	221,776	215,190	215,672	237,990
1888	211,384	205,121	207,414	222,522	228,827	232,171	236,097	233,475	222,273	213,278	214,708	211,854	219,928
1889	212,324	208,576	204,894	213,040	217,361	228,061	233,214	225,275	215,672	205,806	199,732	205,577	214,128
1890	213,992	221,036	224,019	236,624	245,766	256,086	245,491	233,736	228,827	224,019	223,271	217,605	230,873
1891	212,324	211,854	223,021	219,803	215,431	218,824	216,395	209,972	205,806	197,314	187,983	189,433	209,013
1892	190,055	185,737	186,552	198,407	216,877	236,097	239,280	230,108	222,023	208,576	201,062	195,146	209,160
1893	187,165	188,812	193,432	209,740	230,366	235,306	228,061	219,557	210,443	202,406	193,645	195,362	207,858
1894	201,510	198,846	199,510	208,576	217,849	225,275	222,522	213,516	209,507	202,182	196,877	195,362	207,628
1895	188,397	183,724	183,923	189,019	193,645	195,578	193,220	191,525	189,433	179,783	177,852	180,956	187,255
1896	182,930	181,348	180,368	189,433	197,533	203,533	200,838	205,577	198,407	193,220	185,536	186,143	192,072
1897	185,536	189,641	197,533	209 972	217,849	220,296	220,049	216,154	209,507	198,407	195,578	194,931	204,621
1898	196,009	200,395	206,266	220,049	223,770	224,518	219,068	214,231	205,349	200,838	198,188	194,500	208,600
Mean	....	....	....	....	....	....	....	....	....	....	....	....	220,428

thus far made. The reasons for this view may be derived from the preceding discussion of the runoff of Niagara river.[1]

St Lawrence river. According to the report of the Deep Waterways Commission, the area of the water surface of Lake Ontario is 7450 square miles, and the area of the tributary catchment, exclusive of the area of the lake itself, 25,530 square miles. The total area of the catchment basin, including both land and water surfaces, is 32,980 square miles. The area of the water surface of St Lawrence river from Gallops rapids to Montreal[2] is given at 220 square miles, and the area of the tributary catchment at 5710 square miles; hence the total area of the basin of the St Lawrence from Gallops to Montreal becomes 5930 square miles.

In the foregoing figures Lake Ontario is considered as beginning in Niagara river, at the foot of Niagara Falls and terminating at the head of Gallops rapids, whence the following subdivisions of water-surface area are derived; Niagara river, 5 square miles; Lake Ontario proper, 7260 square miles; St. Lawrence river, 185 square miles; giving a total, as above, of 7450 square miles.

Of the total area of catchment of 25,530 square miles, 14,275 square miles lie within the State of New York and 11,255 square

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[1] For literature of discharge of Great Lakes and allied questions see (1) reports Chief of Engineers, 1868, 1869, 1870, and 1882; (2) reports Chief of Engineers, 1893; (3) Eng. News, Vol. XXIX (March 2, 1893); (4) The Lakes and Gulf Waterways, by L. E. Cooley; (5) The Level of the Lakes as affected by the Proposed Lakes and Gulf Waterway, a discussion before the Western Society of Engineers, in Jour. of the Assn. of Eng. Socs., Vol. VIII (March, 1889); (6) An Enlarged Waterway Between the Great Lakes and the Atlantic Seaboard, by E. L. Corthell, with discussion, in Jour. of the Assn. of Eng. Socs., Vols. X and XI (April, June and December, 1891, and July, 1892); (7) Lake Level Effects on Account of the Sanitary Canal at Chicago, by L. E. Cooley, in Proceedings International Deep Waterways Convention, at Cleveland, September, 1895; (8) A Technical Brief, by Thomas T. Johnston, covered by the preceding reference; (9) papers by William Pierson Judson, on An Enlarged Waterway Between the Great Lakes and the Atlantic Seaboard, pamphlets, 1890 and 1893; (10) Report of Board of Engineers on Deep Waterways, Document 149, Fifty-sixth Congress, Second Session, House of Representatives (1900). Also (11), Report on The Regulation of Lake Erie, by George Y. Wisner. Document No. 200, Fifty-Sixth Congress, First Session, House of Representatives (1899). This latter report is also given in The Report of the Board of Engineers on Deep Waterways, as per reference (10).

[2] Report of U. S. Deep Waterways Commission, 1897, House Document No. 192, Fifty-fourth Congress, Second Session, pp. 151-153.

miles in the province of Ontario. The standard low-water elevation of Lake Ontario is taken as 244.53 feet, and the standard high-water elevation as 249.04 feet above tide.

St Lawrence river is considered as beginning at Gallops rapids. The following tabulation gives the elevation of water surface at a number of points.[1]

ELEVATION ABOVE TIDE OF LOW-WATER AND HIGH-WATER SURFACE OF ST. LAWRENCE RIVER

Locality	Standard low water. Feet	Standard high water. Feet
Ogdensburg	244.28	248.57
Lake St Francis, at Valleyfield	153.50	155.94
Lake St Louis, at Melicheville	70.0	77.50
Montreal	23.10	35.78

The area of water surface of the St Lawrence from Gallops rapids to Montreal is 220 square miles, and the total area of catchment not included in the surface of the river is 5710 square miles, of which 3800 square miles lie in New York, 620 in Ontario, and 1290 in Quebec. The total area of the catchment, including water surface of the river, is 5930 square miles.

The only measurements as to the discharge of St Lawrence river thus far made are those of the Lake Survey, which give a mean discharge of 300,000 cubic feet per second. The recent data would indicate that this figure is somewhat too large, as in the Lake Survey discharge of Niagara river. The streams tributary to Lake Ontario, however, issue from a region of heavier rainfall than those tributary to the Upper Great Lakes and, as shown by the runoff tables of this report, are generally much better water yielders. Taking everything into account, it is probable that the minimum discharge of St. Lawrence river will not be less than about 8 to 10 inches per year over the entire catchment area. A runoff of 12 inches per year would give a mean discharge of 234,300 cubic feet per second, or a discharge of 0.884 cubic foot per second per square mile. A mean discharge of 300,000 cubic

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[1] Report of U. S. Deep Waterways Commission, 1897, p. 152.

feet per second, as measured by the Lake Survey, gives 1.13 cubic feet per second per square mile.

These figures are for the minimum discharge—for years, or cycles of years, of average rainfall, the runoff will be more.

RUNOFF OF OTHER STREAMS OF NEW YORK

Aside from Niagara river, comparatively little definite information as to the runoff of streams in New York was available before 1898. Rather singularly, aside from gagings made by John B. Jervis in 1835 of Madison and Eaton brooks, the State of New York had never made any gagings, although one might suppose that in view of its development of an extensive canal system earlier than this it would have investigated this important branch of hydrology. The few streams gaged in New York before 1898 are as follows:

Streams gaged before 1898. Measurements of Croton river have been made by the City of New York since 1868. Measurements of Oatka creek, a tributary of Genesee river, were made for the Warsaw Waterworks Company from April, 1890, to November, 1892. Genesee river at Mount Morris was also gaged from September, 1893, to March, 1897, and this stream has been gaged at Rochester by the City Engineer from March, 1893 to 1904. Genesee river was also gaged for a short time at Mount Morris in 1890. Hemlock lake, a tributary of Genesee river, was gaged by the Rochester Waterworks for the years 1880–1891, inclusive. The Hudson river has been measured at Mechanicville from October, 1887, to 1904. A record of the water drained from Skaneateles lake has been kept by the Canal Department of the State for a good many years, but precise measurements have only been made since March, 1895, at which time a weir was established at Willow Glen, one and one-half miles below the foot of the lake. These measurements have been made by the city of Syracuse. The Normanskill, flowing into the Hudson river at Kenwood, was gaged at French Mills by the Water Department of Albany, from June 1, to December 1, 1891. Kinderhook creek was also gaged by the Albany Water Department at East Nassau and at Wilson's dam from July, 1893, until December, 1894. Quackenkill creek was gaged by the Troy Water Department from January to December,

1894. The west branch of Canadaway creek at Fredonia was gaged from July 18 to September 2, 1883, and Morris run, a tributary of Oatka creek, from July 4 to December 26, 1894. Gibson's creek, another tributary of Oatka creek, was also gaged from September 20,1894, to June 21, 1895. During the autumns of 1856 and 1857 gagings were made of the following streams on Long Island, which are now a part of the Brooklyn water supply, in order to obtain the minimum delivery: Hempstead, Rockville, Valley, Clear, Brookfield, Springfield and Jamaica brooks.

Possibly there are other measurements for short periods in the State of New York which have not been made public, but so far as the writer can learn the foregoing include all the systematic measurements of streams made in the State previous to 1898, except those by John B. Jervis, of Madison and Eaton brooks, made in 1835, the results of which are presented in Mr. Jervis' report for that year to the Canal Commissioners. The broad proposition is therefore true that previous to 1898 the data for computing runoff of streams based on careful measurements of the same were limited in the State of New York.

Rainfall records, however, were more common, and engineers were in the habit of assuming that about 50 per cent of the rainfall would appear as runoff in the streams. How far from true this is may be seen by inspecting the tables on the following pages. There was absolutely no preception of the fact that in the State of New York streams vary from a minimum runoff of 2 to 4 inches to 10 to 12 inches, and that average runoffs of from 8 to 10 inches to 20 to 25 inches are common.

Probably no one mistake of engineers has been more far-reaching than this. The great bulk of the earlier water supplies throughout the State are insufficient; power projects have been overestimated, and while there is no way of stating the amount of damage done, it may be easily assumed to rise to several million dollars. This oversight is purely one of the engineering profession, and the same kind of an oversight is taking place in many other states, in 1904. Indeed, comparatively few engineers fully realize the significance of gagings.

Streams gaged for Board of Engineers on Deep Waterways. In 1898 the writer undertook an investigation for the Board of Engineers on Deep Waterways as to possibilities of water supply for enlarged canals through the State of New York. The scope of this investigation was exceedingly broad. It showed that a water supply of from 1200 to 1600 cubic feet per second would be required for the proposed canal. This water, it was also found, must be drawn from some stream whose headwaters lay in the Adirondack plateau, which, so far as precise information in regard to its water resources was concerned, was practically an unknown land. In order to gain information as to the water yielding possibilities of the region, its flood flows, etc. the following gaging stations were established:

Stream	Gaging station	County	Catchment area, square miles
1. Seneca river	Baldwinsville	Onondaga	3,103
2. Oswego river	Fulton	Oswego	4,915
3. Chittenango creek	Bridgeport	Madison	307
4. Oneida creek	Kenwood	Madison	59
5. Wood creek	Near mouth	Oneida	127
6. W. Branch Fish creek	McConnellsville	Oneida	187
7. E. Branch Fish creek	Above Point Rock	Oneida	104
8. Salmon river	About one mile above falls	Oswego	191
9. Mohawk river	Ridge Mills	Oneida	153
10. Nine mile creek	One mile below Stittsville	Oneida	63
11. Oriskany creek	State dam, Oriskany	Oneida	144
12. Oriskany creek	Coleman	Oneida	141
13. Sauquoit creek	New York Mills	Oneida	52
14. W. Canada creek	Middleville	Herkimer	519
15. Mohawk river	Little Falls	Herkimer	1,306
16. E. Canada creek	Dolgeville	Herkimer	256
17. Garoga creek	Three miles above mouth	Montgomery	81
18. Cayadutta creek	Below Johnstown	Fulton	40
19. Schoharie creek	State dam, Fort Hunter	Montgomery	947
20. Mohawk river	Rexford Flats	Saratoga	3,385
21. Hudson river	Mechanicville	Saratoga	4,500
22. Hudson river	Fort Edward	Saratoga	2,800
23. Schroon river	Warrensburg	Warren	563
24. Black river	Huntingtonville	Jefferson	*1,889

Of the foregoing stations, those on Hudson river at Mechanicville, Hudson river at Fort Edward, and Schroon river at Warrensburg had been established, in 1895, in connection with the Upper Hudson storage surveys. The station on Black river at Huntingtonville had been established in March, 1897, by the Watertown Waterworks, the data of which were furnished by the Board of Water Commissioners of the city of Watertown. Aside from these four stations, the foregoing were established in 1898 in connection with the deep waterways work.

Streams gaged by United States Geological Survey. The following is a list of the stations in New York State where gagings were

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*Some of these areas are approximate only, due to the inaccuracy of available maps.

kept in 1902 together with a few at which gagings were not kept. Those at which gagings were not kept are marked thus +.

Stream	Gaging station	County	Catchment area, square miles
1. Beaver river	Tisse's Bridge	Lewis	242
2. Black river	Felt's Mills	Jefferson	1,851
3. Black river	Huntingtonville dam	Jefferson	1,889
4. Black river	Watertown	Jefferson	1,892
5. Byram river, W. branch	Portchester	Westchester	——
6. Catskill creek	South Cairo	Greene	——
7. Cayadutta creek	Johnstown	Fulton	40
8. Chenango river	Binghamton	Broome	1,582
9. Chittenango creek+	Bridgeport	Madison	307
10. Chittenango creek	Chittenango	Madison	77
11. Croton river	Croton dam (old)	Westchester	339
12. Delaware river	Port Jervis	Orange	3,600
13. E. Branch Delaware R.	Hancock	Delaware	919
14. W. Branch Delaware R.	Hancock	Delaware	685
15. East Canada creek	Dolgeville	Herkimer	256
16. Esopus creek	Kingston	Ulster	312
17. Fishkill creek	Glenham	Dutchess	198
18. W. Branch Fish creek	McConnellsville	Oneida	187
19. Genesee river	Rochester	Monroe	*2,365
20. Honeoye creek	East Rush	Monroe	——
21. Hudson river	Fort Edward	Saratoga	2,800
22. Hudson river	Mechanicville	Saratoga	4,500
23. Indian river	Indian Lake dam	Hamilton	146
24. Kinderhook creek+	East Nassau	Rensselaer	121
25. Kinderhook creek+	Wilson's dam	Rensselaer	68
26. Lake Champlain outlet	Fort Montgomery	Clinton	7,750
27. Mianus river	Bedford	Westchester	——
28. Mohawk river	Dunsbach Ferry	Saratoga	3,440
29. Mohawk river	Little Falls	Herkimer	1,306
30. Mohawk river	Rexford Flats	Saratoga	3,385
31. Mohawk river	Ridge Mills	Oneida	153
32. Mohawk river	Schenectady	Schenectady	3,321
33. Mohawk river	Utica	Oneida	500
34. Moose river	Moose river	Lewis	346
35. Neversink river	Port Jervis	Orange	346
36. Normanskill	French's Mill	Albany	111
37. Oneida creek	Kenwood	Madison	59
38. Oneida river	Brewerton	Onondaga	——
39. Oneida river	Oak Orchard	Onondaga	1,313
40. Oriskany creek	Oriskany State dam	Oneida	144
41. Oswego river	Fulton	Oswego	4,916
42. Oswego river	High dam	Oswego	5,000
43. Oswego river	Minetto	Oswego	4,990
44. Quackenkill creek	Quackenkill	Rensselaer	19
45. Raquette river	Hannawa Falls	St. Lawrence	967
46. Reels creek	Utica	Oneida	——
47. Richelieu river	Fort Montgomery	Clinton	7,750
48. Rondout creek	Honk Falls	Ulster	88
49. Rondout creek	Rosendale	Ulster	365
50. Sauquoit creek	New York Mills	Oneida	52
51. Salmon river	Pulaski	Oswego	264
52. Seneca river	Baldwinsville	Onondaga	3,103
53. Schoharie creek	Fort Hunter dam	Montgomery	947
54. Schoharie creek	Mill Point	Montgomery	934
55. Schoharie creek	Prattsville	Greene	243
56. Schoharie creek	Schoharie Falls	Montgomery	930
57. Schroon river	Warrensburg	Warren	563
58. Skaneateles outlet	Willow Glen	Onondaga	74
59. Susquehanna river	Binghamton	Broome	3,982
60. Ten Mile river	Dover Plains	Dutchess	195
61. Wallkill river	New Paltz	Ulster	736
62. West Canada creek	Twin Rock bridge	Oneida	352

Methods of gaging pursued. The method of gaging pursued at these several stations varies considerably. At one or two small stations sharp-crested weirs are used; at other places the flow is gaged over dams, while at a number of stations the current meter

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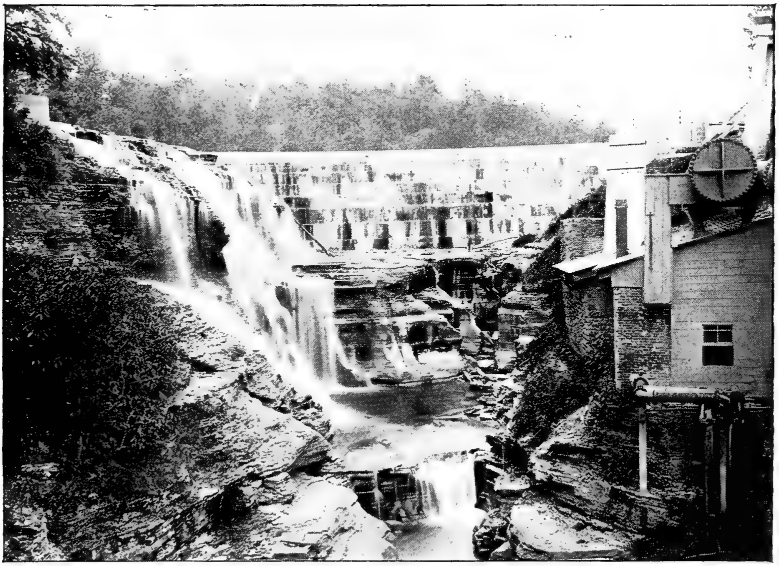
This does not include the catchment of Hemlock lake of 43 square miles.

Plate 5.



General view of hydraulic laboratory of Cornell university.

is employed. Gagings are also sometimes made by the use of floats, but so far as New York streams are concerned, the results would be so unsatisfactory as to render this method undesirable. It has also been attempted to gage the flow of the Mohawk river by velocity and slope measurements, but thus far the results are not satisfactory.

The method of gaging streams by the use of the current meter has some advocates who consider it superior to any other. Probably the reason for such an opinion is that tests of a current meter in uniform masonry or concrete channels, where the conditions are the most favorable possible to obtain, have shown fairly accurate results; but in a shallow stream, flowing over a boulder bed, the conditions are so different as to make rational comparison impossible. The current meter is indeed only really useful when the following conditions obtain:

1) A smooth, uniform channel for a considerable distance on either side of the point selected.

2) Considerable depth at the point selected and for several hundred feet to either side.

3) Smooth bottom of either fine sand, hard earth or very fine gravel.

4) That the current be positive and of some little velocity throughout the whole section.

New York streams as a whole do not, except rarely, answer to these conditions. They are usually shallow, rapid flowing in places, and frequently encumbered with boulders. Current meter observation may be at times from 100 per cent to 200 per cent in error. Broadly, we may say therefore that where a good dam exists on a stream the gagings should preferably be first of all made at this point. Or, if there is money available, a special weir may be erected. Failing in either of these the current meter is a proper instrument, with due understanding of the limitations indicated in the foregoing.

Streams discussed in this report. It is impossible to give in the following discussion the measurements of all the streams now being gaged in the State of New York, and accordingly a number of the more important have been selected for which the records will be given. The detail of the balance may be obtained from the

Annual Reports of the State Engineer and Surveyor. The following are the streams discussed in this connection:

Genesee river.
Oatka creek.
Hemlock lake.
Oswego river.
Seneca river.
Skaneateles outlet.
Chittenango creek.
Black river.
Hudson river.
Croton river.
Mohawk river.
East Canada creek.
West Canada creek.
Sauquoit creek.
Oriskany creek.
Schroon river.
Richelieu river—Outlet of Lake Champlain.

Of the foregoing, Hemlock lake has been gaged by weir and measurements of the amount flowing through the conduit leading therefrom to the city of Rochester; Skaneateles outlet has been gaged by weir and the amount flowing through conduit; Lake Champlain outlet by rating curve, and Eaton and Madison brooks by weir. The balance of the streams have been gaged by measurements over dams, in accordance with the method described (1) in the Report to the Board of Engineers on Deep Waterways; and (2) in the paper On the Flow of Water Over Dams.

Gagings over dams and through water wheels. Before proceeding to describe these gagings we will consider somewhat the methods used. Several of these gaging stations, as at Baldwinsville, High dam, Little Falls, Middleville, Dolgeville, etc. have extensive power developments, with large quantities of water passing through turbine water wheels for either the whole or a portion of each day. The dams at these places vary greatly in type form. Hardly any two cross-sections are alike, although some of them conform generally to certain types. Many of them have considerable irregularity in the crests longitudinally. The method of treatment in order to obtain approximately correct results becomes, therefore, a matter of difficulty. In some cases, as on West Canada creek, where the crest was very irregular, a small amount of work has been done in the way of leveling it. Generally, however, the crests were left in nearly the same condition as found. A profile was carefully taken and the crest divided into a series of approximately level sections for computation. A gaging blank was furnished the gage readers, with columns for entering depth on crest of dam, and number of water wheels used, size of same, name of manufacturer and daily

Plate 6.

Experiment on model of Rexford Flats dam at Cornell university, June 3, 1899.

run, working head on wheels, readings of head-race and tail-race gages, and other information necessary for keeping an accurate account of the water passing over the crest in 24 hours, as well as through water wheels for the same period. Gage readers were employed to take these readings twice each day.

In order to obtain flows through water wheels, recourse was had to records of the test flume of the Holyoke Water Power Company of Holyoke, Mass., where the principal wheels now in common use in New York State have, at one time or another, been tested. On requesting a record of such tests, as applying to wheels at the several gaging stations, the Holyoke Water Power Company responded that they would furnish the records under the condition that they be not published unless the consent of parties for whom the wheels had been tested were first obtained. This condition being assented to, information was furnished as to tests of the principal wheels in use, giving proportional part of opening of speed gate for various conditions of tests, revolutions of wheel, quantity of water discharged, power developed, efficiency, etc. From these records, wheel-discharge curves have been prepared for the water wheels in use at each dam. By the use of such curves, derived from actual tests, it is believed that the discharges through turbine water wheels at the various gaging stations have been computed with a very high degree of accuracy. Under these conditions turbine water wheels become in effect efficient water meters. In a few cases, where there were no tests applying, the discharges as per manufacturers' tables have been used. The writer's thanks are due to the Holyoke Water Power Company for the courtesy of furnishing these useful data.

The work of Henry Bazin. In order to apply the results of these gagings, the work of Henry Bazin, *Inspecteur General des Ponts et Chaussées,* which may be found in *Annales des Ponts et Chaussées,* for the years 1888, 1890, 1891, 1894, 1896 and 1898, is used. In these papers Bazin has determined coefficients for a large number of cases, not only of crests of different widths, but with varying front and rear slopes, as well as for curved profiles. Indeed, taking into account the backward state of knowledge of flow over weirs, his work is in many respects revolutionary.

In the beginning of his first paper Bazin remarks that the theory of the weir is the least advanced of all branches of hydraulics. The coefficients used in practice vary between such wide limits that in most cases we are unable to make a rational selection from the many numerical values assigned to them.

The problem, he says, is in fact a complicated one, being connected on the one hand with the theory of flow through orifices and on the other with that of open channels. The value of the coefficients in each case is influenced by many elements. Thus we ought to consider:

1) The velocity of approach; that is, the velocity with which the upstream water reaches the weir, the effect of which can not be neglected in weirs of small hight.

2) The contraction of the vertical section of the stream at the weir, the amount depending upon the hight of the weir and the form of the crest.

3) The lateral contraction which, though unimportant in weirs of great length, seriously modifies the results in shorter weirs.

As a further condition, Bazin points out that when the downstream channel has a width of the length of the weir, so that the overflowing sheet of water, or nappe, touches at the sides, thus preventing free admission of air under the nappe, there occur special phenomena greatly affecting the flow.[1]

Bazin's method of experimentation may be referred to briefly. A standard weir was set up at the head of a long chamber, in which the actual volume passing over was measured a sufficient number of times to give averages, which Bazin considers are accurate to within probably less than 1 per cent. Having established in this way the values of the coefficients for a standard weir, with heads varying from about 0.164 ft. to 1.969 ft., the experiments on weirs of irregular profiles were made by placing

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[1] Bazin's earlier papers are directed specially to a detailed investigation of these several points. Space will not be taken here to describe his experiments in detail. The original data may be found in the *Annales des Ponts et Chaussées* for the years already cited. A translation of the earlier numbers has also been made by Messrs. Arthur Marichal and John C. Trautwine Jr., and may be found in the Proceedings of the Engineers' Club of Philadelphia for January, 1890; July, 1892; October, 1892, and April, 1893.

Plate 7.

Another view of the hydraulic laboratory at Cornell university.

each experimental weir below the standard weir, and observing the heads synchronously on each. In these experiments a steady current was established in the channel, and observations of the known value passing over the standard weir were made, which volume also passed over the weir under investigation, lower down.

If we let H and h denote, respectively, the head upon the standard weir and upon the lower weir, L and l, their corresponding lengths, and M and m, the coefficients of discharge, and then, adopting provisionally Formula (1) for the standard weir—

$$Q = MLH \sqrt{2g\,H}; \qquad (32)$$

and similarly for the lower weir

$$Q = m\,l\,h \sqrt{2g\,h} \qquad (33)$$

Equating these two values of Q, we have

$$MLH\sqrt{H}\sqrt{2g} = m\,l\,h\sqrt{h}\sqrt{2g}, \text{ or}$$

$$MLH^{\frac{3}{2}} = m\,l\,h^{\frac{3}{2}}$$

from which we deduce the value of m:

$$m = M\left(\frac{L}{l}\right) \times \left(\frac{H}{h}\right)^{\frac{3}{2}} \qquad (34)$$

or, conversely :

$$M = m\left(\frac{l}{L}\right) \times \left(\frac{h}{H}\right)^{\frac{3}{2}} \qquad (35)$$

As already stated, Bazin's preliminary gaging operations gave, once for all, the coefficient M for the standard weir for each value of H. The ratio $\frac{L}{l}$ which is very nearly unity, remained constant for all experiments of any one series, and, therefore, we have only to measure the heads H and h in order to obtain the coefficient m.[1]

A description of the method of gaging pursued on the several streams is not given at length here because it may be found in full detail in the places cited, namely, in the Report to the Board of Engineers on Deep Waterways and in the paper On the Flow of Water Over Dams, to either of which reference may be made.

Discharge measurements of Genesee river. The runoff data of Genesee river for the water years 1890-1898, inclusive, in inches on the catchment area, have been given in table No. 43. The

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[1] On the Flow of Water Over Dams, Trans. Am. Soc. C. E., Vol. XLIV, pp. 220-398.

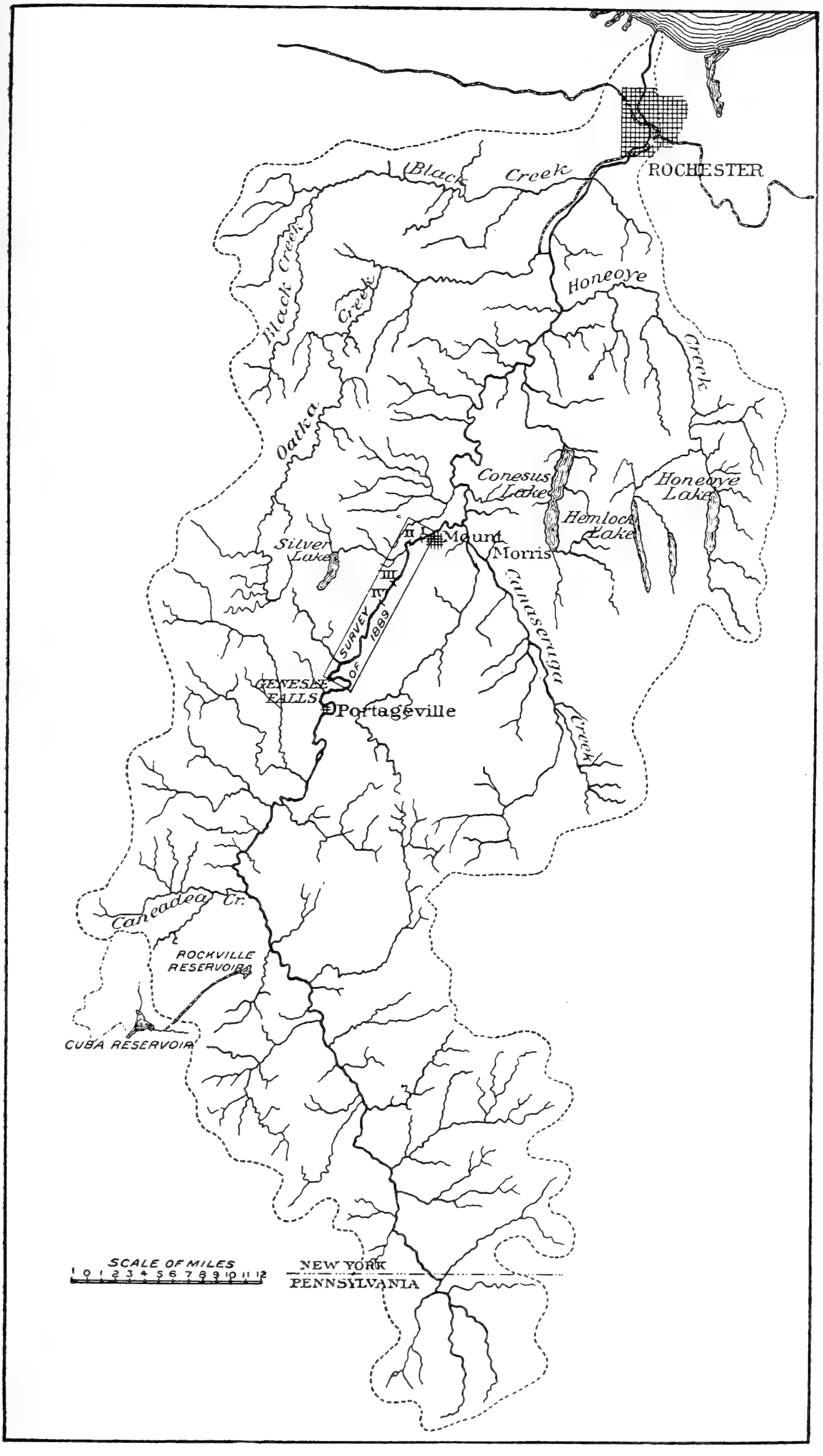
runoff in cubic feet per second is given in table No. 46. Runoff of Genesee River at Mount Morris for the water years 1890-1898, inclusive, in cubic feet per second per square mile is given in table No. 47.

TABLE NO. 46—RUNOFF OF GENESEE RIVER AT MOUNT MORRIS FOR THE WATER YEARS, 1890–1898, INCLUSIVE

(Catchment area = 1070 square miles)

MONTH	IN CUBIC FEET PER SECOND									
	1890	1891	1892	1893	1894	1895	1896	1897	1898	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
December	.....	888	965	1,346	2,170	568	1,226	733	882	.....
January	.....	2,393	724	1,810	1,297	604	436	724	1,810	.....
February	.....	3,474	1,624	1,325	884	224	907	812	1,900	.....
March	.....	2,663	1,803	2,144	3,074	1,803	2,786	2,459	2,552	.....
April	2,046	1,312	2,119	2,397	3,245	1,927	3,245	1,256	1,582	.....
May	2,895	579	1,624	2,413	4,108	174	157	919	1,160	.....
Mean of storage period	.....	1,860	1,471	1,913	2,485	889	1,456	1,150	1,644	1,609
June	1,794	425	1,352	336	1,050	128	374	422	767	.....
July	1,776	347	1,912	278	132	105	226	427	418	.....
August	270	232	1,327	325	200	115	188	408	742	.....
Mean of growing period	1,280	334	1,532	313	454	116	261	419	641	509
September	1,274	425	230	316	888	100	148	173	464	.....
October	2,084	232	306	373	407	104	1,664	167	724	.....
November	2,007	386	547	518	782	449	782	355	1,342	.....
Mean of replenishing period	1,788	346	360	402	689	216	873	231	842	495
Yearly mean	.....	1,098	1,210	1,133	1,525	526	1,011	737	1,191	1,054

Plate 8.



Catchment area of Genesee river.

TABLE No. 47—RUNOFF OF GENESEE RIVER AT MOUNT MORRIS FOR THE WATER YEARS, 1890–1898, INCLUSIVE

(Catchment area = 1070 square miles)

MONTH	IN CUBIC FEET PER SECOND PER SQUARE MILE									
	1890	1891	1892	1893	1894	1895	1896	1897	1898	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
December	.....	0.83	0.90	1.26	2.03	0.53	1.15	0.69	0.82	.....
January	.....	2.24	0.68	1.70	1.21	0.56	0.41	0.68	1.69	.....
February	.....	3.25	1.52	1.24	0.83	0.21	0.85	0.76	1.78	.....
March	.....	2.49	1.68	2.00	2.87	1.69	2.60	2.30	2.39	.....
April	1.91	1.23	1.98	2.24	3.03	1.80	3.03	1.17	1.47	.....
May	2.71	0.54	1.52	2.26	3.84	0.16	0.15	0.86	1.08	.....
Mean of storage period	.....	1.74	1.37	1.79	2.32	0.83	1.36	1.07	1.54	1.50
June	1.68	0.40	1.26	0.31	0.98	0.12	0.35	0.39	0.72	.....
July	1.66	0.32	1.79	0.26	0.12	0.10	0.21	0.40	0.39	.....
August	0.25	0.22	1.15	0.30	0.19	0.11	0.18	0.38	0.69	.....
Mean of growing period	1.20	0.31	1.43	0.29	0.42	0.11	0.25	0.39	0.60	0.48
September	1.19	0.40	0.21	0.30	0.83	0.09	0.14	0.16	0.43	.....
October	1.95	0.22	0.28	0.35	0.38	0.10	1.56	0.16	0.68	.....
November	1.88	0.36	0.51	0.48	0.73	0.42	0.73	0.33	1.75	.....
Mean of replenishing period	1.67	0.32	0.34	0.38	0.64	0.20	0.82	0.22	0.79	0.46
Yearly mean	.....	1.03	1.13	1.06	1.43	0.49	0.94	0.69	1.11	0.99

This record of Genesee river is made up as follows: From April, 1890, to November, 1892, actual gagings of Oatka creek, above the village of Warsaw, with a catchment area of 27.5 square miles, have been used. From December, 1892, to August, 1893, inclusive, gagings were not kept of Genesee river, and accordingly for this period the runoff is approximately computed from the rainfall. September, 1893, to February, 1897, inclusive, the record is that of Genesee river at Mount Morris (catchment, 1070 square miles). Early in March, 1897, the dam over which the gagings were made was carried away by a flood and the record for the balance of that year and for the year 1898 is deduced from the record at Rochester (catchment, not including Hemlock lake, water supply of the city of Rochester, 2365 square miles).

In 1896 a sharp-crested weir was erected on Genesee river about two and one-half miles above the gaging dam, where rock bottom clear across the river afforded an opportunity for such construction without heavy expense. This weir was made perfectly tight.

H=head-on weir, in feet (1)	*h*=head-on dam, in feet (2)	Computed discharge over weir, in cubic feet per second, for heads=*H* (3)	Computed discharge over dam, in cubic feet per second, for heads=*h* (4)	Percentage difference in discharges (5)
0.50	0.60	185	135	—37.0
0.70	0.83	310	330	+ 6.0
0.80	0.90	450	445	— 1.0
1.02	1.00	540	505	— 7.0
1.86	1.55	1 325	1 260	— 5.0
2.01	1.75	1 490	1 605	+10.0
2.42	2.00	1 965	2 100	+ 7.0
2.65	2.50	2 250	3 230	+44.0
3.20	2.75	2 990	3 860	+29.0
3.78	3.00	3 840	4 554	+19.0
4.37	3.25	4 770	5 280	+11.0
4.65†	3.35†	5 240	5 590	+ 7.0

In order to correlate the measurements at the Hydraulic Power Company's dam with those at the weir, observations were taken at each place as nearly cotemporaneously as they could be made by a man going immediately from one to the other. The foregoing tabulation gives some of the heads actually observed at the weir and dam, together with the discharge over the weir in comparison with the computed discharge over the dam, and the percentage difference.

The crest of the Mount Morris dam was quite irregular, and in order to apply weir formulas an accurate profile was taken and the crest subdivided into a number of approximately level sections with each section computed separately, advancing by 0.1 foot up to 10 feet. The flow over the entire dam was obtained by adding together the sums of the several sections at the corresponding hights and tabulating them. A gage graduated to 0.05 foot was erected on the river bridge a short distance away, with its zero level coinciding with the lowest point of the dam. During ordinary stages of the river, readings of this gage were taken twice each day, but in time of high water, in order to obtain the movement of floods as accurately as possible, readings were taken several times a day. In order to compute the flow readily a curve was projected from which, with the given gage hights, the flows in cubic feet per second could be read off.

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† Approximate; taken from curve.

When the measurements were first begun, it was considered that the formula $Q=1142\ H^{\frac{3}{2}}$ was best suited to the form of the dam, but after more careful consideration it was apparent that the results given by this formula were somewhat in excess of the actual discharge, specially for the low-water flows. The computed discharges, as shown by columns (3) and (4) of the preceding tabulation, are somewhat irregular. This result is due to the disturbing effect of the irregular sections of the crest, the highest point of which was 2 feet above the lowest.

Column (5) shows the percentage variations between the discharges as determined by a sharp-crested weir, up to 5200 cubic feet per second, and the discharges computed by the formula. For discharges beyond 5000 cubic feet per second the original determination has been used. An extension of the plotted curves shows that some little distance above 5000 cubic feet per second discharge, the results of the two methods are substantially the same. The two curves crossed at the point of about 6000 cubic feet per second discharge. For discharges above 10,000 or 15,000 cubic feet per second there is probably an error in the results of from 5 to 10 per cent. Below 5000 cubic feet per second it is believed that the results are now accurate within a few per cent. Francis's formula, $Q=3.33\ L\ H^{\frac{3}{2}}$, has been used for the weir computations.

The measurements taken previously to the construction of the weir and the rating of the dam, have all been corrected to conform to the new determinations; hence all the data of the Genesee measurements of this table may be considered as accurate within the limits stated.

The original Genesee river data show for a portion of the range more error than is consistent with good work, and which remained inexplicable until the experiments at Cornell University were carried out. These experiments showed that for high heads the tendency was to neutralize the differences at lower heads. The flow of all the weirs, in short, became sensibly uniform at from 5 to 6 feet depth and at 10 feet depth, there will be very little difference.[1]

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[1] Ten feet depth on the crest is not unusual in flood flows. In order to measure such flows, a weir formula should be worked out to at least 10 feet depth on the crest. Such a formula will apply without more than 15 per cent to 20 per cent error to almost any form of crest.

The preceding discussion shows that while the Genesee river record is a composite one, nevertheless it is believed to be a good record. The reason for this belief is largely founded on the curve as per fig.11.

Gagings have also been kept at Mount Morris from June to December, 1890, and at Rochester from March, 1893, to the present time, but the gagings at Rochester are not very reliable. Possibly some method of correcting them may be worked out in the future.

In table No. 48, a comparison has been made of the measurements at Rochester with those at Mount Morris for the water years 1894-1896, inclusive.

TABLE NO. 48—COMPARISON OF ORIGINAL AND CORRECTED RECORD AT ROCHESTER WITH REDUCED RECORD AT MOUNT MORRIS 1894 TO 1896, INCLUSIVE

[In cubic feet per second]

MONTH	1894			1895			1896		
	As per record	Corrected	Estimated from measurements at Mount Morris[a]	As per record	Corrected	Estimated from measurements at Mount Morris[a]	As per record	Corrected	Estimated from measurements at Mount Morris[a]
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	3,914	3,914	4,797	1,459	1,100	1,256	1,839	1,700	2,710
January	2,841	2,841	2,867	1,619	1,200	1,335	1,645	1,400	964
February	2,584	2,584	1,954	977	700	495	2,702	2,702	2,005
March	6,008	6,008	6,794	4,035	4,035	3,985	3,725	3,725	6,158
April	5,646	5,646	7,172	3,083	3,083	4,257	7,623	7,623	7,172
May	6,304	6,304	9,080	1,309	900	385	1,576	1,300	347
Mean of storage period	4,576	4,576	5,477	2,099	1,848	1,958	3,181	3,054	3,218
June	2,951	2,800	2,321	885	535	283	1,317	1,000	654
July	1,055	792	292	645	390	232	854	645	501
August	973	732	442	600	400	254	585	440	416
Mean of growing period	1,656	1,426	1,003	728	440	256	977	692	522
September	1,664	1,500	1,963	407	250	221	324	240	327
October	1,226	920	899	366	220	230	2,271	2,000	3,667
November	1,782	1,600	1,729	834	500	993	993	745	1,728
Mean of replenishing period	1,573	1,335	1,523	534	333	478	1,353	1,006	1,926
Yearly mean	3,088	2,978	3,370	1,364	1,116	1,163	2,174	1,951	2,220
Inches on catchment	19.20	18.35	19.38	8.48	6.41	6.67	12.48	11.20	12.80

[a] Increased in proportion to increased catchment area at Rochester

Geologically, the catchment area of the Genesee river above Mount Morris lies in the shales, sandstones, etc. of the Portage and Chemung groups. Its extreme headwaters south of the Pennsylvania line issue from the Carboniferous. Generally the soils throughout the whole basin are heavy and tenacious, inclining to clay. Their capacity for absorbing and retaining water must therefore be considered small.

Discharge measurements of Oatka creek. The measurements of Oatka creek, referred to in the preceding, were made at the milldam in the south part of the village of Warsaw, in Wyoming county. The dam was new, practically tight, and well adapted for securing accurate results. Measurements were also made of the outflow of the head raceway leading from the dam for different elevations of water on the dam, and a curve prepared from which the discharge of the raceway was read off and added to the discharge over the dam.

The catchment area of Oatka creek above Warsaw includes 27.5 square miles of rolling, semi-mountainous country. The valley of the creek is deep cut, with numerous springs at the headwaters. The catchment is mostly deforested and in a high state of cultivation, the soil inclining to clay for a considerable portion. Geologically the stream lies in the rocks of the Portage formation, as developed in western New York. The runoff from this area may be taken as typical of many small streams in western New York.

Discharge measurements of Hemlock lake. Measurements of the runoff of the Hemlock lake area for the water years 1880 to 1884, inclusive, were made by the Rochester Waterworks. Hemlock lake lies at an elevation of 896 feet above tide, and has a length of 6.5 miles, with an average width of about 0.5 of a mile. The area of the surface at low water is 1828 acres. The total catchment, including the area of the lake, is 27,554 acres, or about 43 square miles. The shores are bold, and on the east side rise to a hight of several hundred feet above the lake in a distance of 2 or 3 miles. At the head of the lake there is a swamp of 118 acres, partially covered at high water.

The outflow of the lake during the period covered by the measurements included in the following table may be considered as having taken place at three points: (1) At the natural outlet of the lake; (2) at an artificial channel through which water was discharged at will for the benefit of the millers on the outlet; and (3) through the conduit of the Rochester Waterworks. The runoffs given are the sums of these several outgoes. In order to determine the outflow of the natural outlet, a weir was constructed and the discharge observed at different hights of the lake surface. The discharge into the artificial channel was through submerged orifices of known dimensions, and has been computed from standard formulas for the discharge of such orifices, the size of the openings and the difference of level of water surfaces above and below being known.

The discharge of the conduit of the Rochester Waterworks is as computed from standard formulas for discharge through pipes. Measurements made by the writer and others during the last few years show that the computed quantities passing through the conduit were not far from correct.

TABLE NO. 49—WATER DRAWN FROM HEMLOCK LAKE FOR THE WATER YEARS 1880 TO 1884, INCLUSIVE

[In inches on the catchment]

MONTH	1880					1881				
	Mean monthly elevation of lake surface	Rainfall	Water drawn	Rainfall less the water drawn	Temperature	Mean monthly elevation of lake surface	Rainfall	Water drawn	Rainfall less the water drawn	Temperature
(1)	(2)	(3)	(4)	(5)	(6)	(2)	(3)	(4)	(5)	(6)
December	—1.67	1.26	0.16	......	*a*31.4	—1.33	0.72	0.49	......	27.3
January	—0.91	1.37	0.15	......	*a*25.5	—1.47	2.24	0.44	......	24.7
February	—0.11	1.45	0.16	......	*a*27.3	—0.11	1.08	0.54	......	29.7
March	+0.21	1.47	0.15	......	*a*31.8	+1.20	1.92	1.73	......	39.1
April	+0.79	1.25	0.15	......	*a*45.7	+1.47	0.52	1.24	......	45.2
May	+0.87	2.08	0.17	......	71.8	+1.32	2.23	1.11	......	69.7
Storage period	—0.14	8.88	0.94	7.94	38.9	+0.18	8.71	5.55	3.16	39.3
June	+0.45	1.66	0.36	......	76.5	+1.08	3.13	0.76	......	73.9
July	—0.15	1.93	0.41	......	77.1	+0.58	3.71	0.43	......	75.6
August	—0.70	3.46	0.35	......	74.4	......	0.95	0.50	......	80.0
Growing period	—0.13	7.05	1.12	5.93	76.0	+0.55	7.79	1.69	6.10	76.5
September	—1.13	1.35	0.31	......	69.7	—0.69	1.73	0.35	......	77.9
October	—1.57	3.85	0.31	......	53.4	—0.81	4.23	0.33	......	59.1
November	—1.24	0.86	0.39	......	37.1	—0.71	1.81	0.46	......	44.8
Replenishing period	—1.31	6.06	1.01	5.05	53.4	—0.74	7.77	1.14	6.63	60.6
Yearly mean or total	—0.43	21.99	3.07	18.92	51.8	+0.04	24.27	8.38	15.89	53.9

a Interpolated from average of fifteen years

TABLE No. 49 (*concluded*)

MONTH	1882					1883				
	Mean monthly elevation of lake surface	Rainfall	Water drawn	Rainfall less the water drawn	Temperature	Mean monthly elevation of lake surface	Rainfall	Water drawn	Rainfall less the water drawn	Temperature
(1)	(2)	(3)	(4)	(5)	(6)	(2)	(3)	(4)	(5)	(6)
December	−0.05	4.02	0.66	......	39.8	−1.51	0.91	0.19	......	31.0
January	+1.63	1.03	2.04	......	29.4	−1.56	0.84	0.21	......	25.7
February	+1.39	1.07	1.40	......	37.0	+0 03	3.11	0.28	......	30.6
March	+1.67	1.47	2.82	......	38.7	+0.95	0.90	0.68	......	33.3
April	+1.51	2.49	1.53	......	48.5	+1.57	2.43	1.58	......	47.8
May	+1.61	5.29	1.74	......	57.4	+1.59	9.54	2.59	......	59.1
Storage period	+1.29	15.37	10.19	5.18	41.8	+0.18	17.73	5.53	12.20	37.9
June	+1.45	2.31	1.85	......	71.9	+1.38	4.52	1.65	......	74.2
July	+0.81	1.42	0.62	......	78.0	+1.29	2.13	1.08	......	75.7
August	+0.15	2.17	0.41	......	76.8	+0.64	2.86	0.45	......	73.7
Growing period	+0.80	5.90	2.88	3.02	75.6	+1.10	9.51	3.18	6.33	74.5
September	−0.44	1.78	0.43	......	69.4	+0.25	2.36	0.21	......	65.1
October	−0.99	1.00	0,65	......	61.4	+0.07	1.62	0.18	......	55.7
November	−1.38	1.41	0.36	......	41.8	+0.17	2.02	0.19	......	45.1
Replenishing period	−0.94	4.19	1.44	2.75	57.5	+0.16	6.00	0.58	5.42	55.3
Yearly mean or total	+0.61	25.46	14.51	10.95	54.2	+0.41	33.24	9.29	23.95	51.4

MONTH	1884				
	Mean monthly elevation of lake surface	Rainfall	Water drawn	Rainfall less the water drawn	Temperature
(1)	(2)	(3)	(4)	(5)	(6)
December	+0.44	2.01	0.54	....	34.0
January	+0.46	1.78	1.01	....	24.7
February	+1.28	2.17	2.70	....	30.2
March	+1.47	3.18	2.71	....	30.5
April	+1.56	2.21	1.47	....	42.7
May	+1.62	3.30	1.69	....	56.7
Storage period	+1.14	14.65	10.12	4.53	36.5
June	+1.01	2.44	0.75	....	70.4
July	+0.58	3.98	0.37	....	68.4
August	+0.27	1.08	0.24	....	70.8
Growing period	+0.62	7.50	1.36	6.14	69.9
September	−0.26	2.24	0.71	....	66.9
October	−0.70	1.34	0.20	....	52.3
November	−1.17	1.01	0.18	....	38.9
Replenishing period	−0.71	4.59	1.09	3.50	52.7
Yearly mean or total	+0.55	26.74	12.57	14.17	48.9

The catchment area of Hemlock lake is, as stated, 27,554 acres, and the area of the lake itself at the elevation ± 0.0 is 1828 acres; hence the lake surface is 6.6 per cent of the total catchment area, or the catchment area is 15.1 times the area of the lake surface. On this basis 1 inch on the whole area is 15.1 inches on the lake. Taking into account these statements, it is clear that the data of the table give approximately the natural runoff, although for exact figures corrections for actual elevations of lake surface at the beginning, as well as at the end of each year, should be applied. On this point see the discussion on the minimum flow of Hemlock lake.

Comparison of the runoff of Hemlock lake with that of the river Thames in England. Hemlock lake may be compared with the river Thames in England, where somewhat similar climatic conditions obtain. The catchment area of the Thames above the point of gaging is 3789 square miles, while the catchment area of Hemlock lake is given at 43.1 square miles. It is shown on a preceding page that comparison may be legitimately made between streams with even as great variation in catchment areas as here exists. Accurate gagings are at hand of the Thames from 1883-1891, inclusive, from which it appears that the mean or average rainfall during this period was 27.01 inches, and the mean or average runoff, 8.49 inches, or the runoff was 31 per cent of the rainfall. In order to compare the climate of the catchment of the Thames with that of Hemlock lake we may consider the following;

The mean annual rainfall at Hemlock lake for the water years 1877-1900, inclusive, was 27.70 inches; the mean annual temperature for the same years was 50° Fahr., and the mean annual evaporation for the years 1896 to 1903, at Mount Hope reservoir, 28 miles north of Hemlock lake, was 34.55 inches. The rainfall of Hemlock lake exceeds that of the Thames by only 0.69 inch.

The mean evaporation from a water surface at Oxford, England, for five years, 1852-1856, inclusive, was 31.01 inches; the mean annual rainfall at Oxford for the same period was 27.30 inches, and the mean annual temperature, 48.5° Fahr. We have, therefore, 3.54 inches less mean annual evaporation, as measured in the catchment of the Thames, than at Hemlock lake.

During the ten-year period, 1893-1902, inclusive, the mean runoff of the river Thamas was only 7.29 inches, instead of 8.49 inches, as in the previous ten-year period. In consideration of the showing made of the low runoffs of streams in the State of New York, it is probable that when a complete computation of the runoff of Hemlock lake is made, it will be found to be somewhat less than that of the Thames in England.[1]

Geologically the Hemlock lake catchment is in the Hamilton and Marcellus shale, with the hills at the sides rising to the rocks of the Portage group.

Discharge measurements of Oswego river. The following record of Oswego river is taken daily, with the exception of Sundays and holidays.

These gagings are made at the State dam, three miles from Lake Ontario, with an effective head at the dam of about 32 feet. This dam is of masonry, with its crest 365.5 feet long. Flashboards are maintained during the greater part of the year. In estimating the flow, when flashboards are removed, a discharge curve has been prepared using coefficients in the weir formula, as per Cornell experiment No. 3, given in the paper On the Flow of Water Over Dams.

It is possible that the records are somewhat too small, owing to leakage and settlement of the dam. A headrace supplies water to an electric-light plant and the Oswego water works pumping station. There are eight water wheels in use. The amount of water passed through these wheels varies from 300 cubic feet per second to about 650 cubic feet per second. In the

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[1] Discussion of the flow of the river Thames from 1883-1892, may be found in (1) the Report on the Flow of the Thames, by A. R. Binnie, Chief Engineer to the London County Council—a publication of the Council, 1892; and (2) a Report on the Shrinkage of the Thames and Lea, by Maurice Fitz Maurice, Chief Engineer—a publication of the London County Council, presented to the Water Committee on February 10, 1903.

accompanying table allowance for diversion to the Oswego canal, which is also supplied from this dam, has not been made, but such diversion can not be very large because of the small amount of business on that canal during the last few years.

Gagings of Oswego river above Minetto have also been made from September, 1900, to date, at which time a current meter station was established at this point.

Gagings were also begun in 1898 at the upper dam at Fulton, which is a well-built stone dam and has no leakage. The dam is 404.6 feet in length, with a crest practically level. The following cut shows the form of this dam:

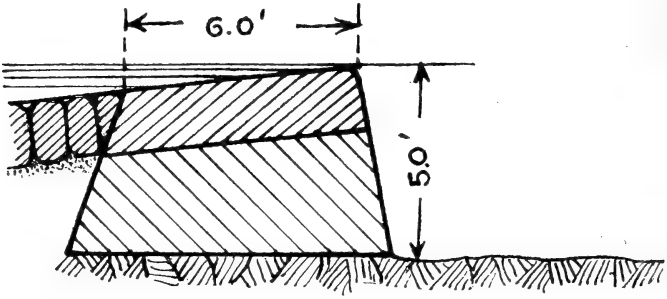

Fig. 22 Section of dam at Fulton.

Geologically the Oswego river lies in the horizon of the Medina sandstone and Clinton groups.

Discharge measurements of Seneca river. This station is located at the stone dam on Seneca river at Baldwinsville. The outlets of Otisco, Skaneateles and Owasco lakes, tributaries of Seneca river, are crossed by the Erie canal and a portion of their flow intercepted for the supply of this canal. The chief supply for the Erie canal to Montezuma marsh is from Lake Erie and Lake Erie water is discharged into Seneca river and thus returned through the Oswego river to Lake Ontario. It is uncertain, therefore, whether the abstraction from Otisco, Skaneateles and Owasco lakes is very material, as the amount discharged in Seneca river varies and has never been closely measured.

The upper reaches of Seneca river are canalized, forming the Cayuga and Seneca canal, while the portion below Baldwinsville,

Table No. 50—Runoff of Oswego river at high dam for the water years 1897–1901, inclusive

(Catchment area = 5000 square miles)

MONTH	1897			1898			1899		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	....	....	....	4,168	0.95	0.83	3,899	0.90	0.78
January	....	....	....	4,896	1.13	0.98	4,252	0.98	0.85
February	....	....	....	6,238	1.29	1.24	2,475	0.51	0.49
March	....	....	....	9,898	2.29	1.99	4,874	1.12	0.97
April	....	....	....	7,578	1.68	1.51	7,684	1.70	1.53
May	....	....	....	8,161	1.78	1.63	6,754	1.55	1.35
Storage period	....	....	....	6,829	9.12	1.37	5,016	6.76	1.00
June	3,801	0.85	0.76	4,331	0.97	0.87	2,002	0.44	0.40
July	2,174	0.49	0.43	1,834	0.41	0.36	748	0.17	0.15
August	2,370	0.54	0.47	925	0.20	0.18	612	0.14	0.12
Growing period	2,771	1.88	0.55	2,340	1.58	0.47	1,111	0.75	0.22
September	1,244	0.28	0.25	1,377	0.30	0.27	615	0.13	0.12
October	1,076	0.24	0.21	2,018	0.46	0.40	585	0.12	0.11
November	1,821	0.40	0.36	4,452	0.99	0.89	1,095	0.24	0.22
Replenishing period	1,377	0.92	0.27	2,609	1.75	0.52	763	0.49	0.15
Yearly mean or total	....	....	....	4,645	12.45	0.93	2,972	8.00	0.59

TABLE NO. 50—RUNOFF OF OSWEGO RIVER AT HIGH DAM FOR THE WATER YEARS 1897–1901, INCLUSIVE (*concluded*)

(Catchment area = 5000 square miles)

MONTH	1900			1901			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	1,612	0.36	0.32	9,022	2.08	1.80	....	....	....
January	3,077	0.70	0.61	5,326	1.23	1.07	....	....	....
February	4,653	0.96	0.93	1,874	0.38	0.37	....	....	....
March	4,991	1.14	0.99	7,270	1.67	1.45	....	....	....
April	14,025	3.12	2.80	16,957	3.80	3.39	....	....	....
May	7,645	1.76	1.53	10,006	2.30	2.00	....	....	....
Storage period	5,979	8.04	1.19	8,470	11.46	1.69	6,574	8.85	1.31
June	3,132	0.69	0.62	8,152	1.83	1.63	....	....	....
July	966	0.22	0.19	3,740	0.86	0.75	....	....	....
August	669	0.15	0.13	1,928	0.45	0.39	....	....	....
Growing period	1,572	1.06	0.31	4,568	3.14	0.92	2,398	1.63	0.48
September	670	0.14	0.13	1,871	0.41	0.37	....	....	....
October	853	0.19	0.17	2,150	0.49	0.43	....	....	....
November	2,418	0.53	0.48	2,901	0.65	0.58	....	....	....
Replenishing period	1,309	0.86	0.26	2,306	1.55	0.46	1,748	1.16	0.35
Yearly mean or total	3,704	9.96	0.74	5,950	16.15	1.19	4,318	11.64	0.86

which is deep and without current, admits of slack-water navigation, forming a part of Oswego canal. This canal enters at Mud lock, five miles below Baldwinsville. There is also a towpath along Seneca river, admitting of the passage of boats through a lock into and above the dam at Baldwinsville. The Baldwinsville pond is navigable for a few miles.

Water is diverted at Baldwinsville through power canals. Power is used at ten mills, having a total of forty water wheels. Owing to leakage of the water wheels and penstocks, some difficulty has been experienced in securing accurate results during low water at Baldwinsville, but in 1901 repairs were made to a number of penstocks and water wheels, considerably reducing the leakage. When this station was originally established the leakage was taken at 100 cubic feet per second. This quantity was added to the computed flow over the dam and through the water wheels. The following cut shows a section of the dam on Seneca river at Baldwinsville:

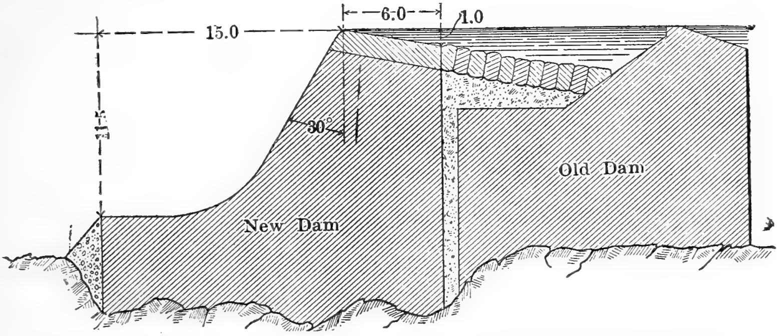

Fig. 23 Cross-section of dam on Seneca river at Baldwinsville.

Geologically the Seneca river lies in the horizon of the Salina group, with its tributaries to the south rising into the lower and upper Helderberg and Hamilton shales. The extreme headwaters are in the Portage and Chemung groups.

Discharge measurements of Skaneateles outlet. The measurements of the runoff of Skaneateles lake, as given in table No. 53, have been made by the Syracuse Waterworks over a dam at the foot of the lake, or over a weir a short distance below, since October, 1890, but the record is only given from March, 1895.

TABLE No. 51—RUNOFF OF SENECA RIVER AT BALDWINSVILLE FOR THE WATER YEARS 1899–1902, INCLUSIVE
(Catchment area = 3103 square miles)

MONTH	1899			1900			1901			1902			MEAN		
	Cubic feet per second.	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	2,689	1.00	0.87	1,722	0.63	0.55	4,126	1.53	1.33	3,387	1.26	1.09	......	......	......
January	2,851	1.06	0.92	2,150	0.79	0.69	2,630	0.98	0.85	3,279	1.22	1.06	......	......	......
February	1,769	0.59	0.57	3,129	1.05	1.01	1,930	0.64	0.62	2,341	0.78	0.75	......	......	......
March	3,875	1.44	1.25	4,441	1.65	1.43	4,049	1.50	1.30	8,375	3.11	2.70	......	......	......
April	4,543	1.63	1.46	6,845	2.47	2.21	8,951	3.21	2.88	5,056	1.82	1.63	......	......	......
May	2,568	0.95	0.83	3,120	1.15	1.00	5,545	2.06	1.79	2,799	1.04	0.90	......	......	......
Storage period	3,062	6.67	0.99	3,557	7.74	1.14	4,557	9.96	1.47	4,232	9.23	1.36	3,852	8.40	1.24
June	1,573	0.57	0.51	1,508	0.54	0.48	4,272	1.53	1.37	2,264	0.81	0.73	......	......	......
July	776	0.25	0.22	720	0.26	0.23	2,024	0.75	0.65	2,864	1.00	0.92	......	......	......
August	455	0.17	0.15	551	0.21	0.18	2,099	0.78	0.68	3,114	1.15	1.00	......	......	......
Growing period	928	0.99	0.29	920	1.01	0.29	2,782	3.06	0.89	2,753	2.96	0.95	1,846	2.00	0.60
September	481	0.17	0.15	471	0.17	0.15	1,776	0.63	0.57	1,848	0.67	0.60	......	......	......
October	637	0.24	0.20	1,063	0.39	0.34	1,892	0.70	0.61	2,210	0.82	0.71	......	......	......
November	1,612	0.58	0.52	1,498	0.54	0.48	2,071	0.73	0.66	2,539	0.91	0.82	......	......	......
Replenishing period	907	0.99	0.29	1,011	1.10	0.32	1,913	2.06	0.61	2,199	2.40	0.71	1,508	1.64	0.48
Yearly mean or total	1,987	8.65	0.64	2,258	9.85	0.73	3,451	15.08	1.11	3,352	14.59	1.10	2,762	12.04	0.89

Previous to 1886 Skaneateles lake was the principal feeder of the Jordan level of Erie canal, but in that year Otisco and Owasco lakes were also made feeders. The Skaneateles lake dam was reconstructed 9 feet high by the State in 1887, and in 1893 was again rebuilt by the Syracuse Water Board with its spillway 2 feet higher than the crest of the old dam. The following are the catchment areas of this stream:

	Square miles
Land surface above State dam	60.3
Water surface of lake	12.3
Total catchment area, above foot of lake	73.0
Total area above Willow Glen weir	74.3
Total catchment above Jordan	93.0

The elevation of Skaneateles lake is 867 feet plus tidewater, while that of the outlet at the Erie canal crossing, near Jordan, is about 400 feet. The lake lies in a deep valley, with bold shores rising several hundred feet at either side. The figures given in table No. 53 do not represent in any degree the natural runoff of this catchment, but merely the water yield during the years indicated, in which there was large storage.

In March, 1895, the city of Syracuse began to draw water through the new conduit to Skaneateles lake. The results given in table No. 53 are the quantity flowing in the outlet as measured on the weir located at Willow Glen, plus the outflow through the conduit.

In table No. 52 the mean monthly elevations of Skaneateles lake, above and below an arbitrary datum, as derived from observations taken on the first, eighth, fifteenth and twenty-second days of each month, are given for the water years 1890-1901, inclusive. These observations have been made by gate keepers of the Canal Department and are approximate merely. In the original record they are given to the nearest quarter of an inch, while in the present record they have been translated to feet and tenths—it has not been considered worth while to carry out the hundredths of a foot.

Geologically, Skaneateles lake catchment lies in the horizon of the Hamilton shales.

TABLE NO. 52—MEAN MONTHLY ELEVATIONS OF SKANEATELES LAKE, AS DERIVED FROM OBSERVATIONS TAKEN ON 1ST, 8TH, 15TH AND 22D DAY OF EACH MONTH, FOR THE WATER YEARS 1890–1901, INCLUSIVE

(Elevation above and below an arbitrary datum)

MONTH	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
December	—1.9	—1.0	—5.8	—2.6	—4.8	—1.6	—4.6	—3.9	—5.3	—3.9	—6.3	—3.5
January	—2.1	—1.5	—5.5	—2.7	—4.5	—1.2	—4.3	—4.1	—5.4	—3.7	—5.8	—3.1
February	—2.3	—1.0	......	—2.9	......	—1.8	—4.6	—4.3	—4.5	—3.9	—4.8	—3.1
March	+0.3	+0.2	—5.0	—2.8	......	—0.4	—4.1	—4.6	—3.9	—3.7	—4.1	—3.0
April	+0.3	+0.5	—3.7	—1.3	......	—0.2	—2.4	—3.5	—3.1	—3.0	—2.5	—2.8
May	+0.3	......	—1.8	......	—2.5	+0.1	—1.4	—2.7	—2.4	—2.8	—1.6	—0.2
Storage period	......	......	......	......	......	......	......	......	......	......	......	......
June	+0.4	—0.8	—0.7	+0.3	—1.3	—0.4	—1.6	—2.5	—2.2	—2.9	—1.6	+0.3
July	+0.5	—1.4	—0.3	—0.7	+0.3	—0.9	—1.9	—2.7	—2.7	—3.3	—1.6	—0.3
August	—0.4	—2.2	—0.7	—1.4	—0.1	—1.7	—2.2	—3.3	—3.1	—4.0	—2.0	—1.0
Growing period	......	......	......	......	......	......	......	......	......	......	......	......
September	—1.3	—3.3	—1.1	—2.2	—0.9	—2.2	—2.9	—4.2	—3.6	—4.8	—2.8	—1.8
October	—1.1	—4.1	—1.8	—3.0	—1.0	—3.1	—3.4	—4.9	—4.2	—5.7	—3.7	—4.8
November	—1.2	—5.3	—2.6	—3.8	—1.2	—4.1	—3.9	—4.5	—3.9	—5.9	—4.3	—3.5
Replenishing period	......	......	......	......	......	......	......	......	......	......	......	......

TABLE No. 53—RUNOFF OF SKANEATELES OUTLET AT WILLOW GLEN FOR THE WATER YEARS 1895–1902, INCLUSIVE

(Catchment area=74 square miles)

MONTH	1895			1896			1897			1898			1899		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	......	......	97	1.51	1.31	83	1.29	1.12	79	1.23	1.07	86	1.32	1.15
January	......	......	......	93	1.44	1.25	77	1.19	1.04	82	1.27	1.10	91	1.41	1.23
February	......	......	......	96	1.39	1.29	74	1.03	0.99	80	1.12	1.08	85	1.19	1.14
March	103	1.59	1.39	102	1.59	1.38	66	1.01	0.88	82	1.28	1.11	85	1.31	1.14
April	162	2.44	2.18	95	1.43	1.28	17	0.26	0.23	83	1.25	1.12	92	1.39	1.24
May	127	1.97	1.71	97	1.51	1.31	74	1.15	1.00	86	1.33	1.16	87	1.35	1.17
Storage period	......	......	......	97	8.87	1.31	65	5.93	0.88	82	7.48	1.11	88	7.97	1.19
June	102	1.53	1.37	102	1.55	1.38	85	1.29	1.15	84	1.28	1.14	94	1.42	1.27
July	108	1.68	1.46	91	1.41	1.23	89	1.38	1.20	88	1.36	1.19	95	1.47	1.28
August	115	1.78	1.55	92	1.43	1.24	138	2.14	1.86	87	1.35	1.17	85	1.31	1.14
Growing period	108	4.99	1.46	95	4.39	1.28	101	4.81	1.36	86	3.99	1.16	91	4.20	1.23
September	112	1.69	1.51	96	1.46	1.30	89	1.38	1.21	86	1.29	1.15	81	1.22	1.09
October	114	1.77	1.54	91	1.41	1.23	97	1.51	1.31	87	1.36	1.18	76	1.18	1.03
November	111	1.67	1.49	87	1.32	1.18	93	1.39	1.24	86	1.29	1.15	75	1.14	1.02
Replenishing period	112	5.13	1.51	91	4.19	1.23	93	4.28	1.25	86	3.94	1.16	77	3.54	1.04
Yearly mean or total	......	......	......	95	17.45	1.28	81	15.02	1.09	84	15.41	1.14	86	15.71	1.16

TABLE No. 53—RUNOFF OF SKANEATELES OUTLET AT WILLOW GLEN FOR THE WATER YEARS 1895–1902, INCLUSIVE (*concluded*)

(Catchment area=74 square miles)

MONTH	1900			1901			1902			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	43	0.66	0.57	67	1.05	0.91	100	1.56	1.35	......	......	......
January	31	0.47	0.41	54	0.84	0.73	89	1.38	1.20	......	......	......
February	45	0.62	0.60	49	0.69	0.67	89	1.24	1.19	......	......	......
March	30	0.47	0.41	61	0.94	0.82	96	1.50	1.30	......	......	......
April	27	0.40	0.36	106	1.60	1.43	95	1.43	1.28	......	......	......
May	35	0.54	0.47	138	2.14	1.86	95	1.48	1.28	......	......	......
Storage period	35	3.16	0.47	80	7.26	1.08	94	8.59	1.27	75	6.78	1.01
June	52	0.79	0.71	194	2.95	2.63	96	1.44	1.29	......	......	......
July	64	1.00	0.87	142	2.22	1.93	119	1.93	1.67	......	......	......
August	88	1.37	1.19	114	1.78	1.54	169	2.63	2.28	......	......	......
Growing period	68	3.16	0.92	150	6.95	2.03	128	6.00	1.73	99	4.58	1.33
September	86	1.30	1.16	102	1.54	1.38	147	2.21	1.98	......	......	......
October	111	1.71	1.49	117	1.82	1.58	......	......	......	......	......	......
November	99	1.50	1.34	121	1.82	1.63	......	......	......	......	......	......
Replenishing period	99	4.51	1.34	113	5.18	1.53	......	......	......	93	4.27	1.26
Yearly mean or total	59	10.83	0.80	106	19.39	1.43	......	......	......	85	15.63	1.15

Discharge measurements of Chittenango creek. Gagings of this creek have been made at the mill-dam at Bridgeport, a short distance above its mouth. Gage readings were taken three times a day, showing the hight of water above crest of dam, head on wheels and width of gate openings. The dam is of timber, backed with stone, and has a nearly level crest, 215 feet long, with flood gates at the ends. Figure 24 shows a section of this dam.

The relatively low runoff of Chittenango creek during the summer months may be attributed to the diversion of a portion of the flow to supply the Rome level of Erie canal. For this purpose State dams are situated on the main stream at Chittenango and on its two tributaries, Limestone and Butternut creeks. Cazenovia lake, Erieville, De Ruyter and Jamesville reservoirs are situated on these streams.

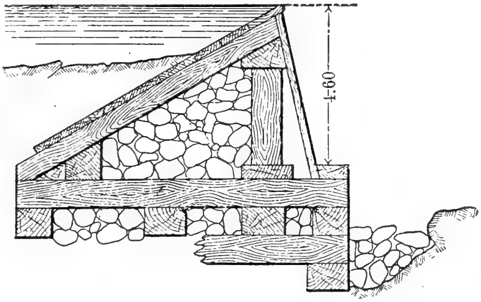

Fig. 24 Cross-section of dam on Chittenango creek at Bridgeport

The Erieville reservoir has a tributary catchment of 5.4 square miles. The storage capacity is 318,425,000 cubic feet, and the water surface 340 acres.

Cazenovia lake has a tributary catchment of 8.7 square miles. The storage capacity is 207,000,000 cubic feet and the area of water surface 1.7 square miles.

De Ruyter reservoir has a tributary catchment area of 18.5 square miles, which is naturally tributary to Tioughnioga river, a tributary of Chenango river. The storage capacity is 504,500,000 cubic feet and the area of water surface 626 acres. The outflow is diverted into Limestone creek, entering Erie canal through Fayetteville feeder.

Jamesville reservoir has a tributary catchment area of 46.2 square miles. The storage capacity is 170,000,000 cubic feet and the area of water surface 252 acres. It is situated on the headwaters of Butternut creek, tributary to Chittenango creek through Limestone creek. The outflow reaches Erie canal through the Orrville feeder.

From Chittenango falls to Chittenango village, a distance of five miles, this stream falls from elevation 860 + T. W. to elevation 420. From the foot of Chittenango falls to Chittenango village, the stream flows through a deep, narrow valley, where several water powers formerly in use are now mostly abandoned.

Owing to its location below three feeders of the canal, the records at Bridgeport do not show the actual runoff of the catchment area during the canal season. During the winter, drainage into the canal is sometimes drawn off into Chittenango creek at the aqueducts crossing the main stream and its tributaries. Owing to uncertainty in the runoff, the Bridgeport station was abandoned in May, 1901.

Geologically, Chittenango creek lies in the horizon of the Niagara, Salina and Lower Helderberg groups and Hamilton shales.

Discharge measurements of Black river. Observations of the flow in Black river have been made at the dam of the Watertown Waterworks, located about two miles above Watertown, at Huntingtonville. This station was established in February, 1897, and the record has been furnished by the Board of Water Commissioners of Watertown. At this gaging station the stream flows in two channels with an island between. A high dam on the right creates a settling basin for the water supply of Watertown. The second dam, on the opposite side of the island, is of timber with crest slightly irregular in profile. For ease in computation this crest has been divided into six parts, each being considered as horizontal. The discharge over the dam has been computed, using coefficients derived from Cornell University experiments Nos. 2 and 12, as given in detail in the paper On the Flow of Water Over Dams.

The entire flow of Black river, aside from the leakage and diversion for the water supply of Watertown, passes over the

TABLE No. 54—RUNOFF OF CHITTENANGO CREEK AT BRIDGEPORT, FOR THE WATER YEARS 1898–1901

(Catchment area=307 square miles)

MONTH	1898			1899			1900			1901			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	......	......	597	2.23	1.94	281	1.05	0.91	562	2.10	1.83	......	......	......
January	......	......	......	662	2.49	2.15	561	2.07	1.80	391	1.46	1.27	......	......	......
February	......	......	......	551	1.87	1.80	725	2.45	2.36	236	0.80	0.77	......	......	......
March	......	......	......	893	3.34	2.90	697	2.61	2.27	955	3.59	3.12	......	......	......
April	......	......	......	921	3.34	3.00	911	3.31	2.97	1,174	4.29	3.83	......	......	......
May	......	......	......	245	0.92	0.80	207	0.77	0.67	308	1.15	1.00	......	......	......
Storage period	......	......	......	645	14.19	2.10	559	12.26	1.82	607	13.39	1.98	602	13.23	1.96
June	......	......	......	161	0.58	0.52	93	0.33	0.30	......	......	......	......	......	......
July	......	......	......	127	0.46	0.40	110	0.40	0.36	......	......	......	......	......	......
August	......	......	......	96	0.35	0.31	73	0.27	0.24	......	......	......	......	......	......
Growing period	......	......	......	128	1.39	0.42	92	1.00	0.30	......	......	......	110	1.19	0.36
September	129	0.47	0.42	76	0.28	0.25	68	0.24	0.22	......	......	......	......	......	......
October	344	1.29	1.12	64	0.23	0.21	81	0.30	0.26	......	......	......	......	......	......
November	612	2.24	2.00	95	0.34	0.31	327	1.20	1.07	......	......	......	......	......	......
Replenishing period	372	4.00	1.18	78	0.85	0.25	158	1.74	0.51	......	......	......	118	1.30	0.38
Yearly mean or total	......	......	......	373	16.43	1.22	341	15.00	1.11	......	......	......	357	15.72	1.16

Huntingtonville dam. Two or more readings of the gage are taken daily and a mean taken. In computing the flow an allowance of 200 cubic feet per second has been made for leakage through seams and crevices in the rock underlying the dam. This amount is somewhat general, as it has only been arrived at from an estimate of the size of the openings from the statement of eye witnesses when the water was drawn down in the summer of 1897. The following cut shows a section of the Huntingtonville dam on Black river:

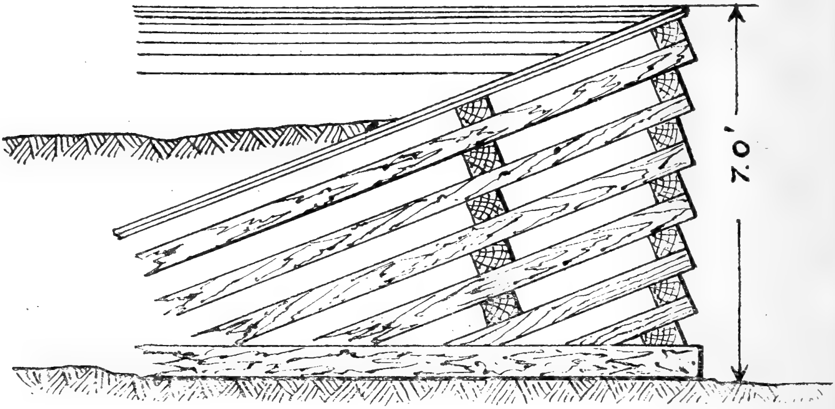

Fig. 25 Section of dam on Black river.

Geologically, Black river lies in the horizon of the Trenton limestone, with its tributaries rising into the unclassified granites and gneisses of the Adirondack region.

Discharge measurements of Lake Champlain. Lake Champlain drains an area of 7960 square miles, which is subdivided as follows:

	Square miles.
Area in Quebec	740
Area in Vermont	4,270
Area in New York	2,950
Area of water surface of lake	400
Total	8,360

TABLE No. 55—RUNOFF OF BLACK RIVER AT HUNTINGTONVILLE DAM FOR THE WATER YEARS 1897-1901, INCLUSIVE

(Catchment area=1889 square miles)

MONTH	1897			1898			1899		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	......	......	4,725	2.88	2.50	2,720	1.66	1.44
January	......	......	......	3,402	1.36	1.18	4,712	2.77	2.49
February	2,160	1.18	1.14	3,806	2.09	2.01	2,326	1.28	1.23
March	6,317	3.85	3.34	9,609	5.77	5.08	5,051	3.08	2.67
April	9,484	5.60	5.02	4,654	2.74	2.46	13,894	8.20	7.35
May	4,267	2.60	2.26	3,174	1.86	1.68	5,609	3.42	2.97
Storage period	......	......	......	4,914	16.70	2.60	5,730	20.41	3.03
June	2,713	1.60	1.44	1,639	0.97	0.87	1,528	0.90	0.81
July	879	0.54	0.47	1,128	0.69	0.60	1,205	0.73	0.64
August	2,280	1.39	1.21	1,495	0.91	0.79	897	0.54	0.47
Growing period	1,949	3.53	1.03	1,418	2.57	0.75	1,206	2.17	0.64
September	......	......	......	1,483	0.87	0.78	990	0.58	0.52
October	954	0.58	0.51	3,138	1.91	1.66	1,018	0.60	0.54
November	4,155	2.45	2.20	3,932	2.32	2.08	1,652	0.97	0.87
Replenishing period	......	......	......	2,854	5.10	1.51	1,218	2.15	0.64
Yearly mean or total	......	......	......	3,520	24.37	1.86	3,465	24.73	1.83

TABLE No. 55—RUNOFF OF BLACK RIVER AT HUNTINGTONVILLE DAM FOR THE WATER YEARS 1897–1901, INCLUSIVE (*concluded*)
(Catchment area=1889 square miles)

MONTH	1900			1901			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	3,501	1.52	1.85	4,230	2.58	2.24	......	......	......
January	2,834	1.73	1.50	2,844	1.73	1.50	......	......	......
February	5,734	3.16	3.04	2,421	1.33	1.28	......	......	......
March	2,970	1.81	1.57	6,024	3.66	3.18	......	......	......
April	13,926	8.22	7.37	14,354	8.51	7.60	......	......	......
May	5,711	3.48	3.02	5,007	3.05	2.65	......	......	......
Storage period	5,735	19.92	3.03	5,822	20.66	3.08	5,550	19.42	2.94
June	1,630	0.96	0.86	5,316	3.15	2.81	......	......	......
July	1,321	0.80	0.70	1,626	0.99	0.86	......	......	......
August	1,134	0.69	0.60	2,135	1.30	1.13	......	......	.....
Growing period	1,359	2.45	0.72	3,001	5.44	1.59	1,746	3.16	0.92
September	1,020	0.60	0.54	3,089	1.83	1.63	......	......	......
October	1,218	0.71	0.64	3,316	2,62	2.28	......	......	......
November	5,014	2.96	2.65	2,712	1,60	1.43	......	......	......
Replenishing period	2,404	4.27	1.27	3,042	6.05	1.61	2,379	4.39	1.26
Yearly mean or total	3,802	26.64	2.01	4,418	32.15	2.34	3,801	26.97	2.01

We have, then, a total area of the basin of 8360 square miles.[1]

The rainfall of this catchment is stated in the Report of the Board of Engineers on Deep Waterways at an average of about 33 inches per year. But table No. 25 shows that for the 12 years from 1891 to 1902, inclusive, the rainfall of Champlain valley was 37.06 inches.

The lake is considered as terminating on the south at Whitehall and on the north at St Johns, on Richelieu river. The low-water elevation is 95.03 feet + T. W. and the high water, 103.78 feet + T. W. The length is 125 miles from Whitehall to St Johns, and the breadth 13 miles. The outlet of Lake Champlain is Richelieu river, which flows northerly across the Province of Quebec, entering the St Lawrence at Sorel. The length of the river is 75 miles. It receives from New York the drainage from the northeast slope of the Adirondacks, amounting to 35 per cent of the whole. A record of the elevation of lake surface at Rouses Point has been kept by the United States Corps of Engineers since 1875.

In 1896 the construction of a power plant at Chambly was begun by the Royal Electric Company of Montreal. The dam is of concrete masonry, strengthened with imbedded iron bars. The hight from apron to crest is 18 feet, affording a fall of 28 feet at the power-house. A calibration curve of Richelieu river was constructed by the Board of Engineers on Deep Waterways by comparing the computed discharge over this dam with the corresponding stage of Lake Champlain at Fort Montgomery, and taking into consideration the slope of Richelieu river in the intervening distance of thirty-five miles. The discharge in cubic feet per second has been deduced from this curve.

The record of Lake Champlain is given not only because it is computed over a dam, but because it is a long record, although in the following tables it has only been taken from 1880-1902, inclusive. The catchment area of 7750 square miles, as given by the Board of Engineers on Deep Waterways, is placed at the head of the tables.

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[1] The preceding figures are derived from the Report of the United States Deep Waterways Commission (1896). The Board of Engineers on Deep Waterways gave the area of Lake Champlain at 437 square miles and the total area of the catchment at 7,750 square miles.

Table No. 56—Runoff of Richelieu river—outlet of Lake Champlain—at Chambly, Quebec, for the water years 1880-1902, inclusive

(In cubic feet per second. Catchment area=7750 square miles)

MONTH (1)	1880 (2)	1881 (3)	1882 (4)	1883 (5)	1884 (6)	1885 (7)	1886 (8)	1887 (9)	1888 (10)	1889 (11)	1890 (12)	1891 (13)
December	11,000	8,300	8,500	4,400	4,900	8,300	16,700	13,100	9,700	16,200	14,900	13,300
January	11,300	6,900	12,100	4,000	5,300	11,400	17,000	10,700	10,600	19,300	13,900	12,700
February	14,000	8,200	11,500	5,000	8,700	11,200	16,000	15,000	10,900	16,200	16,000	16,000
March	15,900	13,900	16,800	6,800	14,900	9,900	15,400	13,100	12,900	14,300	18,800	23,400
April	17,100	15,500	15,600	17,800	25,300	19,600	22,900	23,600	23,900	20,200	20,800	28,600
May	15,800	20,300	14,700	21,800	23,400	24,900	19,200	29,000	30,200	19,600	25,500	23,100
Storage period	14,200	12,200	13,300	10,000	13,700	14,300	17,800	17,400	16,400	17,600	18,300	19,500
June	11,400	14,500	17,200	17,700	16,100	15,300	13,900	19,500	19,700	17,500	23,200	14,200
July	8,500	10,100	13,800	13,500	10,300	11,600	10,300	13,400	12,900	15,300	14,000	9,900
August	6,300	8,000	9,700	9,700	8,900	9,600	8,100	9,900	9,200	12,900	9,700	8,200
Growing period	8,700	10,800	13,500	13,600	11,700	12,200	10,700	14,300	13,900	15,200	15,600	10,800
September	4,400	6,500	7,600	6,300	5,500	9,700	6,200	7,400	9,900	9,600	14,200	7,300
October	3,800	5,400	7,200	4,700	5,000	6,600	6,200	5,300	11,700	11,400	13,800	5,400
November	9,100	6,900	5,500	4,700	5,700	16,800	8,400	5,000	15,200	12,000	14,200	5,000
Replenishing period	5,700	6,300	6,700	5,300	5,400	10,800	7,200	5,900	12,200	11,000	14,000	6,000
Yearly mean	10,700	10,400	11,700	9,700	11,100	12,900	13,400	13,700	14,700	15,300	16,600	13,900

TABLE NO. 56—RUNOFF OF RICHELIEU RIVER—OUTLET OF LAKE CHAMPLAIN—AT CHAMBLY, QUEBEC, FOR THE WATER YEARS 1880-1902, INCLUSIVE (*concluded*)

(In cubic feet per second. Catchment area=7750 square miles)

MONTH	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
December	7,200	11,000	6,700	7,100	12,500	9,700	15,400	9,600	11,400	13,300	10,500	......
January	13,400	8,400	9,900	7,800	14,800	8,300	14,400	10,600	10,900	11,900	12,300	......
February	12,700	7,900	10,100	7,400	11,800	7,900	14,900	9,600	14,500	9,900	10,900	......
March	11,300	9,700	16,200	7,600	18,000	10,600	22,900	13,300	16,000	10,300	28,700	......
April	20,000	16,200	17,300	17,600	30,500	21,600	24,500	21,700	22,200	30,600	31,300	......
May	17,300	21,700	14,900	21,300	24,900	24,800	18,600	24,600	18,000	28,400	22,200	......
Storage period	13,300	12,500	12,500	11,500	18,800	13,900	18,500	14,900	15,500	17,400	19,400	15,343
June	19,100	15,800	12,800	14,200	14,100	21,900	13,800	13,900	18,800	20,900	20,500	......
July	23,900	9,800	9,800	9,400	10,300	19,300	9,800	9,600	12,000	13,200	16,300	......
August	18,700	8,000	6,900	7,600	7,900	18,400	7,400	6,900	9,300	10,100	13,300	......
Growing period	20,500	11,200	9,800	10,200	10,800	19,800	10,300	10,100	13,300	14,700	16,700	12,974
September	15,300	11,800	5,300	7,200	6,100	12,300	6,500	5,200	7,200	7,600	10,200	......
October	10,400	8,500	5,200	5,400	6,500	8,500	8,700	4,500	6,600	6,400	8,700	......
November	11,000	6,600	6,900	6,700	9,100	9,800	10,300	9,000	8,000	6,100	10,800	......
Replenishing period	12,000	9,000	5,800	6,400	7,200	10,200	8,500	6,200	7,300	6,700	9,900	8,074
Yearly mean	14,800	11,300	10,100	9,900	13,900	14,500	14,000	11,500	12,900	14,100	16,300	12,931

Table No. 57—Runoff of Richelieu river—outlet of Lake Champlain—at Chambly, Quebec, for the water years 1880–1902, inclusive

(In inches on the catchment. Catchment area = 7750 square miles)

MONTH	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
December	1.63	1.23	1.26	0.66	0.72	1.23	2.47	1.94	1.44	2.40	2.21	1.98
January	1.68	1.02	1.79	0.60	0.78	1.69	2.52	1.59	1.58	2.86	2.06	1.89
February	1.95	1.10	1.54	0.67	1.21	1.50	2.14	2.01	1.52	2.16	2.14	2.14
March	2.36	2.06	2.50	1.01	2.21	1.47	2.29	1.94	1.91	2.12	2.79	3.50
April	2.48	2.24	2.25	2.58	3.65	2.83	3.30	3.40	3.45	2.92	3.00	4.13
May	2.35	3.01	2.19	3.23	3.47	3.69	2.85	4.30	4.49	2.91	3.78	3.43
Storage period	12.45	10.66	11.53	8.75	12.04	12.41	15.57	15.18	14.39	15.37	15.98	17.07
June	1.65	2.09	2.49	2.55	2.33	2.21	2.00	2.82	2.84	2.53	3.35	2.05
July	1.26	1.49	2.05	2.00	1.53	1.72	1.53	1.99	1.91	2.27	2.08	1.47
August	0.93	1.18	1.44	1.44	1.32	1.43	1.20	1.47	1.37	1.91	1.44	1.22
Growing period	3.84	4.76	5.98	5.99	5.18	5.36	4.73	6.28	6.12	6.71	6.87	4.74
September	0.64	0.94	1.10	0.91	0.80	1.40	0.90	1.06	1.43	1.39	2.05	1.05
October	0.56	0.81	1.07	0.70	0.74	0.89	0.92	0.78	1.74	1.69	2.05	0.81
November	1.31	1.00	0.80	0.68	0.83	2.43	1.21	0.72	2.20	1.74	2.05	0.78
Replenishing period	2.51	2.75	2.97	2.29	2.37	4.72	3.03	2.56	5.37	4.72	6.15	2.64
Yearly total	18.80	18.17	20.48	17.03	19.59	22.49	23.33	24.02	25.88	26.80	29.00	24.45

TABLE NO. 57—RUNOFF OF RICHELIEU RIVER—OUTLET OF LAKE CHAMPLAIN—AT CHAMBLY, QUEBEC, FOR THE WATER YEARS 1880–1902, INCLUSIVE (*concluded*)

(In inches on the catchment. Catchment area = 7750 square miles)

MONTH (14)	1892 (15)	1893 (16)	1894 (17)	1895 (18)	1896 (19)	1897 (20)	1898 (21)	1899 (22)	1900 (23)	1901 (24)	1902 (25)	Mean (26)
December	0.74	1.63	0.99	1.06	1.85	1.44	2.99	1.43	1.69	1.98	1.55	......
January	1.99	1.24	1.47	1.16	2.20	1.23	2.14	1.58	1.62	1.76	1.83	......
February	1.77	1.06	1.35	0.99	1.64	1.06	2.00	1.30	1.94	1.33	1.42	......
March	1.68	1.44	2.39	1.13	2.67	1.58	3.39	1.87	2.37	1.53	4.27	......
April	2.89	2.34	2.50	2.54	4.40	3.12	3.54	3.14	3.20	4.42	4.51	......
May	2.56	3.22	2.21	3.16	3.69	3.68	2.76	3.65	2.67	4.21	3.31	......
Storage period	11.63	10.93	10.91	10.04	16.45	12.11	16.82	12.97	13.49	17.23	16.89	13.52
June	2.76	2.28	1.85	2.05	2.04	3.17	1.99	2.00	2.72	3.02	2.95	......
July	3.54	1.44	1.44	1.39	1.53	2.86	1.45	1.44	1.77	1.52	2.43	......
Angust	2.77	1.18	1.02	1.13	1.17	2.73	1.09	1.02	1.38	1.96	1.98	......
Growing period	9.07	4.90	4.31	4.57	4.74	8.76	4.53	4.46	5.87	6.50	7.36	5.72
September	2.21	1.70	0.76	1.04	0.88	1.78	0.94	0.75	1.03	1.10	1.47	......
October	1.54	1.26	0.77	0.81	0.97	1.26	1.29	0.67	0.98	0.94	1.29	......
November	1.50	0.95	1.00	0.95	1.31	1.41	1.49	1.29	1.16	0.87	1.55	......
Replenishing period	5.25	3.91	2.53	2.80	3.16	4.45	3.72	2.71	3.17	2.91	4.31	3.52
Yearly total	25.95	19.74	17.75	17.41	24.35	25.32	25.07	20.14	22.53	26.64	28.56	22.76

TABLE NO. 58—RUNOFF OF RICHELIEU RIVER—OUTLET OF LAKE CHAMPLAIN—AT CHAMBLY, QUEBEC, FOR THE WATER YEARS 1880–1902, INCLUSIVE

(In cubic feet per second per square mile. Catchment area = 7750 square miles)

MONTH	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	1891
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
December	1.42	1.07	1.10	0.57	0.63	1.07	2.15	1.69	1.25	2.09	1.92	1.72
January	1.46	0.89	1.56	0.52	0.68	1.47	2.19	1.38	1.37	2.49	1.79	1.64
February	1.81	1.06	1.48	0.64	1.12	1.44	2.06	1.93	1.41	2.08	2.06	2.06
March	2.05	1.79	2.17	0.88	1.92	1.28	1.99	1.69	1.66	1.84	2.43	3.04
April	2.21	2.00	2.01	2.30	3.26	2.53	2.95	3.04	3.08	2.61	2.68	3.69
May	2.04	2.62	1.90	2.81	3.02	3.21	2.48	3.74	3.90	2.53	3.29	2.98
Storage period	1.83	1.58	1.71	1.29	1.77	1.84	2.30	2.25	2.11	2.27	2.36	2.52
June	1.47	1.87	2.22	2.28	2.08	1.97	1.79	2.52	2.54	2.26	2.99	1.83
July	1.10	1.30	1.78	1.74	1.33	1.50	1.33	1.73	1.66	1.97	1.81	1.28
August	0.81	1.03	1.25	1.25	1.15	1.24	1.04	1.28	1.19	1.66	1.25	1.06
Growing period	1.12	1.39	1.74	1.75	1.51	1.57	1.38	1.84	1.79	1.96	2.01	1.39
September	0.57	0.84	0.98	0.81	0.71	1.25	0.80	0.95	1.28	1.24	1.83	0.94
October	0.49	0.70	0.93	0.61	0.64	0.77	0.80	0.68	1.51	1.47	1.78	0.70
November	1.17	0.89	0.71	0.61	0.74	2.17	1.08	0.64	1.96	1.55	1.83	0.70
Replenishing period	0.74	0.81	0.86	0.68	0.70	1.39	0.93	0.76	1.58	1.42	1.81	0.78
Yearly mean	1.38	1.34	1.51	1.25	1.44	1.66	1.73	1.77	1.90	1.98	2.14	1.80

TABLE No. 58—RUNOFF OF RICHELIEU RIVER—OUTLET OF LAKE CHAMPLAIN—AT CHAMBLY, QUEBEC, FOR THE WATER YEARS 1880–1902, INCLUSIVE (*concluded*)

(In cubic feet per second per square mile. Catchment area = 7750 square miles)

MONTH	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
December	0.64	1.42	0.86	0.92	1.61	1.25	1.99	1.24	1.47	1.72	1.35	....
January	1.73	1.08	1.28	1.01	1.91	1.07	1.86	1.37	1.41	1.53	1.59	....
February	1.64	1.02	1.30	0.95	1.52	1.02	1.92	1.25	1.87	1.28	1.40	....
March	1.46	1.25	2.09	0.98	2.32	1.37	2.95	1.63	2.06	1.33	3.70	....
April	2.58	2.09	2.23	2.27	3.93	2.79	3.16	2.80	2.86	3.95	4.04	....
May	2.23	2.80	1.92	2.75	3.21	3.20	2.40	3.17	2.32	3.66	2.87	....
Storage period	1.71	1.62	1.62	1.48	2.42	1.79	2.38	1.92	2.00	2.25	2.50	1.98
June	2.46	2.04	1.65	1.83	1.82	2.83	1.78	1.79	2.42	2.70	2.64	....
July	3.08	1.26	1.26	1.21	1.33	2.49	1.26	1.25	1.54	1.32	2.11	....
August	2.41	1.03	0.89	0.98	1.02	2.37	0.95	0.89	1.20	1.70	1.72	....
Growing period	2.65	1.45	1.26	1.32	1.39	2.56	1.33	1.30	1.71	1.90	2.15	1.67
September	1.97	1.52	0.68	0.93	0.79	1.59	0.84	0.67	0.92	0.98	1.32	....
October	1.34	1.10	0.67	0.70	0.84	1.10	1.12	0.58	0.85	0.82	1.12	....
November	1.34	0.85	0.89	0.86	1.17	1.26	1.33	1.15	1.04	0.78	1.39	....
Replenishing period	1.55	1.16	0.75	0.83	0.93	1.31	1.10	0.80	0.94	0.86	1.27	1.04
Yearly mean	1.91	1.46	1.31	1.28	1.79	1.87	1.80	1.48	1.66	1.82	2.11	1.67

The following are the mean monthly elevations of Lake Champlain at Fort Montgomery, New York, 1875-1898, inclusive:

TABLE NO. 59—MONTHLY MEAN ELEVATIONS OF LAKE CHAMPLAIN AT FORT MONTGOMERY 1875–1898, INCLUSIVE

YEAR	January	February	March	April	May	June	July	August	September	October	November	December	Means 1 year
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1875	94.22	94.24	95.09	97.88	98.41	97.07	95.94	95.30	94.92	95.24	96.09	95.81	95.85
1876	96.68	96.56	97.11	98.66	100.11	98.23	96.56	95.28	94.47	94.27	94.18	93.98	96.34
1877	93.96	94.04	94.97	97.86	97.39	95.93	95.72	95.50	95.06	94.89	95.72	96.10	95.60
1878	95.56	95.06	96.04	97.92	98.34	96.52	95.49	96.32	96.21	95.05	95.25	97.55	96.28
1879	96.82	96.20	96.51	97.94	99.50	97.23	96.00	95.14	94.52	94.16	94.31	95.74	96.17
1880	95.83	96.56	97.06	97.38	97.04	95.83	95.01	94.37	93.81	93.65	95.20	94.97	95.56
1881	94.54	94.94	96.56	96.96	98.13	96.71	95.49	94.88	94.44	94.12	94.56	95.04	95.53
1882	96.05	95.87	97.30	97.00	96.76	97.39	96.51	95.36	94.75	94.63	94.13	93.80	95.80
1883	93.70	94.00	94.52	97.55	98.48	97.52	96.43	95.30	94.36	93.90	93.90	93.96	95.30
1884	94.08	95.08	96.80	99.18	98.80	97.13	95.55	95.13	94.13	93.98	94.20	94.95	95.75
1885	95.86	95.79	95.44	97.98	99.10	96.90	95.91	95.35	95.38	95.46	97.29	97.26	96.48
1886	97.34	97.08	96.93	98.70	97.89	96.56	95.55	94.89	94.33	94.34	94.98	96.32	96.24
1887	95.64	96.84	96.31	98.86	99.87	97.95	96.41	95.44	94.69	94.08	93.97	95.37	96.29
1888	95.62	95.70	96.27	98.90	100.07	98.01	96.27	95.22	95.43	95.93	96.88	97.15	96.79
1889	97.91	97.14	96.63	98.12	97.97	97.48	96.91	96.26	95.35	95.86	96.02	96.82	96.87
1890	96.54	97.08	97.80	98.26	99.22	98.77	96.57	95.36	96.63	96.51	96.62	96.38	97.15
1891	96.21	97.08	98.80	99.81	98.73	96.63	95.44	94.93	94.66	94.11	94.00	94.63	96.25
1892	96.40	96.20	95.82	98.07	97.42	97.87	98.91	97.77	96.92	95.56	95.75	95.73	96.87
1893	95.00	94.83	95.37	97.15	98.46	97.03	95.39	94.87	95.96	95.04	94.46	94.49	95.67
1894	95.43	95.49	97.14	97.43	96.80	96.22	95.38	94.53	94.09	94.06	94.56	94.61	95.48
1895	94.81	94.70	94.73	97.51	98.36	96.63	95.26	94.76	94.63	94.10	94.50	96.17	95.51
1896	96.78	95.96	97.64	100.13	99.09	96.59	95.54	94.85	94.30	94.43	95.19	95.36	95.49
1897	94.97	94.84	95.62	98.43	99.08	98.49	97.92	97.70	96.11	95.04	95.41	96.93	96.71
1898	96.67	96.82	98.70	99.03	97.75	96.50	95.41	94.69	94.44	95.07	95.54	95.35	96.33

Mean elevation, 1875 to 1898, 96.10 feet.

Geologically, Lake Champlain lies mostly in the horizon of the Trenton limestone, the drainage being from the Laurentian granites and Plutonic norites.

Discharge measurements of Hudson river at Mechanicville. Measurements of the flow of the Hudson river at Mechanicville have been made over the dam of the Duncan Company. In 1887 this company began daily measurement of the amount of water flowing in the Hudson river at their mill.[1] With the exception of one or two days, this record has been kept for every working day since October 1, 1887. A record has also been kept of the number, size, and kind of turbine water wheels in use for the same period. The Duncan Company placed all this material at the disposal of the survey of the upper Hudson valley, thus enabling one to compute the mean daily flow of the river for each working day from October 1, 1887, to November, 1897. The flow of Sundays and holidays, when no observations were taken, has been assumed as a mean between the preceding Saturday and the following Monday, etc. The dam is a substantial structure of masonry 16 feet high, with a length of 794 feet between the abutments. The crest is stated to be perfectly level, and from all that can be learned it appears that the daily observations have been taken with such care as to leave no reason for doubting that this is a fairly accurate exhibit of the daily flow of the stream for the period covered.

The catchment area of the Hudson river above the Mechanicville dam is taken at 4500 square miles, although a recomputation from the latest maps made for the Board of Engineers on Deep Waterways gave 4507 square miles. This is only 0.15 of one per cent different from the former computation of 4500 square miles and is not enough to make it worth while to recompute the runoff.

The flow of the Hudson river at Mechanicville prior to 1899 has been computed by using the East Indian engineers' formula for flow over a dam, and when flashboards are on, the Francis formula for a sharp-crested weir has been used. Since that time, the computations have been made by R. P. Bloss, Engineer of the

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[1] Ann. Rept. of State Engineer and Surveyor of New York, 1895, p. 104.

Duncan Company, who has used the Francis formula for the Merrimac dam, namely:

$$Q = 3.012\ L\ H^{1.53}; \qquad (36)$$

in which—

L = length of dam = 794 feet;

H = depth on crest of dam, in feet.

This formula has been used in all cases, whether flashboards are on or off. Mr Bloss states that his reason for using this formula is that there was a litigation at Mechanicville in which the quantity of water flowing over the dam became an important element. He therefore used the Francis formula for the Merrimac dam because the courts were familiar with this formula, whereas, had he continued to use the East Indian engineers' formula, the courts would not be familiar with it and might not accept it. The difference between the two formulas is not very great. At 4 feet depth it is about one cubic foot per second per foot of crest, which would make at that depth 794 cubic feet per second for the entire dam. Probably the greatest oversight in this computation is the use of the formula for the Merrimac dam when the flashboards are on. At 4 feet depth the variation between the formula for the Merrimac dam and Francis formula for a sharp-crested weir is about 13 cubic feet per second per linear foot of dam, and even at 2 feet depth on crest the variation is over 6 cubic feet per second per foot of dam. It is concluded, therefore, that the computations from 1899 to date are somewhat less reliable than those of the previous years. The following cut shows a section of the Mechanicville dam.

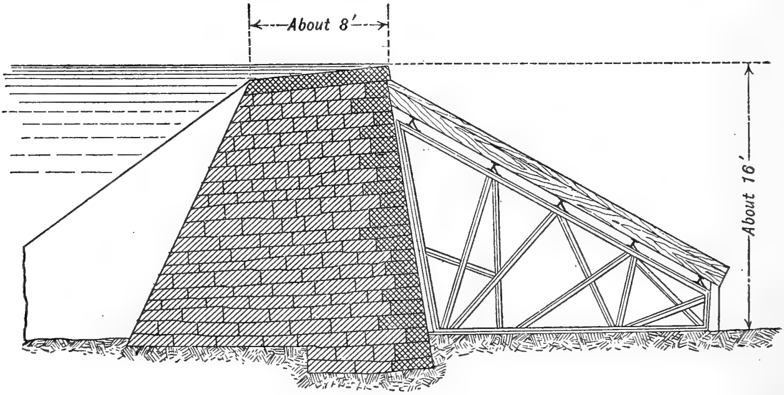

Fig. 26 Section of Mechanicville dam.

TABLE No. 60—RUNOFF OF HUDSON RIVER AT MECHANICVILLE FOR THE WATER YEARS 1888–1902, INCLUSIVE

(In cubic feet per second. Catchment area = 4500 square miles)

MONTH (1)	1888 (2)	1889 (3)	1890 (4)	1891 (5)	1892 (6)	1893 (7)	1894 (8)	1895 (9)
December	8,018	10,014	13,226	3,244	8,577	4,031	7,217	4,367
January	6,367	10,983	11,272	8,284	18,857	3,192	6,757	3,876
February	3,714	3,790	7,913	11,664	9,263	4,805	4,836	3,543
March	6,845	8,280	11,129	17,736	10,929	8,250	14,738	4,204
April	21,200	13,690	15,053	20,021	21,554	17,889	11,135	23,822
May	21,420	8,871	17,931	5,533	19,622	22,285	7,566	6,850
Storage period	11,289	9,337	12,821	11,021	14,831	10,114	8,759	7,759
June	4,917	6,869	7,392	3,200	12,395	4,801	7,097	2,816
July	1,537	5,727	1,950	2,337	9,287	2,521	3,168	2,559
August	1,725	4,272	2,019	2,666	5,485	5,005	2,456	3,901
Growing period	2,703	5,718	3,748	2,957	9,019	4,102	4,209	3,095
September	2,851	1,963	8,844	2,040	4,448	6,870	1,889	2,629
October	4,608	3,740	9,215	1,472	2,819	3,865	3,649	2,631
November	10,642	7,888	9,121	4,088	7,604	3,639	6,379	8,421
Replenishing period	6,018	4,522	9,061	2,521	4,934	4,781	3,969	4,539
Yearly mean	7,820	7,197	9,597	6,867	10,909	7,271	6,418	5,780

TABLE NO. 60—RUNOFF OF HUDSON RIVER AT MECHANICVILLE FOR THE WATER YEARS 1888–1902, INCLUSIVE (*concluded*)

(In cubic feet per second. Catchment area = 4500 square miles)

MONTH (10)	1896 (11)	1897 (12)	1898 (13)	1899 (14)	1900 (15)	1901 (16)	1902 (17)	Mean (18)
December	10,889	6,913	13,741	5,436	7,303	5,331	8,491	......
January	6,787	4,007	7,723	6,668	5,841	3,087	*7,336	......
February	4,668	3,895	6,754	5,258	12,484	2,888	4,741	......
March	13,600	12,214	20,220	9,618	7,740	8,095	25,130	......
April	24,972	19,080	13,712	23,645	22,614	28,268	15,222	......
May	4,610	12,151	11,095	9,752	8,992	11,658	7,949	......
Storage period	10,893	9,754	12,300	10,070	10,786	9,902	11,569	10,747
June	4,738	11,861	5,280	2,598	4,093	7,806	6,315	......
July	2,772	10,722	2,570	2,273	2,352	3,551	8,934	......
August	2,442	8,240	5,101	1,393	2,703	4,661	6,286	......
Growing period	3,302	10,257	4,307	2,083	3,038	5,313	7,188	4,736
September	2,879	2,756	3,872	2,074	1,886	4,024	3,643	......
October	4,106	2,524	7,895	2,617	2,128	4,264	6,894	......
November	11,352	9,962	9,243	6,382	5,077	3,732	7,076	......
Replenishing period	6,900	5,053	7,013	3,680	3,020	4,009	5,882	5,006
Yearly mean	7,791	8,709	8,962	6,464	6,897	7,276	9,047	7,800

*Interpolated—mean of fourteen years.

TABLE No. 61—RUNOFF DATA OF HUDSON RIVER AT MECHANICVILLE FOR THE WATER YEARS 1888–1901, INCLUSIVE

(In inches)

(Catchment area = 4500 square miles)

MONTH	1888			1889			1890			1891			1892		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	2.05	......	......	2.57	......	......	3.39	......	3.01	0.83	......	4.41	2.27	......
January	......	1.62	......	......	2.81	......	......	2.89	......	4.82	2.12	......	5.99	4.83	......
February	......	0.89	......	......	0.88	......	......	1.83	......	4.91	2.70	......	3.15	2.22	......
March	......	1.75	......	......	2.12	......	......	2.85	......	3.70	4.55	......	3.59	2.80	......
April	......	5.26	......	......	3.39	......	......	3.73	......	2.46	4.97	......	1.62	5.35	......
May	......	5.49	......	......	2.27	......	......	4.59	......	1.79	1.42	......	6.19	5.03	......
Storage period	*20.40	17.06	3.34	*17.10	14.04	3.06	*24.75	19.28	5.47	20.69	16.59	4.10	24.95	22.50	2.45
June	......	1.22	......	......	1.70	......	......	1.83	......	3.42	0.79	......	5.38	3.08	......
July	......	0.39	......	......	1.47	......	......	0.50	......	6.06	0.60	......	4.90	2.38	......
August	......	0.44	......	......	1.09	......	......	0.52	......	4.01	0.68	......	8.84	1.41	......
Growing period	*10.25	2.05	8.20	*15.05	4.26	10.79	*13.50	2.85	10.65	13.49	2.07	11.42	19.12	6.87	12.25
September	......	0.71	......	......	0.49	......	......	2.19	......	1.96	0.51	......	3.41	1.10	......
October	......	1.18	......	......	0.96	......	......	2.36	......	2.90	0.38	......	2.16	0.72	......
November	......	2.64	......	......	1.96	......	......	2.26	......	3.92	1.01	......	4.23	1.89	......
Replenishing period	*13.27	4.53	8.74	*10.81	3.41	7.40	*12.10	6.81	5.29	8.78	1.90	6.88	9.80	3.71	6.09
Yearly total	*43.92	23.64	20.28	*42.96	21.71	21.25	*50.35	28.94	21.41	42.96	20.56	22.40	53.87	33.08	20.79

* Approximate. Note: The rainfall of 1888-1890, inclusive, is less satisfactory than for balance of time, but it cannot be far from right because evaporations are not far from the average.

TABLE NO. 61—RUNOFF DATA OF HUDSON RIVER AT MECHANICVILLE FOR THE WATER YEARS 1888–1901, INCLUSIVE (*continued*)

(In inches)

(Catchment area = 4500 square miles)

MONTH	1893			1894			1895			1896			1897		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	2.11	1.03	......	5.75	1.85	......	3.01	1.12	......	4.18	2.79	......	1.84	1.77	......
January	2.16	0.82	......	3.48	1.73	......	2.96	0.99	......	2.25	1.74	......	2.93	1.03	......
February	4.43	1.09	......	2.87	1.12	......	1.58	0.82	......	6.36	1.12	......	1.99	0.90	......
March	1.97	2.11	......	2.26	3.78	......	2.14	1.08	......	5.56	3.49	......	4.88	3.13	......
April	3.52	4.44	......	1.81	2.76	......	3.11	5.91	......	1.19	6.20	......	3.72	4.73	......
May	5.64	5.71	......	5.20	1.94	......	2.99	1.76	......	2.63	1.18	......	4.41	3.04	......
Storage period	19.83	15.20	4.63	21.37	13.18	8.19	15.79	11.68	4.11	22.17	16.52	5.65	19.77	14.60	5.17
June	3.20	1.19	......	4.40	1.76	......	2.61	0.70	......	2.87	1.18	......	4.97	2.94	......
July	3.34	0.65	......	2.89	0.81	......	3.13	0.66	......	4.80	0.72	......	7.36	2.74	......
August	6.83	1.28	......	1.44	0.63	......	4.63	1.00	......	2.58	0.63	......	3.47	2.11	......
Growing period	13.37	3.12	10.25	8.73	3.20	5.53	10.37	2.36	8.01	10.25	2.53	7.72	15.80	7.79	8.01
September	3.90	1.70	.....	4.00	0.47	......	3.42	0.65	......	4.93	0.71	......	2.25	0.68	......
October	1.96	0.99	......	5.10	0.94	......	2.14	0.69	......	2.85	1.05	......	1.70	0.65	......
November	3.12	0.90	......	2.77	1.58	......	4.95	2.08	......	5.01	2.82	......	6.99	2.47	......
Replenishing period	8.98	3.59	5.39	11.87	2.99	8.88	10.51	3.42	7.09	12.79	4.58	8.21	10.94	3.80	7.14
Yearly total	42.18	21.91	20.27	41.97	19.37	22.60	36.67	17.46	19.21	45.21	23.63	21.58	46.51	26.19	20.32

TABLE No. 61—RUNOFF DATA OF HUDSON RIVER AT MECHANICVILLE FOR THE WATER YEARS 1888–1901, INCLUSIVE (*concluded*)

(In inches)

(Catchment area = 4500 square miles)

MONTH	1898			1899			1900			1901			MEAN		
	Rain-fall	Runoff	Evapo-ration	Rain fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	4.59	3.67	......	4.17	1.40	......	4.82	1.86	......	3.21	1.36	......	......	......	......
January	5.46	1.97	......	3.40	1.71	......	3.92	1.50	......	2.28	0.79	......	......	......	......
February	3.29	1.56	......	2.38	1.22	......	3.93	2.88	......	1.34	0.67	......	......	......	......
March	2.09	5.18	......	4.79	2.47	......	5.07	1.98	......	3.25	2.00	......	......	......	......
April	3.28	3.40	......	1.64	5.86	......	1.01	5.60	......	3.45	7.03	......	......	......	......
May	4.09	2.83	......	3.10	2.49	......	2.38	2.30	......	4.94	2.99	......	......	......	......
Storage period	22.80	18.61	4.19	19.48	15.15	4.33	21.13	16.12	5.01	18.47	14.84	3.63	20.62	16.10	4.52
June	3.78	1.30	......	2.10	0.65	......	3.12	1.01	......	4.75	1.93	......	......	......	......
July	3.28	0.64	......	3.77	0.62	......	4.11	0.60	......	5.25	0.91	......	......	......	......
August	6.46	1.30	......	1.53	0.36	......	4.88	0.69	......	5.09	1.18	......	......	......	......
Growing period	13.52	3.24	10.28	7.40	1.63	5.77	12.11	2.30	9.81	15.09	4.02	11.07	12.72	3.45	9.27
September	3.67	0.96	......	3.37	0.51	......	2.92	0.47	......	3.72	1.00	......	......	......	......
October	4.89	2.02	......	2.95	0.67	......	2.30	0.54	......	2.69	1.08	......	......	......	......
November	3.63	2.29	......	2.59	1.58	......	6.95	1.24	......	2.61	0.92	......	......	......	......
Replenishing period	12.19	5.27	6.92	8.91	2.76	6.15	12.17	2.25	9.92	9.02	3.00	6.02	10.87	3.72	7.15
Yearly total	48.51	27.12	21.39	35.79	19.54	16.25	45.41	20.67	24.74	42.58	21.86	20.72	44.21	23.27	20.94

Experience in flows over dams of this length and with depths as great as from 7 to 8 feet is as yet rather limited in this country, and the question was raised as to the best method of computing the discharge for a case like the one under discussion. The engineers of the British government in India have had, in connection with their large irrigation works, perhaps more experience in this class of measurement than all others combined, and the formulas used by them appear more rational in form than those commonly used in the United States for such computations, and after some study it was decided to use these. As many American engineers may not be familiar with these formulas they are here reproduced. They take the following form—

$$Q=\tfrac{2}{3}\,L\,C\,\sqrt{2\,gd^3}, \qquad (37)$$

in which—

Q = the discharge over a thin-edged clear overfall, in cubic feet per second,

L = the length of the dam in linear feet,

C = coefficient depending for its value on d,

g = acceleration of gravity = 32.2,

d = depth on crest, in linear feet.

Equation (37) may also take the form—

$$Q = 5.35\,L\,C\,\sqrt{d^3}. \qquad (38)$$

To find C for different values of d, we have—

$$C = 1 - \left(\frac{0.04\,(34.6 + d)}{4}\right).^{1} \qquad (39)$$

This gives a series of values of C corresponding to d. For instance, for $d = 0.25$ foot, $C = 0.651$; for $d = 0.50$ foot, $C = 0.649$, and so on.

For a wide-crested dam the coefficient is further modified to suit the actual width of the crest. For this we have given the expression—

$$C' = C - \left(\frac{0.025\,C\,(B + 1)}{1 + d}\right), \qquad (40)$$

---

[1] Equation (39) may be written in a simpler form, $C=1-0.01(34.6+d)$.

in which—

B = the width of the crest in linear feet;

C = the coefficient for a thin-edged weir, corresponding to a depth d, as per equation (39), and

C′ = the adjusted coefficient corresponding to a given breadth B and a depth d.[1]

In the case of the Mechanicville dam we have a stone crest 7 feet in width and slightly inclined upstream. The width of the river a short distance above the dam is considerably over 800 feet; the depth for some distance back is from 16 to 20 feet. In order to avoid a correction for velocity of approach, a crest was assumed 5 feet wide and values of C′ were computed on that basis.

Having obtained values of C′ for $d = 0.25$, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 feet, and so on up to 8 feet, corresponding values of Q were computed and plotted at a large scale as a curve with values of d as abscissas and the corresponding flows as ordinates. From this curve intermediate values of Q have been read off.

The water wheels at Mechanicville have a capacity when they are all running of about 2400 cubic feet per second. The working head varies from 15 to 17 feet, depending upon the condition of the flashboards. A test of a 39-inch Hercules wheel, which has been in use about eight years, shows the actual discharge to be substantially as given in the manufacturers' tables when running at the speed of greatest efficiency.

The crest gage is read twice a day and a mean taken for the hight. A continuous record is also kept of the run of the water wheels at the mill.

Discharge measurements of Hudson river at Fort Edward. This station is located at the dam of the International Paper Company, which was established by the writer in 1895 in connection with the upper Hudson storage surveys. The dam is of timber on rock foundation and with very little leakage. The crest is nearly level, 587.6 feet in length. Flashboards are maintained on the dam 15 to 18 inches in hight.

There are sixty-two water wheels in the adjoining mill. A record is kept of the daily run of each in hours, as well as the working head, which is about 19 feet. The capacity of the wheels

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[1] The method of deducing equations (39) and (40) may be found in Mullin's Irrigation Manual, 1890, pp. 11, 12, 138, 139, 171, 172.

TABLE NO. 62—RUNOFF OF HUDSON RIVER AT MECHANICVILLE FOR THE WATER YEARS 1888–1902, INCLUSIVE

(In cubic feet per second per square mile. Catchment area = 4500 square miles)

MONTH	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
December	1.78	2.22	2.93	0.72	1.91	0.90	1.60	0.97	2.42	1.54	3.05	1.22	1.62	1.13	1.88	....
January	1.41	2.44	2.50	1.84	4.19	0.71	1.50	0.86	1.51	0.89	1.72	1.49	1.30	0.69	*1.64	....
February	0.82	0.84	1.76	2.58	2.06	1.07	1.08	0.79	1.04	0.87	1.50	1.17	2.77	0.64	1.52	....
March	1.52	1.84	2.47	3.94	2.43	1.83	3.28	0.93	3.02	2.49	4.49	2.14	1.72	1.80	5.53	....
April	4.73	3.04	3.34	4.44	4.79	3.98	2.47	5.31	5.55	4.24	3.07	5.25	5.02	6.28	3.38	....
May	4.76	1.97	4.00	1.22	4.36	4.95	1.68	1.52	1.02	2.70	2.47	2.17	2.00	2.60	1.76	....
Storage period	2.55	2.08	2.85	2.45	3.30	2.24	1.96	1.72	2.42	2.12	2.72	2.23	2.40	2.20	2.57	2.39
June	1.09	1.52	1.64	0.71	2.76	1.07	1.58	0.63	1.05	2.64	1.17	0.58	0.91	1.73	1.40	....
July	0.34	1.28	0.43	0.52	2.08	0.56	0.70	0.50	0.62	2.39	0.57	0.54	0.52	0.79	1.98	....
August	0.38	0.95	0.45	0.59	1.22	1.11	0.55	0.87	0.54	1.83	1.13	0.31	0.60	1.03	1.40	....
Growing period	0.60	1.21	0.83	0.65	2.00	0.91	0.94	0.67	0.74	2.29	0.96	0.47	0.67	1.18	1.60	1.05
September	0.63	0.44	1.96	0.45	0.99	1.53	0.41	0.58	0.51	0.51	0.84	0.46	0.42	0.89	0.81	....
October	1.02	0.83	2.04	0.33	0.63	0.86	0.81	0.58	0.91	0.56	1.75	0.58	0.47	0.94	1.53	....
November	2.36	1.77	2.03	0.91	1.69	0.81	1.42	1.87	2.97	2.21	2.05	1.42	1.11	0.83	1.41	....
Replenishing period	1.34	1.00	2.02	0.56	1.09	1.06	0.88	1.01	1.46	1.09	1.55	0.82	0.67	0.89	1.31	1.11
Yearly mean	1.74	1.60	2.13	1.53	2.43	1.62	1.43	1.28	1.74	1.93	1.98	1.44	1.53	1.62	2.01	1.73

* Interpolated—mean of fourteen years.

is about 4000 cubic feet per second. They are mostly of modern types and have been tested at Holyoke. When the flashboards are on, computations at Fort Edward have been made by the Francis formula for sharp-crested weir, but when the flashboards are off, the flow is computed by means of the East Indian engineers' formula.

In the winter of 1896-97 a flood spillway was cut in the rock at the south end of the dam over which the water begins to flow whenever it reaches the level of the crest of the flashboards. The profile of this spillway is irregular and causes a good deal of uncertainty in the calculated flows during high water. Indeed, the uncertainty is so great that the writer has for a number of years been unwilling to publish the record of this dam. He has, however, finally reviewed it, recomputing a portion of the same, and the figures are given for what they are worth. There is considerable uncertainty in the high-water flows—perhaps as much as 25 per cent. The entire low-water flow passes through the water wheels, and there may be some uncertainty in this, although not as great as in the flood flows.

The summer flow of the Hudson river at Mechanicville and Fort Edward is materially increased by the outgo from Indian river dam, built in 1898. A record of the flow at Indian lake has been kept since July, 1900.

The geology of the Hudson river basin is complicated—from its mouth to its extreme headwaters it crosses nearly every formation appearing in the State of New York.

Discharge measurements of Croton river. This stream serves as the principal source of water supply for the City of New York, Borough of Manhattan. The average daily consumption of water in all the Boroughs of the City of New York was, in 1899, 371,778,000 gallons, distributed as follows:

	Gallons.
Manhattan	230,000,000
Bronx	21,000,000
Brooklyn	102,663,000
Queens	12,925,000
Richmond	5,190,000

The catchment area of the Croton river lies almost entirely in New York, only a small portion being in Connecticut. It

TABLE NO. 63—RUNOFF OF HUDSON RIVER AT FORT EDWARD FOR THE WATER YEARS 1896–1902, INCLUSIVE

(Catchment area = 2800 square miles)

MONTH	1896			1897			1898			1899		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	2.61	......	......	1.12	......	......	5.80	......	2,248	1.08	0.80
January	......	1.40	......	......	0.65	......	......	1.51	......	3,527	1.95	1.26
February	......	0.96	......	......	0.64	......	......	1.27	......	1,902	0.70	0.68
March	......	2.62	......	......	2.32	......	......	5.75	......	5,005	2.05	1.79
April	......	6.46	......	......	5.05	......	......	4.11	......	16,811	6.69	6.00
May	......	1.61	......	......	3.80	......	......	2.93	......	9,561	3.83	3.41
Storage period	......	15.66	......	......	13.58	......	......	21.37	......	6,528	16.30	2.33
June	......	1.48	......	......	3.88	......	......	1.40	......	1,617	0.63	0.58
July	......	1.10	......	......	3.60	......	......	0.56	......	1,150	0.47	0.41
August	......	0.54	......	......	2.75	......	......	1.18	......	714	0.30	0.26
Growing period	......	3.12	......	......	10.23	......	......	3.14	......	1,155	1.40	0.41
September	......	0.63	......	......	0.58	......	......	0.80	......	1,347	0.53	0.48
October	......	1.38	......	......	0.57	......	......	1.38	......	1,033	0.42	0.37
November	......	3.49	......	......	3.00	......	......	2.11	......	5,098	2.03	1.82
Replenishing period	......	5.50	......	......	4.15	......	......	4.29	......	2,477	2.98	0.88
Yearly mean or total	......	24.28	......	......	27.96	......	......	28.80	......	4,164	20.68	1.49

TABLE No. 63—RUNOFF OF HUDSON RIVER AT FORT EDWARD FOR THE WATER YEARS 1896–1902, INCLUSIVE (*concluded*)

(Catchment area = 2800 square miles)

MONTH	1900			1901			1902			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	5,157	2.12	1.84	5,331	1.36	1.18	4,807	1.22	1.06	......	......	......
January	3,211	1.32	1.15	1,827	0.75	0.65	2,422	0.99	0.86	......	......	......
February	7,074	2.64	2.55	1,547	0.57	0.55	2,218	0.82	0.79	......	......	......
March	3,934	1.61	1.40	3,445	1.41	1.23	13,316	5.47	4.75	......	......	......
April	16,914	6.74	6.04	21,154	8.46	7.55	7,060	2.81	2.52	......	......	......
May	6,358	2.61	2.27	8,395	3.45	3.00	4,692	1.93	1.67	......	......	......
Storage period	7,055	17.04	2.52	6,961	16.00	2.49	5,804	13.24	2.07	6,587	16.17	2.35
June	2,834	1.13	1.01	6,256	2.50	2.23	5,293	1.71	1.89	......	......	......
July	1,248	0.51	0.45	2,190	0.90	0.78	7,204	2.96	2.57	......	......	......
August	1,652	0.68	0.59	2,531	1.03	0.90	4,743	1.95	1.69	......	......	......
Growing period	1,101	2.32	0.68	3,631	4.43	1.30	5,752	6.62	2.05	3,110	4.47	1.11
September	1,110	0.44	0.40	2,463	0.99	0.88	2,466	0.98	0.88	......	......	......
October	1,243	0.50	0.44	2,679	1.10	0.96	4,841	1.98	1.73	......	......	......
November	5,077	1.26	1.13	2,138	0.85	0.76	5,191	2.09	1.87	......	......	......
Replenishing period	2,463	2.20	0.88	2,429	2.94	0.87	4,173	5.05	1.49	2,886	3.87	1.03
Yearly mean or total	4,611	21.56	1.65	4,992	23.37	1.78	5,384	24.91	1.92	4,788	24.51	1.71

amounts to 339 square miles above the old Croton dam and to 360 square miles above the new Croton dam under construction. The main river is formed by three branches, known respectively as east, middle and west branches, which, rising in the southern part of Dutchess county, flow through Putnam county and unite near its south boundary. The river then flows across Westchester county to the Hudson river, into which it empties at Croton Point, about thirty miles north of the City of New York. The principal tributaries, aside from the east, middle and west branches, are Kisko, Titicus, Cross, and Muscoot rivers.

The flow of the Croton river is diverted through two aqueducts. A record of the flow has been kept at old Croton dam since 1868.

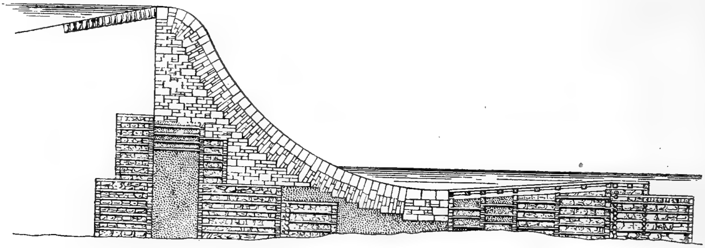

Fig. 27 Diagram of old Croton dam.

This record includes the quantity of water wasted over the crest of the dam, as well as that diverted for the water supply of New York.

In 1900 John R. Freeman made a report on the New York water supply[1] in which is an extended study of the yield of the Croton catchment area. It is stated that the results previously published average 10 per cent too large, the difference between the earlier estimates and the present being due mostly to the use of erroneous data, as follows:

1) The flow wasting over the old Croton dam was overestimated about 9 per cent by the use of a formula not strictly applicable to this peculiar form of dam, and because of a mistaken assumption in length of overfall. On measuring the length of crest line of dam, it was found shorter than heretofore assumed

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[1] Report on New York's Water Supply, with Particular Reference to the Needs of Procuring Additional Sources and Their Probable Costs, by John R. Freeman, C. E., 1900.

by 10 feet 6 inches (or 4 per cent) for all depths less than 8 inches, while the length between wingwalls heretofore used was substantially correct. It was also found that the dam crest is not absolutely level because of settlement near the center pier, and that the method of measuring the depth gave results about 0.30 inch too high.

2) The flow in the old Croton aqueduct at the depth commonly used before the new aqueduct was opened is less than previously estimated by about 14,000,000 gallons per day, or 15 per cent. These earlier estimates were based on using for the old Croton aqueduct the same coefficient of flow found for the new, smooth and clean Sudbury aqueduct, and not upon a gaging of the old aqueduct itself.

3) Gaged by the same observer with the same instrument, the new Croton aqueduct is now delivering less water for a given depth of flow than when new, to the extent of about 40,000,000 gallons per day; or, when the depth measured at the head of the aqueduct is 11 feet, the shortage is about 15 per cent.

4) An error was made five years ago in setting the gage by which depths in the new aqueduct are read, so that it makes the depth appear 2½ inches too large; this cause alone contributes about 6,000,000 gallons per day to the overestimate mentioned above.

5) The effect of storage drawn from Boyd's Corner and Middle Branch reservoirs and the Croton lake in modifying the natural flow had not been taken into account in these earlier estimates, neither had due allowance been made for the controlled natural ponds.[1]

Croton river is an average water yielder. The minimum yield for a complete water year for the whole period 1868-1899, inclusive, was in 1880, when from December to November, inclusive, the total runoff was 13.71 inches.

The Croton catchment contains thirty-one lakes and ponds, many of which have been utilized as natural storage basins by constructing dams at their outlets. The following tabulation gives the entire natural and artificial storage, either actually carried out or under construction in 1902, for the Croton catchment area:

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[1] Freeman's report, pp. 121-123.

Name of reservoir	Capacity up to level of spillway crest, in gallons
Boyd's	2,727,000,000
Middle branch	4,005,000,000
East Branch Sodom	4,883,000,000
Bog brook	4,145,000,000
Titacus	7,167,000,000
West Branch Carmel	10,070,000,000
Amawalk	7,678,000,000
Mahopac	575,000,000
Kirk	565,000,000
Gleneida	165,000,000
Gilead	380,000,000
Barrett's	170,000,000
White	200,000,000
Peach	230,000,000
Waccabuc	200,000,000
Cross	110,000,000
China	105,000,000
Pine	75,000,000
Long	60,000,000
Tonetta	50,000,000
Haines	25,000,000
Old Croton lake	160,000,000
New Croton (approximate)	21,200,000,000
Additional in New Croton lake above Muscoot dam	2,500,000,000
Increase by flashboards	2,800,000,000
Total storage	70,245,000,000

The catchment area above new Croton dam is, as already stated, 360 square miles. It is considered that the storage afforded by this reservoir system will furnish a daily supply of at least 280,000,000 gallons. At this rate the utilization from this catchment will become 778,000 gallons per square mile per day, or 1.20 cubic feet per second per square mile.

The accompanying tables are given in illustration of the yield of the Croton catchment area.

TABLE No. 64—AVERAGE FLOW OF CROTON RIVER AT OLD CROTON DAM, INCLUDING STORAGE DRAFT, WITH CATCHMENT AREA AND RESERVOIRS AS EXISTING IN THE GIVEN YEAR FOR THE YEARS 1868–1899, INCLUSIVE

(Freeman's table at pages 206-207 of his report. In gallons per day.)

MONTH	1868	1869	1870	1871	1872	1873	1874
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
January	332,000,000	380,000,000	672,000,000	98,000,000	347,000,000	729,000,000	1,578,000,000
February	150,000,000	371,000,000	810,000,000	416,000,000	217,000,000	311,000,000	532,000,000
March	742,000,000	945,000,000	600,000,000	595,000,000	292,000,000	687,000,000	564,000,000
April	665,000,000	592,000,000	785,000,000	344,000,000	541,000,000	1,267,000,000	633,000,000
May	1,013,000,000	484,000,000	303,000,000	343,000,000	209,000,000	361,000,000	536,000,000
June	577,000,000	229,000,000	141,000,000	244,000,000	205,000,000	85,000,000	154,000,000
July	186,000,000	102,000,000	81,000,000	117,000,000	99,000,000	84,000,000	237,000,000
August	350,000,000	58,000,000	78,000,000	143,000,000	276,000,000	125,000,000	141,000,000
September	960,000,000	35,000,000	30,000,000	106,000,000	208,000,000	88,000,000	63,000,000
October	503,000,000	453,000,000	48,000,000	338,000,000	182,000,000	240,000,000	136,000,000
November	692,000,000	364,000,000	110,000,000	654,000,000	463,000,000	293,000,000	110,000,000
December	264,000,000	547,000,000	101,000,000	381,000,000	236,000,000	568,000,000	165,000,000
Yearly mean	536,000,000	381,000,000	310,000,000	314,000,000	272,000,000	404,000,000	405,000,000

TABLE NO. 64—AVERAGE FLOW OF CROTON RIVER AT OLD CROTON DAM, INCLUDING STORAGE DRAFT, WITH CATCHMENT AREA AND RESERVOIRS AS EXISTING IN THE GIVEN YEAR FOR THE YEARS 1868–1899, INCLUSIVE (*continued*)

(Freeman's table at pages 206-207 of his report. In gallons per day.)

MONTH	1875	1876	1877	1878	1879	1880	1881
(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
January	91.000,000	241,000,000	143,000,000	490,000,000	235,000,000	465,000,000	150,000,000
February	809,000,000	672,000,000	288,000,000	725.000,000	516,000,000	562,000,000	966,000,000
March	550,000,000	1,208,000,000	1,237,000,000	657,000,000	724,000,000	525,000,000	1,163,000,000
April	1,004,000,000	1,101,000,000	513,000,000	296,000,000	892,000,000	377,000,000	332,000,000
May	304,000,000	334,000,000	146,000,000	276,000,000	306,000,000	158,000,000	231,000,000
June	91,000,000	111,000,000	103,000,000	269,000,000	156,000,000	56,000,000	295,000,000
July	60,000,000	47,000,000	40,000,000	124,000,000	128,000,000	49,000,000	72,000,000
August	965,000,000	48,000,000	44,000,000	105,000,000	224,000,000	27,000,000	15,000,000
September	147,000,000	66,000,000	48,000,000	428,000,000	197,000,000	39,000,000	10,000,000
October	137,000,000	62,000,000	206,000,000	164,000,000	69,000,000	30,000,000	79,000,000
November	381,000,000	133,000,000	821,000,000	386,000,000	101,000,000	94,000,000	99,000,000
December	297,000,000	71,000,000	327,000,000	1,354,000,000	277,000,000	72,000,000	380,000,000
Yearly mean	400,000,000	339,000,000	326,000,000	438,000,000	317,000,000	203,000,000	310,000,000

TABLE NO. 64—AVERAGE FLOW OF CROTON RIVER AT OLD CROTON DAM, INCLUDING STORAGE DRAFT, WITH CATCHMENT AREA AND RESERVOIRS AS EXISTING IN THE GIVEN YEAR FOR THE YEARS 1868–1899, INCLUSIVE (*continued*)

(Freeman's table at pages 206-207 of his report. In gallons per day.)

MONTH	1882	1883	1884	1885	1886	1887	1888
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
January	491,000,000	191,000,000	404,000,000	738,000,000	606,000,000	545,000,000	706,000,000
February	906,000,000	652,000,000	1,035,000,000	477,000,000	926,000,000	976,000,000	892,000,000
March	885,000,000	499,000,000	874,000,000	345,000,000	426,000,000	644,000,000	832,000,000
April	244,000,000	479,000,000	532,000,000	458,000,000	834,000,000	596,000,000	903,000,000
May	382,000,000	226,000,000	321,000,000	267,000,000	362,000,000	220,000,000	468,000,000
June	292,000,000	115,000,000	103,000,000	68,000,000	138,000,000	208,000,000	242,000,000
July	89,000,000	66,000,000	147,000,000	37,000,000	87,000,000	459,000,000	67,000,000
August	19,000,000	28,000,000	199,000,000	75,000,000	70,000,000	613,000,000	188,000,000
September	657,000,000	10,000,000	103,000,000	25,000,000	26,000,000	156,000,000	611,000,000
October	384,000,000	93,000,000	64,000,000	83,000,000	32,000,000	178,000,000	435,000,000
November	165,000,000	145,000,000	199,000,000	461,000,000	184,000,000	169,000,000	555,000,000
December	219,000,000	115,000,000	689,000,000	408,000,000	254,000,000	420,000,000	932,000,000
Yearly mean	392,000,000	215,000,000	387,000,000	286,000,000	324,000,000	429,000,000	567,000,000

Table No. 64—Average flow of Croton river at old Croton dam, including storage draft, with catchment area and reservoirs as existing in the given year for the years 1868–1899, inclusive (*continued*)

(Freeman's table at pages 206-207 of his report. In gallons per day.)

MONTH (25)	1889 (26)	1890 (27)	1891 (28)	1892 (29)	1893 (30)	1894 (31)
January	775,000,000	390,000,000	1,231,000,000	913,000,000	278,000,000	292,000,000
February	444,000,000	618,000,000	1,135,000,000	321,000,000	687,000,000	404,000,000
March	355,000,000	844,000,000	836,000,000	413,000,000	1,246,000,000	883,000,000
April	460,000,000	589,000,000	504,000,000	257,000,000	620,000,000	424,000,000
May	294,000,000	461,000,000	155,000,000	279,000,000	1,049,000,000	322,000,000
June	250,000,000	269,000,000	112,000,000	209,000,000	173,000,000	259,000,000
July	272,000,000	127,000,000	48,000,000	106,000,000	60,000,000	48,000,000
August	719,000,000	89,000,000	60,000,000	183,000,000	121,000,000	48,000,000
September	404,000,000	394,000,000	53,000,000	91,000,000	93,000,000	119,000,000
October	324,000,000	596,000,000	44,000,000	42,000,000	229,000,000	100,000,000
November	970,000,000	369,000,000	120,000,000	320,000,000	359,000,000	641,000,000
December	805,000,000	294,000,000	297,000,000	273,000,000	708,000,000	451,000,000
Yearly mean	506,000,000	419,000,000	379,000,000	284,000,000	469,000,000	332,000,000

Table No. 64—Average flow of Croton river at old Croton dam, including storage draft, with catchment area and reservoirs as existing in the given year for the years 1868–1899, inclusive (*concluded*)

(Freeman's table at pages 206-207 of his report. In gallons per day.)

MONTH	1895	1896	1897	1898	1899
(32)	(33)	(34)	(35)	(36)	(37)
January	584,000,000	383,000,000	371,000,000	652,000,000	622,000,000
February	201,000,000	850,000,000	603,000,000	953,000,000	571,000,000
March	645,000,000	1,367,000,000	647,000,000	570,000,000	1,331,000,000
April	743,000,000	556,000,000	467,000,000	387,000,000	724,000,000
May	225,000,000	104,000,000	513,000,000	856,000,000	172,000,000
June	65,000,000	167,000,000	253,000,000	318,000,000	81,000,000
July	89,000,000	125,000,000	500,000,000	85,000,000	178,000,000
August	48,000,000	98,000,000	571,000,000	526,000,000	41,000,000
September	44,000,000	119,000,000	159,000,000	143,000,000	152,000,000
October	61,000,000	156,000,000	99,000,000	189,000,000	91,000,000
November	144,000,000	334,000,000	275,000,000	450,000,000	139,000,000
December	231,000,000	252,000,000	498,000,000	649,000,000	150,000,000
Yearly mean	257,000,000	374,000,000	413,000,000	479,000,000	359,000,000

TABLE NO. 65—RUNOFF OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1899, INCLUSIVE

(In cubic feet per second. Catchment area = 339 square miles)

MONTH (1)	1868 (2)	1869 (3)	1870 (4)	1871 (5)	1872 (6)	1873 (7)	1874 (8)	1875 (9)	1876 (10)	1877 (11)	1878 (12)
December	*586	408	846	156	589	365	786	237	460	172	506
January	514	588	1,040	152	537	1,128	2,433	158	373	207	758
February	282	574	1,253	644	336	481	801	1,202	1,040	424	1,122
March	1,148	1,462	928	921	452	1,063	783	846	1,869	1,818	1,016
April	1,029	916	1,214	532	837	1,960	979	1,527	1,703	794	444
May	1,567	749	469	531	323	559	829	470	517	229	395
Storage period	860	785	952	487	512	928	1,107	728	989	609	701
June	893	354	218	377	317	142	238	150	181	159	388
July	288	158	132	181	155	127	367	145	139	130	186
August	541	90	132	221	427	186	227	1,431	130	127	169
Growing period	570	199	160	258	298	152	278	580	150	138	246
September	1,485	54	97	164	322	138	153	226	102	93	633
October	777	701	111	523	282	368	203	212	101	271	237
November	931	563	167	1,012	716	453	184	588	186	1,168	557
Replenishing period	1,061	442	125	577	438	320	180	341	129	508	473
Yearly mean	837	552	546	452	440	581	667	594	564	465	530

*Interpolated—mean of 31 years.

TABLE No. 65—RUNOFF OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1899, INCLUSIVE (*continued*)

(In cubic feet per second. Catchment area = 339 square miles)

MONTH	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889
(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
December	2,053	495	138	461	334	161	1,030	548	314	650	1,439
January	362	709	192	614	291	523	1,145	930	758	1,097	1,204
February	798	817	1,323	128	1,009	1,513	738	1,429	1,496	1,375	692
March	1,120	764	1,589	1,364	763	1,343	534	658	996	1,286	548
April	1,380	551	498	376	736	814	709	1,289	913	1,399	704
May	492	229	353	603	348	495	408	560	342	718	453
Storage period	1,036	592	673	600	572	800	761	881	791	1,137	843
June	235	138	455	450	181	178	155	212	320	374	388
July	186	138	147	176	132	212	132	156	710	147	418
August	368	132	132	132	132	311	149	147	951	288	1,115
Growing period	263	136	242	251	148	234	145	171	664	269	643
September	296	132	132	899	133	193	118	132	246	905	627
October	162	130	132	582	170	142	141	132	274	678	506
November	209	152	124	252	181	265	565	234	261	859	1,491
Replenishing period	222	138	129	578	161	199	273	166	260	813	871
Yearly mean	638	365	429	506	363	508	487	524	627	838	800

TABLE NO. 65—RUNOFF OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1899. INCLUSIVE (*concluded*)

(In cubic feet per second. Catchment area = 339 square miles)

MONTH (25)	1890 (26)	1891 (27)	1892 (28)	1893 (29)	1894 (30)	1895 (31)	1896 (32)	1897 (33)	1898 (34)	1899 (35)	Mean (36)
December	1,253	450	333	441	880	599	255	309	608	903	.....
January	605	1,903	1,006	503	444	795	348	371	1,010	1,075	.....
February	948	1,757	418	863	620	309	702	644	1,470	871	.....
March	1,306	1,170	507	1,723	1,363	907	1,564	828	886	2,051	.....
April	910	681	330	958	653	1,067	791	681	597	1,119	.....
May	709	249	391	1,621	498	351	158	764	1,318	336	.....
Storage period	955	1,025	499	1,021	746	675	635	598	976	1,062	798
June	416	220	331	283	424	255	311	405	526	351	.....
July	225	221	248	251	258	255	289	719	320	340	.....
August	164	229	241	292	249	265	313	826	599	354	.....
Growing period	266	223	273	275	309	258	304	653	481	348	300
September	580	223	266	254	261	277	300	342	350	348	.....
October	910	217	232	334	244	254	302	300	391	353	.....
November	572	189	419	422	659	244	439	308	568	353	.....
Replenishing period	690	210	305	337	386	258	347	316	436	351	376
Yearly mean	716	620	394	662	546	466	480	543	716	705	568

TABLE No. 66—RUNOFF DATA OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1876, INCLUSIVE

(In inches)

(Catchment area = 339 square miles)

MONTH	1868			1869			1870			1871			1872		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	2.12	......	......	1.39	......	......	2.86	......	......	0.53	......	......	2.01	......
January	......	1.75	......	......	1.99	......	......	3.54	......	......	0.52	......	......	1.83	......
February	......	0.71	......	......	1.88	......	......	3.85	......	......	1.98	......	......	1.07	......
March	......	3.97	......	......	4.95	......	......	3.16	......	......	3.13	......	......	1.54	......
April	......	3.39	......	......	3.01	......	......	4.00	......	......	1.75	......	......	2.76	......
May	......	5.31	......	......	2.53	......	......	1.60	......	......	1.81	......	......	1.10	......
Storage period	......	17.25	......	......	15.75	......	......	19.01	......	......	9.72	......	......	10.31	......
June	......	2.93	......	......	1.16	......	......	0.72	......	......	1.24	......	......	1.04	......
July	......	0.98	......	......	0.54	......	......	0.43	......	......	0.62	......	......	0.52	......
August	......	1.84	......	......	0.31	......	......	0.41	......	......	0.75	......	......	1.45	......
Growing period	......	5.75	......	......	2.01	......	......	1.56	......	......	2.61	......	......	3.01	......
September	......	4.88	......	......	0.18	......	......	0.15	......	......	0.54	......	......	1.06	......
October	......	2.65	......	......	2.37	......	......	0.25	......	......	1.78	......	......	0.96	......
November	......	3.53	......	......	1.84	......	......	0.56	......	......	3.33	......	......	2.36	......
Replenishing period	......	11.06	......	......	4.39	......	......	0.96	......	......	5.65	......	......	4.38	......
Yearly total	......	34.06	......	......	22.15	......	......	21.53	......	......	17.98	......	......	17.70	......

TABLE No. 66—RUNOFF DATA OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1876, INCLUSIVE (*concluded*)

(In inches)

(Catchment area = 339 square miles)

MONTH	1873			1874			1875			1876			MEAN		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evopo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	1.24	......	......	3.00	......	......	0.87	......	......	1.56	......	......	......	......
January	......	3.83	......	......	8.32	......	......	0.48	......	......	1.27	......	......	......	......
February	......	1.48	......	......	2.53	......	......	3.85	......	......	3.31	......	......	......	......
March	......	3.62	......	......	2.97	......	......	2.90	......	......	6.37	......	......	......	......
April	......	6.45	......	......	3.22	......	......	5.11	......	......	5.62	......	......	......	......
May	......	1.90	......	......	2.82	......	......	1.60	......	......	1.76	......	......	......	......
Storage period	......	18.52	......	......	22.86	......	......	14.81	......	......	19.89	......	......	16.46	......
June	......	0.43	......	......	0.78	......	......	0.46	......	......	0.57	......	......	......	......
July	......	0.44	......	......	1.25	......	......	0.32	......	......	0.25	......	......	......	......
August	......	0.67	......	......	0.74	......	......	5.08	......	......	0.25	......	......	......	......
Growing period	......	1.54	......	......	2.77	......	......	5.86	......	......	1.07	......	......	2.91	......
September	......	0.45	......	......	0.32	......	......	0.75	......	......	0.34	......	......	......	......
October	......	1.26	......	......	0.72	......	......	0.72	......	......	0.33	......	......	......	......
November	......	1.49	......	......	0.56	......	......	1.94	......	......	0.68	......	......	......	......
Replenishing period	......	3.20	......	......	1.60	......	......	3.41	......	......	1.35	......	......	4.00	......
Yearly total	......	23.26	......	......	27.23	......	......	24.08	......	......	22.31	......	......	23.37	......

TABLE No. 67—RUNOFF DATA OF CROTON RIVER FOR THE WATER YEARS 1877-1899, INCLUSIVE

(In inches)

(Catchment area = 339 square miles)

MONTH	1877			1878			1879			1880			1881		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	2.35	0.33	......	1.46	1.73	......	7.62	7.13	......	4.44	1.46	......	2.59	0.38	......
January	2.86	0.75	......	4.71	2.59	......	2.69	1.23	......	3.43	2.45	......	4.85	0.79	......
February	0.94	1.37	......	4.06	3.45	......	3.14	2.46	......	3.40	2.77	......	5.25	4.59	......
March	8.11	6.52	......	3.04	3.46	......	4.57	3.82	......	3.90	2.76	......	6.54	6.12	......
April	2.47	2.62	......	3.05	1.51	......	4.76	4.56	......	3.57	1.92	......	1.27	1.69	......
May	0.76	0.77	......	4.66	1.45	......	2.29	1.61	......	1.04	0.83	......	4.03	1.22	......
Storage period	17.49	12.36	5.13	20.99	14.19	6.80	25.17	20.81	4.36	19.78	12.19	7.59	24.53	14.79	9.74
June	5.16	0.52	......	4.18	1.37	......	5.27	0.79	......	1.40	0.28	......	4.67	1.50	......
July	5.26	0.21	......	4.05	0.65	......	5.87	0.66	......	5.86	0.26	......	2.48	0.38	......
August	2.75	0.23	......	3.06	0.55	......	6.59	1.18	......	4.16	0.14	......	2.46	0.07	......
Growing period	13.17	0.96	12.21	11.29	2.57	8.72	18.09	2.63	15.46	11.42	0.68	10.74	9.61	1.95	7.66
September	1.36	0.23	......	7.83	2.18	......	3.32	1.01	......	2.42	0.20	......	0.78	0.05	......
October	9.15	1.08	......	4.10	0.86	......	0.69	0.36	......	2.83	0.16	......	2.95	0.42	......
November	7.95	4.18	......	4.79	1.97	......	2.95	0.51	......	2.32	0.48	......	5.23	0.50	......
Replenishing period	18.46	5.49	12.97	16.72	5.01	11.71	6.96	1.88	5.08	7.57	0.84	6.73	8.96	0.97	7.99
Yearly total	49.12	18.81	30.31	49.00	21.77	27.23	50.22	25.32	24.90	38.77	13.71	25.06	43.10	17.71	25.39

TABLE NO. 67—RUNOFF DATA OF CROTON RIVER FOR THE WATER YEARS 1877–1899, INCLUSIVE (*continued*)

(In inches)

(Catchment area = 339 square miles)

MONTH	1882			1883			1884			1885			1886		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	6.18	2.00	......	2.49	1.02	......	3.65	0.61	......	6.39	3.63	......	3.08	2.16	......
January	4.68	2.59	......	3.40	1.00	......	4.87	2.13	......	5.41	3.89	......	5.42	3.19	......
February	5.72	4.31	......	5.38	3.10	......	5.52	5.10	......	4.44	2.27	......	4.92	4.41	......
March	3.99	4.65	......	1.78	2.62	......	3.99	4.61	......	1.26	1.82	......	3.91	2.24	......
April	1.42	1.24	......	3.42	2.44	......	2.88	2.71	......	2.27	2.33	......	3.84	4.25	......
May	5.92	2.06	......	2.56	1.19	......	3.90	1.69	......	2.09	1.42	......	4.28	1.91	......
Storage period	27.91	16.85	11.06	19.03	11.34	7.66	24.81	16.85	7.96	21.86	15.36	6.50	25.45	18.16	7.20
June	2.74	1.49	......	4.52	0.59	......	2.52	0.52	......	1.17	0.35	......	3.28	0.70	......
July	3.13	0.47	......	4.89	0.35	......	6.31	0.77	......	5.01	0.19	......	5.31	0.46	......
August	3.16	0.10	......	2.69	0.15	......	6.89	1.05	......	6.71	0.34	......	3.09	0.37	......
Growing period	9.03	2.06	6.97	12.10	1.09	11.01	15.72	2.34	13.38	12.89	0.88	12.01	11.68	1.53	10.15
September	14.63	3.35	......	2.61	0.05	......	0.85	0.52	......	1.10	0.13	......	2.29	0.13	......
October	2.86	2.02	......	6.24	0.49	......	2.92	0.34	......	5.17	0.44	......	2.14	0.16	......
November	1.61	0.84	......	1.56	0.74	......	4.24	1.01	......	5.96	2.35	......	5.39	0.94	......
Replenishing period	19.10	6.21	12.89	10.41	1.28	9.13	8.01	1.87	6.14	12.23	2.92	9.31	9.82	1.23	8.59
Yearly total	56.04	25.12	30.92	41.54	13.74	27.80	48.54	21.06	27.48	46.98	19.16	27.82	46.95	20.92	26.03

TABLE NO. 67—RUNOFF DATA OF CROTON RIVER FOR THE WATER YEARS 1877–1899, INCLUSIVE (*continued*)

(In inches)

(Catchment area = 339 square miles)

MONTH	1887			1888			1889			1890			1891		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	3.87	1.34	......	5.58	2.21	......	5.93	4.90	......	3.03	4.24	......	3.86	1.55	......
January	5.77	2.87	......	5.31	3.72	......	5.05	4.08	......	2.54	2.05	......	9.06	6.48	......
February	6.29	4.64	......	5.02	4.37	......	2.25	2.11	......	4.38	2.94	......	5.71	5.40	......
March	3.72	3.39	......	5.81	4.38	......	1.76	1.87	......	6.09	4.44	......	3.42	4.40	......
April	3.09	3.04	......	2.57	4.60	......	4.45	2.35	......	3.43	3.00	......	3.02	2.57	......
May	0.31	1.16	......	6.04	2.46	......	2.96	1.55	......	5.84	2.43	......	1.59	0.82	......
Storage period	23.05	16.44	6.61	30.33	21.74	8.59	22.40	16.86	5.54	25.31	19.10	6.21	26.66	21.22	5.44
June	6.79	1.06	......	2.24	1.24	......	3.87	1.27	......	3.97	1.37	......	2.13	0.57	......
July	11.23	2.42	......	2.41	0.40	......	9.77	1.43	......	5.07	0.67	......	4.08	0.25	......
August	6.73	3.23	......	6.60	0.99	......	3.73	3.79	......	4.27	0.47	......	5.05	0.32	......
Growing period	24.75	6.71	18.04	11.25	2.63	8.62	17.37	6.49	10.88	13.31	2.51	10.80	11.26	1.14	10.12
September	1.70	0.80	......	10.00	3.11	......	6.42	2.06	......	6.78	2.01	......	1.97	0.27	......
October	3.56	0.94	......	4.69	2.29	......	3.87	1.70	......	6.73	3.14	......	2.32	0.23	......
November	2.52	0.86	......	4.07	2.83	......	8.54	4.94	......	1.09	1.87	......	3.49	0.61	......
Replenishing period	7.78	2.60	5.18	18.76	8.23	10.53	18.83	8.70	10.13	14.60	7.02	7.58	7.78	1.11	6.67
Yearly total	55.58	25.75	29.83	60.34	32.60	27.74	58.60	32.05	26.55	53.22	28.63	24.59	45.70	23.47	22.23

TABLE NO. 67—RUNOFF DATA OF CROTON RIVER FOR THE WATER YEARS 1877–1899, INCLUSIVE (*continued*)

(In inches)

(Catchment area = 339 square miles)

MONTH	1892			1893			1894			1895			1896		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	5.36	1.56	......	1.04	1.44	......	5.10	3.73	......	4.19	2.37	......	4.49	1.22	......
January	6.18	4.82	......	3.61	1.46	......	3.22	1.54	......	4.70	3.08	......	1.14	2.02	......
February	1.14	1.53	......	7.43	3.27	......	4.60	1.88	......	1.86	0.96	......	7.27	4.19	......
March	3.61	2.18	......	4.25	6.56	......	1.77	4.65	......	2.12	3.40	......	7.71	7.20	......
April	1.08	1.31	......	3.13	3.16	......	2.83	2.16	......	4.57	3.78	......	1.20	2.83	......
May	5.56	1.47	......	7.88	5.52	......	5.72	1.69	......	2.11	1.19	......	3.03	0.55	......
Storage period	22.93	12.87	10.06	27.34	21.41	5.93	23.24	15.65	7.59	19.55	14.78	4.77	24.84	18.01	6.83
June	3.54	1.07	......	2.38	0.88	......	1.56	1.32	......	2.35	0.33	......	3.88	0.85	......
July	5.71	0.56	......	2.88	0.32	......	2.68	0.25	......	4.73	0.47	......	4.52	0.66	......
August	6.12	0.97	......	7.13	0.64	......	3.71	0.25	......	4.11	0.25	......	3.84	0.52	......
Growing period	15.37	2.60	12.77	12.39	1.84	10.55	7.95	1.82	6.13	11.19	1.05	10.14	12.25	2.03	10.22
September	2.25	0.47	......	2.56	0.47	......	6.70	0.61	......	1.32	0.22	......	5.39	0.61	......
October	0.93	0.22	......	5.39	1.21	......	5.72	0.53	......	3.64	0.32	......	2.31	0.82	......
November	7.12	1.63	......	3.13	1.83	......	4.63	3.27	......	4.58	0.73	......	3.57	1.70	......
Replenishing period	10.30	2.31	7.99	11.08	3.51	7.57	17.05	4.41	12.64	9.54	1.27	8.27	11.27	3.13	8.14
Yearly total	48.60	17.78	30.82	50.81	26.76	24.05	48.24	21.88	26.36	40.28	17.10	23.18	48.36	23.17	25.19

TABLE NO. 67—RUNOFF DATA OF CROTON RIVER FOR THE WATER YEARS 1877–1899, INCLUSIVE (*concluded*)

(In inches)

(Catchment area = 339 square miles)

MONTH	1897			1898			1899			MEAN		
	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration	Rain-fall	Runoff	Evapo-ration
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	1.98	1.33	......	4.98	2.62	......	3.04	3.42	......	......	......	......
January	3.49	1.95	......	4.98	3.44	......	3.85	3.64	......	......	......	......
February	2.67	2.87	......	4.51	4.53	......	5.43	2.72	......	......	......	......
March	3.40	3.41	......	2.90	3.00	......	6.63	7.01	......	......	......	......
April	3.01	2.38	......	3.67	1.98	......	1.75	3.68	......	......	......	......
May	6.02	2.70	......	7.77	4.51	......	1.96	0.91	......	......	......	......
Storage period	20.55	14.64	5.91	28.81	20.08	8.73	22.66	21.38	1.28	23.68	16.83	6.85
June	3.10	1.29	......	1.41	1.62	......	5.62	0.41	......	......	......	......
July	12.49	2.63	......	4.24	0.44	......	5.93	0.94	......	......	......	......
August	5.20	3.01	......	11.52	2.77	......	0.64	0.22	......	......	......	......
Growing period	20.79	6.93	13.86	17.17	4.83	12.34	12.19	1.57	10.62	13.58	2.57	11.01
September	1.82	0.81	......	2.24	0.73	......	7.19	0.77	......	......	......	......
October	1.25	0.52	......	4.83	0.97	......	1.27	0.48	......	......	......	......
November	5.69	1.40	......	6.29	2.29	......	1.91	0.71	......	......	......	......
Replenishing period	8.76	2.73	6.03	13.36	3.99	9.37	10.37	1.96	8.41	12.08	3.42	8.66
Yearly total	50.10	24.30	25.80	59.34	28.90	30.44	45.22	24.91	20.31	49.33	22.81	26.52

TABLE NO. 68—RUNOFF OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1899, INCLUSIVE

(In cubic feet per second per square mile. Catchment area = 339 square miles)

MONTH	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
December	*1.73	1.21	2.49	0.46	1.74	1.08	2.32	0.70	1.36	0.36	1.49
January	1.52	1.74	3.07	0.45	1.58	3.33	7.18	0.46	1.10	0.61	2.24
February	0.68	1.69	3.70	1.90	0.99	1.42	2.37	3.55	3.07	1.25	3.31
March	3.39	4.32	2.74	2.71	1.33	3.14	2.31	2.49	5.52	5.37	3.00
April	3.04	2.71	3.59	1.57	2.47	5.79	2.89	4.51	5.03	2.34	1.31
May	4.64	2.21	1.38	1.56	0.96	1.65	2.45	1.39	1.53	0.67	1.17
Storage period	2.52	2.31	2.81	1.44	1.51	2.74	3.27	2.15	2.92	1.80	2.07
June	2.64	1.05	0.64	1.12	0.94	0.42	0.70	0.44	0.53	0.47	1.15
July	0.85	0.46	0.39	0.53	0.46	0.37	1.08	0.43	0.41	0.38	0.55
August	1.59	0.26	0.39	0.65	1.26	0.55	0.67	4.22	0.38	0.37	0.49
Growing period	1.68	0.59	0.47	0.76	0.88	0.45	0.82	1.71	0.44	0.41	0.73
September	4.38	0.16	0.28	0.48	0.95	0.41	0.45	0.67	0.30	0.27	1.87
October	2.29	2.07	0.33	1.54	0.83	1.09	0.59	0.63	0.29	0.79	0.69
November	2.75	1.66	0.49	2.98	2.12	1.34	0.51	1.74	0.55	3.45	1.64
Replenishing period	3.13	1.30	0.37	1.66	1.29	0.94	0.53	1.01	0.38	1.50	1.40
Yearly mean	2.46	1.63	1.61	1.33	1.30	1.71	1.97	1.75	1.66	1.37	1.56

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*Interpolated—mean of thirty-one years.

TABLE No. 68—RUNOFF OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1899, INCLUSIVE (*continued*)

(In cubic feet per second per square mile. Catchment area = 339 square miles)

MONTH	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889
(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
December	6.06	1.46	0.41	1.36	0.98	0.47	3.04	1.62	0.93	1.92	4.25
January	1.07	2.09	0.56	1.81	0.86	1.54	3.38	2.74	2.24	3.24	3.55
February	2.36	2.41	3.91	3.79	2.98	4.47	2.18	4.22	4.42	4.06	2.04
March	3.31	2.26	4.69	4.03	2.25	3.96	1.57	1.91	2.94	3.79	1.62
April	4.08	1.63	1.47	1.11	2.17	2.40	2.09	3.80	2.69	4.13	2.08
May	1.45	0.67	1.04	1.78	1.03	1.46	1.21	1.65	1.01	2.12	1.34
Storage period	3.06	1.75	1.98	1.77	1.69	2.36	2.24	2.60	2.33	3.35	2.49
June	0.69	0.41	1.34	1.33	0.53	0.52	0.46	0.63	0.94	1.11	1.15
July	0.55	0.41	0.43	0.52	0.39	0.63	0.39	0.46	2.09	0.43	1.23
August	1.08	0.39	0.39	0.39	0.39	0.92	0.44	0.43	2.81	0.85	3.29
Growing period	0.78	0.40	0.71	0.74	0.44	0.69	0.43	0.50	1.95	0.79	1.90
September	0.87	0.39	0.39	2.65	0.39	0.57	0.35	0.39	0.72	2.67	1.85
October	0.48	0.38	0.39	1.72	0.50	0.42	0.42	0.39	0.81	2.00	1.49
November	0.62	0.45	0.36	0.74	0.53	0.78	1.67	0.69	0.77	2.54	4.41
Replenishing period	0.65	0.41	0.38	1.70	0.47	0.59	0.81	0.49	0.77	2.40	2.57
Yearly mean	1.88	1.08	1.26	1.49	1.07	1.50	1.43	1.54	1.85	2.47	2.36

TABLE No. 68—RUNOFF OF CROTON RIVER AT OLD CROTON DAM FOR THE WATER YEARS 1868–1899, INCLUSIVE (*concluded*)

(In cubic feet per second per square mile. Catchment area = 339 square miles)

MONTH	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	Mean
(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
December	3.70	1.33	0.98	1.30	2.60	1.77	0.75	0.91	1.79	2.67	......
January	1.78	5.62	2.97	1.49	1.31	2.35	1.03	1.10	2.98	3.17	......
February	2.82	5.19	1.23	2.55	1.83	0.91	2.07	1.90	4.34	2.57	......
March	3.86	3.45	1.49	5.09	4.03	2.68	4.62	2.44	2.62	6.06	......
April	2.68	2.01	0.97	2.83	1.93	3.15	2.34	2.01	1.76	3.30	......
May	2.09	0.74	1.15	4.79	1.47	1.04	0.47	2.26	3.89	0.99	......
Storage period	2.82	3.02	1.47	3.01	2.20	1.99	1.87	1.76	2.88	3.13	2.35
June	1.23	0.64	0.98	0.84	1.25	0.75	0.92	1.19	1.55	1.03	......
July	0.66	0.65	0.73	0.74	0.76	0.75	0.85	2.13	0.95	1.00	......
August	0.48	0.67	0.71	0.86	0.74	0.78	0.92	2.44	1.77	1.04	......
Growing period	0.79	0.66	0.81	0.81	0.91	0.76	0.90	1.93	1.42	1.02	0.88
September	1.71	0.66	0.78	0.75	0.77	0.82	0.88	1.01	1.03	1.02	......
October	2.68	0.64	0.68	0.98	0.72	0.75	0.89	0.88	1.15	1.04	......
November	1.69	0.56	1.24	1.25	1.95	0.72	1.29	0.91	1.67	1.04	......
Replenishing period	2.04	0.62	0.90	0.99	1.14	0.76	1.02	0.93	1.29	1.03	1.11
Yearly mean	2.11	1.83	1.16	1.95	1.61	1.37	1.42	1.60	2.11	2.08	1.67

Table No. 64 gives the average daily flow of the Croton river at the old Croton dam, including storage draft with catchment area and reservoirs as existing in the given years. This table is computed from the observed flow by deducting the quantity corresponding to lowering of storage reservoirs or adding the quantity taken to refill, without allowance for evaporation loss from storage reservoirs. In his table, the average for each calendar month is given in gallons for each day of twenty-four hours.[1]

In table No. 65 the mean monthly flow of the Croton river at the old Croton dam is given from 1868 to 1899, inclusive, in cubic feet per second.[2]

In table No. 66 the runoff in inches on the catchment area is given from 1868 to 1876, inclusive. The rainfall is not given because Mr Freeman's investigations showed that previous to 1877 the Croton rainfall is so uncertain as to make it unsafe to draw comparisons.

In table No. 67 the rainfall, runoff and evaporation is given in inches on the catchment area for the water years from 1877 to 1899, inclusive.[3]

In table No. 68 the mean monthly flow of the Croton river at the old Croon dam is given from 1868 to 1899, inclusive, in cubic feet per second per square mile.[4]

It will be seen that the tables on pages 204-5 and on pages 206-7 of Mr Freeman's report vary somewhat under the different suppositions on which they have been computed. There is another table on pages 208-9, giving the average daily flow at the new Croton dam exclusive of storage draft with rainfall as in the given year and with reservoirs as in 1902. This table has been computed from the natural flow at the old dam for the given year and month by adding 6.4 per cent for increase in catchment area and deducting an allowance for evaporation loss caused by substituting water surface for land surface in the new reservoirs constructed between the given years and 1902. The total catchment area is taken at 360 square miles, with 16.1 square miles—equivalent to

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[1] From pp. 206-7 of Freeman's report.

[2] This table is based on the table on pp. 204-5 of Freeman's report.

[3] The basis of tables Nos. 66 and 67 is the table on pp. 206-7 of Freeman's report.

[4] This table is based on the table on pp. 204-5 of Freeman's report.

4.5 per cent—as water surface. The quantities in this table are averages for the calendar months in million gallons per day of twenty-four hours. This table is not given here, because it is in effect a computation as to the future yield of this basin.

Geologically this catchment lies almost entirely in granites and gneisses, although there is a small area of metamorphic Hudson formation, consisting of slate, schist and quartzite, and also a small area of metamorphic Trenton and calciferous limestones.

The present water supply of New York city is derived from the following sources:

1) Catchment of Croton river, thirty-three miles north of New York.

2) Catchment of Bronx and Byram rivers, fifteen miles north of New York.

3) Catchments of a series of streams on the southern shore of Long Island.

4) Ground water which is found underlying a stratum of clay on Long Island and on Staten Island. These statements do not take into account some unimportant well supplies on Manhattan island.

Discharge measurements of Schroon river. This gaging station was established at the dam of the Schroon River Pulp Company, two miles below Warrensburg, November 1, 1895, in connection with the upper Hudson storage surveys. During ordinary water an attempt is made to turn the entire flow of the stream through the water wheels, which run twenty-four hours per day, Sundays excepted. This is accomplished by the use of flashboards and by draft from the storage impounded by the Starbuckville dam. The natural flow of the Schroon river is considerably modified by the temporary storage of Schroon lake, which has a low-water area of 9.1 square miles. There is a dam at Starbuckville, controlled by the Schroon River Pulp Company and which stores from 4 to 5 feet in depth over Schroon lake area, which is let down as required for use during the summer months. This fact explains why the Schroon river area apparently yields more water proportionately in the storage period than the entire Hudson area and less in the replenishing period.

TABLE No. 69.—RUN OFF OF SCHROON RIVER AT WARRENSBURG FOR THE WATER YEARS 1896–1901, INCLUSIVE.

(Catchment area = 563 square miles)

MONTH	1896			1897			1898			1899		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	1,233	2.53	2.19	243	0.48	0.43	2,776	5.69	4.93	783	1.61	1.39
January	2,779	5.70	4.92	335	0.69	0.60	852	1.75	1.16	606	1.25	1.08
February	516	0.93	0.92	188	0.35	0.33	416	0.77	0.74	478	0.89	0.85
March	1,664	3.41	2.96	738	1.51	1.31	3,194	6.55	5.68	564	1.16	1.00
April	3,280	6.51	5.83	3,164	6.28	5.80	2,853	5.66	5.07	2,877	5.72	5.11
May	728	1.49	1.11	1,822	3.73	3.24	2,203	4.52	3.91	3,150	6.47	5.60
Storage period	1,711	20.57	3.00	1,085	13.04	1.93	2,017	24.94	3.58	1,417	17.10	2.52
June	827	1.64	1.47	2,384	4.73	4.24	568	1.13	1.01	1,093	2.17	1.94
July	276	0.57	0.49	1,426	2.92	2.54	216	0.44	0.38	*210	0.43	0.37
August	265	0.54	0.47	1,377	2.82	2.45	223	0.46	0.40	*150	0.31	0.27
Growing period	452	2.75	0.80	1,722	10.47	3.06	333	2.03	0.59	477	2.91	0.85
September	215	0.43	0.38	281	0.56	0.50	166	0.33	0.30	*234	0.46	0.41
October	330	0.68	0.59	161	0.33	0.29	263	0.54	0.47	462	0.95	0.82
November	1,089	2.16	1.94	2,077	4.12	3.69	464	0.92	0.82	1,047	2.08	1.86
Replenishing period	542	3.27	0.97	832	5.01	1.48	297	1.79	0.53	580	3.49	1.03
Yearly mean or total	1,102	26.59	1.94	1,184	28.52	2.10	1,166	28.76	2.07	971	23.50	1.74

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* Records not kept from July 13 to September 19, inclusive — flow for this period has been taken as 150 cubic feet per second, being the assumed leakage of Starbuckville dam.

TABLE NO. 69.—RUNOFF OF SCHROON RIVER AT WARRENSBURG FOR THE WATER YEARS 1896–1901, INCLUSIVE—*Concluded.*
(Catchment area = 563 square miles.)

MONTH	1900			1901			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment.	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	948	1.93	1.68	773	1.58	1.37	......	......	......
January	810	1.66	1.44	774	1.59	1.38	......	......	......
February	1,380	2.54	2.45	561	1.04	1.00	......	......	......
March	1,140	2.32	2.02	658	1.35	1.17	......	......	......
April	3,688	7.31	6.55	4,786	9.50	8.48	......	......	......
May	1,688	3.46	3.00	2,235	4.55	3.96	......	......	......
Storage period	1,601	19.22	2.84	1,632	19.61	2.90	1,577	19.08	2.80
June	1,280	2.53	2.27	1,522	3.01	2.69	......	......	......
July	528	1.05	0.94	617	1.24	1.09	......	......	......
August	474	0.97	0.84	481	0.98	0.85	......	......	......
Growing period	754	4.55	1.34	866	4.23	1.54	767	4.49	1.36
September	285	0.56	0.50	650	1.29	1.15	......	......	......
October	488	0.99	0.86	685	1.39	1.21	......	......	......
November	530	1.05	0.94	588	1.18	1.05	......	......	......
Replenishing period	435	2.60	0.77	641	3.86	1.14	555	3.34	0.99
Yearly mean or total	1,097	26.37	1.95	1,192	27.70	2.12	1,119	26.91	1.99

A comparison of the gagings at Warrensburg with those of the Hudson river at Mechanicville indicates that the runoff of Schroon river is considerably greater than that of the Hudson, the difference occurring mostly in the storage period. This is probably true, although some uncertainty attaches to the gagings at Warrensburg, owing to an increase in the leakage from year to year. The writer visited Warrensburg in October, 1895. At that time the pulp mill was not running, and due to the fact that Starbuckville dam was closed tightly very little water was running in Schroon river. The water in the Warrensburg dam stood about 4 feet below the crest. The bed of Schroon river below the dam was very nearly dry, the flow not exceeding one to two cubic feet per second. The writer has not seen this dam in several years, but reports indicate that the leakage may be anywhere from 30 to 50 cubic feet per second.

When the flashboards are on, the computations have been calculated by means of Francis' formula for sharp-crested weir. Without the flashboards, the quantities are taken from a diagram deduced from the Cornell University experiments. In 1902 this mill was rebuilt.

Geologically the headwaters of this stream lie in the horizon of the Plutonic norites and flow across the unclassified granites and gneisses.

Discharge measurements of Mohawk river at Dunsbach Ferry. Mohawk river has been an important avenue of commerce ever since the early settlement of the country. Nevertheless very little was known as to the water yield until the investigations of the Board of Engineers on Deep Waterways in 1898-9. The writer established for this Board gaging stations at Ridge Mills, Little Falls and Rexford Flats. The station at Dunsbach Ferry was established in March, 1898, by D. J. Howell. At present gagings over dams are kept at Dunsbach Ferry and Little Falls, while gagings by current meter are made at Schenectady and Utica.

The Dunsbach Ferry record is kept at the dam of the West Troy Water Company, just above Dunsbach Ferry bridge, nine miles from the mouth of the river. This dam is in two sections, on opposite sides of an island. The left wing has a crest length of 380 feet, while the right wing has a crest 280 feet long. The discharge over the main dam has been calculated by means of a coefficient determined in Cornell University experiment No. 18, representing a cross-section nearly identical with that of the West Troy Water Company's dam. With a rise of 5 feet on the gage, the water begins to flow over a masonry racewall. The discharge over this portion has been computed from Cornell University experiment No. 12, as detailed in the paper On the Flow of Water Over Dams. Plate 9 shows the dam on the Mohawk river at Dunsbach Ferry.

Discharge measurements of Mohawk river at Rexford Flats. This station is located at the canal feeder dam four miles below Schenectady, where there is a masonry dam with a timber apron. Experiments on the Rexford Flats cross-section were made at Cornell University. The following cut shows the dam on Mohawk river at Rexford Flats:

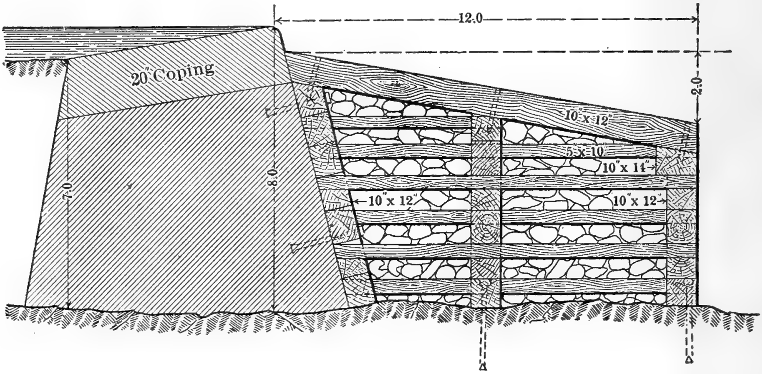
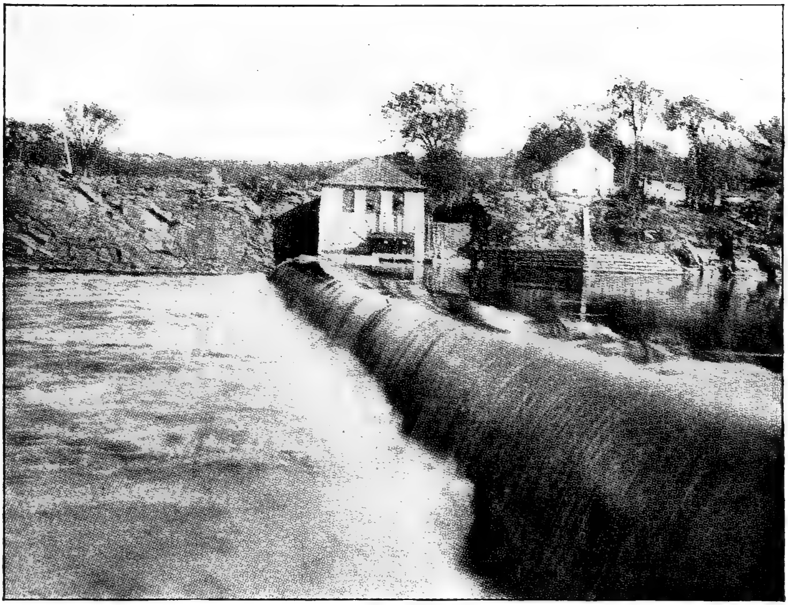


Fig. 28 Dam on Mohawk river at Rexford Flats.

Discharge measurements of Mohawk river at Little Falls. This gaging station is located at the lower or Gilbert's dam at Little Falls. It is a circular dam of masonry, furnishing power for the Astoronga Knitting Mill and the Little Falls Paper Company's Mills. There are six water wheels in these two mills, of which the records are kept. The following cut shows a section of this dam:

Plate 9.



Dam in the Mohawk river at Dunsbach Ferry.

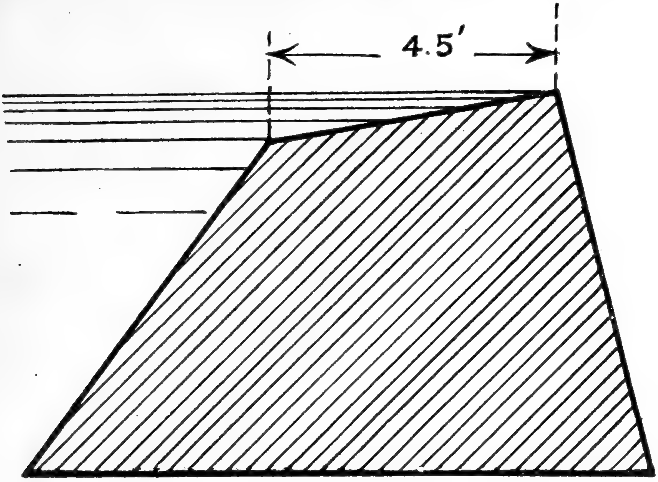


Fig. 29 Section of dam at Little Falls.

In addition to Gilbert's dam, there are two other dams at Little Falls, the upper one being a State dam, diverting water to the Erie canal. The record as given in table No. 72 does not include the diversion to the canal.

Discharge measurements of Mohawk river at Ridge Mills. The gaging station at Ridge Mills was located at the dam of the Rome Waterworks, three miles above Rome. This dam is of rough timber with plank facing, having a slightly irregular crest, 123 feet in length, which is divided into several sections to facilitate discharge computations. The computations have been made from data as per Cornell University experiment No. 6. The following cut shows a section of the dam on the Mohawk river at Ridge Mills in comparison with Bazin's series No. 162:

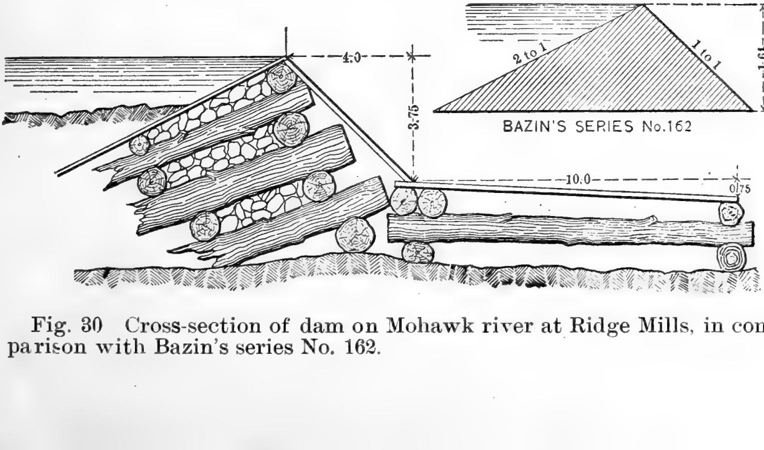


Fig. 30 Cross-section of dam on Mohawk river at Ridge Mills, in comparison with Bazin's series No. 162.

TABLE No. 70—RUNOFF OF MOHAWK RIVER AT DUNSBACH FERRY FOR THE WATER YEARS 1901–1902, INCLUSIVE

(Catchment area=3440 square miles).

MONTH	1900			1901			1902			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	......	......	5,362	1.79	1.56	8,055	2.79	2.42	......	......	......
January	......	......	......	2,567	0.86	0.75	3,253	1.09	0.95	......	......	......
February	......	......	......	1,141	0.34	0.33	1,948	0.59	0.57	......	......	......
March	......	......	......	9,332	3.13	2.72	[1]16,986	5.68	4.94	......	......	......
April	......	......	......	18,068	5.89	5.26	7,361	2.39	2.14	......	......	......
May	......	......	......	6,622	2.22	1.93	3,906	1.31	1.14	......	......	......
Storage period	......	......	......	7,222	14.23	2.10	6,998	13.85	2.03	7,110	14.04	2.07
June	......	......	......	6,300	2.05	1.83	3,554	1.15	1.03	......	......	......
July	......	......	......	1,633	0.54	0.47	4,251	1.43	1.24	......	......	......
August	......	......	......	1,580	0.53	0.46	2,592	0.86	0.75	......	......	......
Growing period	......	......	......	3,137	3.12	0.91	3,465	3.44	1.01	3,301	3.28	0.96
September	672	0.22	0.20	1,672	0.55	0.49	2,386	0.77	0.69	......	......	......
October	885	0.30	0.26	2,066	0.69	0.60	6,466	2.17	1.88	......	......	......
November	4,922	1.60	1.43	2,004	0.65	0.58	4,771	1.59	1.39	......	......	......
Replenishing period	2,146	2.12	0.62	1,916	1.89	0.56	4,562	4.53	1.33	3,239	3.21	0.94
Yearly mean or total	......	......	......	4,869	19.24	1.42	5,500	21.82	1.60	5,185	20.53	1.51

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[1] Record incomplete—flow for days of maximum discharge not available.

TABLE NO. 71—RUNOFF OF MOHAWK RIVER AT REXFORD FLATS FOR THE WATER YEARS 1899–1901, INCLUSIVE
(Catchment area = 3385 square miles)

MONTH	1899			1900			1901			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	4,471	1.52	1.32	7,001	2.38	2.07	6,066	2.06	1.79	......	......	......
January	5,739	1.96	1.70	7,860	2.67	2.32	2,822	0.95	0.83	......	......	......
February	3,935	1.21	1.17	9,032	2.77	2.67	1,299	0.40	0.38	......	......	......
March	9,004	3.06	2.66	4,235	1.44	1.25	9,221	3.14	2.72	......	......	......
April	17,057	5.62	5.04	14,996	4.94	4.43	16,701	5.52	4.93	......	......	......
May	4,084	1.38	1.20	2,857	0.96	0.84	6,348	2.15	1.87	......	......	......
Storage period	7,385	14.75	2.18	7,601	15.16	2.25	7,119	14.22	2.10	7,368	14.71	2.18
June	2,014	0.66	0.59	1,503	0.49	0.44	6,668	2.21	1.97	......	......	......
July	498	0.17	0.15	1,447	0.49	0.43	1,830	0.62	0.54	......	......	......
August	294	0.10	0.09	1,746	0.58	0.51	1,320	0.45	0.39	......	......	......
Growing period	924	0.93	0.27	1,566	1.56	0.46	3,236	3.28	0.96	1,909	1.92	0.56
September	980	0.32	0.29	9.81	0.32	0.29	1,995	0.66	0.59	......	......	......
October	1,608	0.54	0.47	784	0.26	0.23	1,057	0.36	0.31	......	......	......
November	2,824	0.92	0.83	8,440	2.79	2.49	2,090	0.69	0.62	......	......	......
Replenishing period	1,802	1.78	0.53	3,373	3.37	1.00	1,707	1.71	0.50	2,294	2.29	0.68
Yearly mean or total	4,365	17.46	1.29	5,026	20.09	1.48	4,791	19.21	1.42	4,727	18.92	1.40

TABLE No. 72—RUNOFF OF MOHAWK RIVER AT LITTLE FALLS FOR THE WATER YEARS 1899–1902, INCLUSIVE

(Catchment area = 1306 square miles)

MONTH	1898			1899			1900		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	.....	.....	.....	2,036	1.74	1.56	3,360	2.69	2.57
January	.....	.....	.....	2,753	2.35	2.11	5,523	4.86	4.23
February	.....	.....	.....	1,510	1.19	1.15	3,862	3.08	2.96
March	.....	.....	.....	3,757	3.32	2.88	2,469	2.18	1.89
April	.....	.....	.....	8,102	6.92	6.20	8,142	6.95	6.23
May	.....	.....	.....	2,651	2.34	2.03	2,063	1.82	1.58
Storage period	.....	.....	.....	3,475	17.86	2.66	4,221	21.58	3.23
June	.....	.....	.....	1,014	0.87	0.78	801	0.68	0.61
July	.....	.....	.....	803	0.70	0.61	943	0.83	0.72
August	.....	.....	.....	223	0.19	0.17	694	0.61	0.53
Growing period	.....	.....	.....	676	1.76	0.52	813	2.12	0.62
September	2,378	2.05	1.84	298	0.25	0.23	630	0.53	0.48
October	2,493	2.20	1.91	509	0.45	0.39	899	0.79	0.69
November	2,891	2.46	2.21	1,699	1.45	1.30	3,854	3.30	2.95
Replenishing period	2,586	6.71	1.98	832	2.15	0.64	1,784	4.62	1.37
Yearly mean or total	.....	.....	.....	2,111	21.77	1.62	2,755	28.32	2.11

TABLE NO. 72—RUNOFF OF MOHAWK RIVER AT LITTLE FALLS FOR THE WATER YEARS 1899–1902, INCLUSIVE (*concluded*)

(Catchment area = 1306 square miles)

MONTH	1901			1902			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	3,240	2.85	2.48	3,970	3.47	3.02	.....	.....	.....
January	1,741	1.53	1.33	1,433	1.27	1.10	.....	.....	.....
February	1,125	0.89	0.86	1,173	0.94	0.90	.....	.....	.....
March	4,574	4.02	3.50	9,457	8.34	7.25	.....	.....	.....
April	7,061	6.06	5.41	3,513	3.00	2.69	.....	.....	.....
May	2,874	2.53	2.20	2,641	2.33	2.02	.....	.....	.....
Storage period	3,454	17.88	2.64	3,740	19.35	2.86	3,723	19.16	2.85
June	3,290	2.82	2.52	3,171	2.71	2.43	.....	.....	.....
July	1,124	0.99	0.86	4,984	4.40	3.82	.....	.....	.....
August	1,167	1.02	0.89	2,202	1.94	1.68	.....	.....	.....
Growing period	1,845	4.83	1.41	3,455	9.05	2.64	1,697	4.44	1.30
September	1,171	1.01	0.90	1,350	1.15	1.03	.....	.....	.....
October	1,472	1.30	1.13	3,284	2.89	2.51	.....	.....	.....
November	1,600	1.38	1.23	2,508	2.21	1.92	.....	.....	.....
Replenishing period	1,415	3.69	1.08	2,391	6.25	1.83	1,606	4.18	1.23
Yearly mean or total	2,540	26.40	1.94	3,332	34.65	2.55	2,685	27.78	2.06

TABLE NO. 73—RUNOFF OF MOHAWK RIVER AT RIDGE MILLS FOR THE WATER YEARS 1899–1900, INCLUSIVE

(Catchment area = 153 square miles)

MONTH	1899			1900			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	261	1.61	1.40	532	4.00	3.47	.....	.....	.....
January	377	2.83	2.46	160	1.20	1.04	.....	.....	.....
February	244	1.65	1.59	581	3.95	3.80	.....	.....	.....
March	467	3.15	3.05	336	2.52	2.19	.....	.....	.....
April	997	7.27	6.52	1,062	7.74	6.94	.....	.....	.....
May	320	2.41	2.09	126	0.95	0.82	.....	.....	.....
Storage period	445	18.92	2.91	458	20.36	2.99	452	19.64	2.95
June	281	2.05	1.84	180	1.30	1.17	.....	.....	.....
July	310	2.33	2.02	160	1.20	1.04	.....	.....	.....
August	226	1.70	1.48	140	1.06	0.92	.....	.....	.....
Growing period	272	6.08	1.78	160	3.56	1.04	216	4.82	1.41
September	81	0.59	0.53	198	1.45	1.30	.....	.....	.....
October	278	2.08	1.81	212	1.60	1.39	.....	.....	.....
November	291	2.12	1.90	971	7.08	6.35	.....	.....	.....
Replenishing period	217	4.79	1.42	458	10.13	2.99	338	7.46	2.21
Yearly mean or total	344	29.79	2.25	383	34.05	2.50	364	31.92	2.38

Geologically the main Mohawk lies largely in the Hudson river shales and schists. The tributaries to the north flow across the Trenton limestone into the unclassified granites and gneisses of the Adirondack region. To the south the tributaries flow across the Hamilton shales and upper and lower Helderberg groups. The headwaters of Schoharie creek—the principal tributary—lie in the Catskill group.

Discharge measurements of East Canada Creek. This gaging station is located at the masonry dam of the Dolgeville Electric Light & Power Company, about seven miles from the mouth of the stream. Readings of the depth on the crest are taken twice a day and the mean used in computing the discharge. As at the other stations herein discussed, a record is also kept of the run of the water wheels and the elevation of water in the tailrace.

The dam is of rubble masonry, 19 feet high, and has a flat crest 6 feet wide. It is 190.25 feet long between the abutments. The following cut shows a section of this dam:

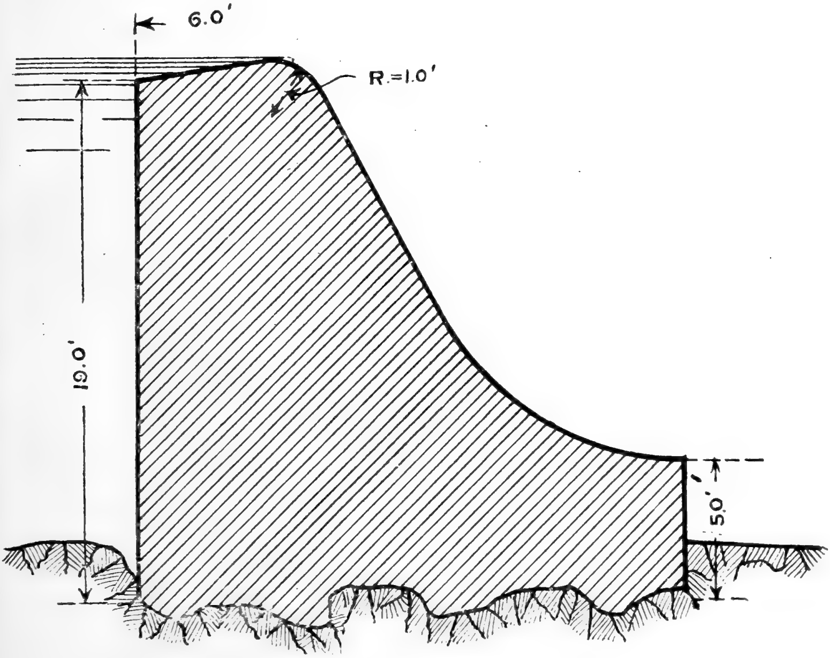

Fig. 31 Section of dam on East Canada creek at Dolgeville.

TABLE No. 74—RUNOFF OF EAST CANADA CREEK AT DOLGEVILLE FOR THE WATER YEARS 1899–1902, INCLUSIVE

(Catchment area = 256 square miles)

MONTH	1898			1899			1900		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile.
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	.....	.....	.....	564	2.53	2.20	706	3.13	2.72
January	.....	.....	.....	816	3.67	3.19	531	2.39	2.08
February	.....	.....	.....	439	1.77	1.71	879	3.56	3.43
March	.....	.....	.....	519	2.34	2.03	276	1.24	1.08
April	.....	.....	.....	1,978	8.65	7.72	2,086	9.12	8.15
May	.....	.....	.....	633	2.84	2.47	486	2.19	1.90
Storage period	....	....	....	825	21.80	3.13	820	21.63	3.20
June	.....	.....	.....	196	0.85	0.76	370	1.60	1.44
July	.....	.....	.....	166	0.75	0.65	221	0.99	0.86
August	.....	.....	.....	97	0.43	0.38	144	0.64	0.56
Growing period	.....	.....	.....	153	2.03	0.59	244	3.23	0.95
September	638	2.79	2.49	92	0.40	0.36	133	0.58	0.52
October	581	2.61	2.27	112	0.49	0.43	195	0.87	0.76
November	689	3.01	2.69	377	1.64	1.47	957	4.18	3.73
Replenishing period	635	8.41	2.48	193	2.53	0.75	426	5.63	1.66
Yearly mean or total	.....	.....	.....	498	26.36	1.90	576	30.49	2.25

TABLE No. 74—RUNOFF OF EAST CANADA CREEK AT DOLGEVILLE FOR THE WATER YEARS 1899–1902, INCLUSIVE (*concluded*)

(Catchment area = 256 square miles)

MONTH	1901			1902			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	368	1.66	1.44	935	4.20	3.65	.....	.....	.....
January	235	1.06	0.92	257	1.15	1.00	.....	.....	.....
February	248	1.01	0.97	178	0.72	0.69	.....	.....	.....
March	691	3.09	2.69	1,689	7.35	6.59	.....	.....	.....
April	2,094	9.12	8.15	813	3.65	3.17	.....	.....	.....
May	629	2.81	2.45	101	0.45	0.39	.....	.....	.....
Storage period	709	18.75	2.83	669	17.52	2.61	75	19.92	2.94
June	564	2.46	2.20	565	2.99	2.59	.....	.....	.....
July	174	0.78	0.68	804	3.50	3.14	.....	.....	.....
August	190	0.85	0.74	194	0.84	0.76	.....	.....	.....
Growing period	307	4.09	1.20	521	7.33	2.16	306	4.17	1.23
September	249	1.09	0.97	246	1.07	0.96	.....	.....	.....
October	252	1.13	0.98	864	3.87	3.36	.....	.....	.....
November	359	1.56	1.40	585	2.28	2.28	.....	.....	.....
Replenishing period	286	3.78	1.12	568	7.22	2.21	368	4.79	1.43
Yearly mean or total	502	26.62	1.99	607	32.07	2.40	546	28.88	2.14

From the date of establishing the station at Dolgeville in 1898 to June 1, 1899, the discharge was computed from a curve derived from Cornell University experiment No. 13. From June, 1899, it has been computed from a revised curve, based on experiments by John R. Freeman on a model of the round-crested portion of the Croton dam, which corresponds with the section of the Dolgeville dam as regards friction, vertical contraction, siphonage, etc. The flow through the turbines has also been computed since June, 1899, from current-meter measurements in the tailrace, instead of the manufacturers' rating tables, as formerly. The effect of the changes has been to slightly increase the extremes of flow—both as regards high and low water—the flow for the mean stage remaining substantially the same. This dam is practically watertight and no allowance is made for leakage.

The headwaters of this stream lie in the horizon of the granites and gneisses. It crosses the Trenton group and the Hudson river shales.

Discharge measurements of West Canada creek. Measurements of West Canada creek have been made at Middleville at the timber dam of the Nelson Knitting Company, which supplies power to four mills. Aside from an ice slide, the crest of this dam is nearly level. The leakage of the dam is taken at 50 cubic feet per second, although the leakage is stated to have increased so much during 1901 as to lead to the abandonment of the station. The following cut shows cross-sections and profile of this dam:

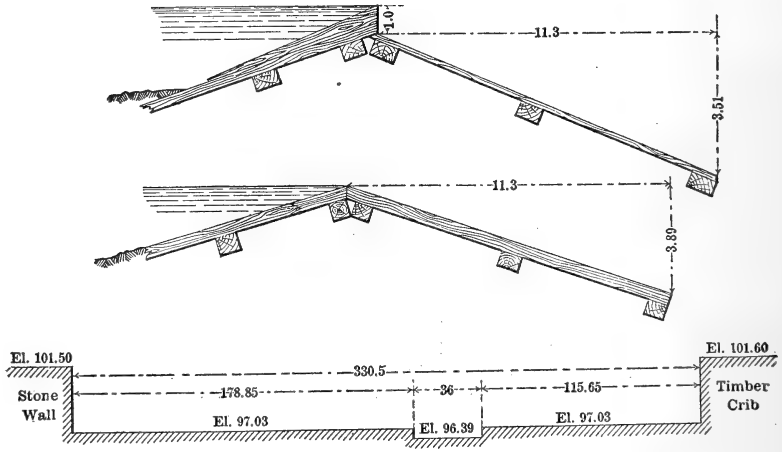

Fig. 32 Cross-sections and profile of dam on West Canada creek at Middleville.

TABLE NO. 75—RUNOFF OF WEST CANADA CREEK AT MIDDLEVILLE FOR THE WATER YEARS 1899—MAY, 1901, INCLUSIVE

(Catchment area = 518 square miles)

MONTH	1899			1900			1901			Mean		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	1,024	2.27	1.97	1,259	2.80	2.43	800	1.77	1.54	......	......	......
January	1,150	2.54	2.21	1,366	3.03	2.63	871	1.93	1.68	......	......	......
February	1,594	3.19	3.07	*1,109	*2.22	*2.14	624	1.25	1.20	......	......	......
March	1,176	2.60	2.26	*1,253	*2.78	*2.42	1,330	2.96	2.57	......	......	......
April	3,365	7.23	6.48	*3,266	*7.04	*6.30	3,167	6.85	6.12	......	......	......
May	1,456	3.22	2.80	924	2.05	1.78	1,114	2.48	2.15	......	......	......
Storage period	1,619	21.05	3.11	1,527	19.92	2.94	1,319	17.24	2.55	1,573	20.49	3.03
June	397	0.85	0.76	406	0.87	0.78	......	......	......	......	......	......
July	324	0.71	0.62	451	1.00	0.87	......	......	......	......	......	......
August	235	0.52	0.45	463	1.02	0.89	......	......	......	......	......	......
Growing period	318	2.08	0.61	440	2.89	0.85	......	......	......	379	2.49	0.73
September	221	0.58	0.52	419	0.89	0.80	......	......	......	......	......	......
October	324	0.71	0.62	448	0.99	0.86	......	......	......	......	......	......
November	577	1.23	1.11	1,536	3.33	2.97	......	......	......	......	......	......
Replenishing period	264	2.52	0.75	797	5.21	1.54	......	......	......	531	3.86	1.15
Yearly mean or total	953	25.65	1.89	1,071	28.02	2.06	......	......	......	1,012	26.84	1.98

* No record—Mean of corresponding months in 1899 and 1901.

Geologically the headwaters of this stream lie in the horizon of the granites and gneisses. It flows across the Trenton group and Hudson river shales.

Discharge measurements of Sauquoit creek. This station is at a dam which is the property of the New York Mills, used to operate an extensive cotton mill. The dam is of earth, with timber facing, having a spillway 105.8 feet in length. The following cut shows cross-section and longitudinal profile of this dam in comparison with Bazin's series No. 175:

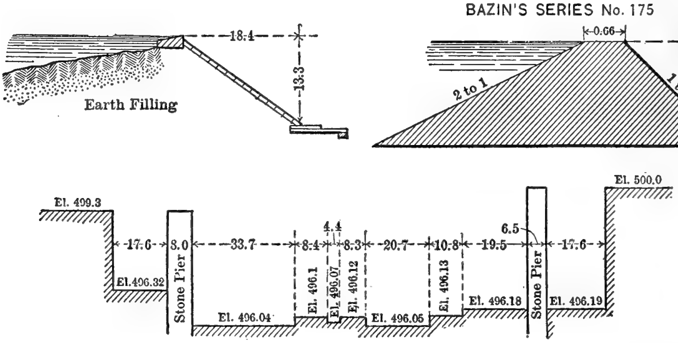

Fig. 33 Cross-section and longitudinal profile of dam on Sauquoit creek at the New York Mills, in comparison with Bazin's series No. 175.

When this station was established in the fall of 1898 the dam was watertight and leakage consequently neglected, but the statement is made that in May, 1900, the leakage was found to be 5.6 cubic feet per second and the station was accordingly abandoned in October, 1900. The flow has been computed, using Bazin's series No. 175, for which reference is made to the paper On the Flow of Water Over Dams.

Geologically this stream lies in the horizon of the Hamilton shales, crossing the Helderberg and Salina groups.

Discharge measurements of Oriskany creek. This station is located at the canal feeder timber dam at Oriskany, with a crest length of 214 feet. The profile is irregular and has been divided into three sections to facilitate computation. The dam is about four feet in hight. A section is shown in the following cut.

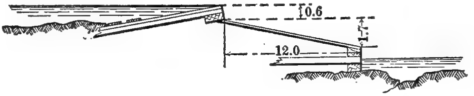

Fig. 34 Cross-section of dam on Oriskany creek at Oriskany.

The coefficients derived from Cornell University experiment No. 14 have been used in computing the flow over this dam. The flow of Oriskany creek represents the natural runoff of the tributary catchment modified by pond storage, with additional flow during the summer months due to diversion from storage reservoirs on the Chenango river catchment, through the summit level of the abandoned Chenango canal, into Oriskany creek. The natural catchment area above the gaging station is 144 square miles, while that of the Chenango river, made partially tributary through Chenango canal, is 87 square miles. The effective catchment area during the navigation season is therefore 231 square miles, while the effective catchment area with canals closed is 144 square miles, less the storage of the several reservoirs. These reservoirs are situated in Madison, Eaton, Nelson and Lebanon townships in Madison county, and include Hatch lake, Eaton brook, Bradley brook, Leland pond, Madison brook and Kingsley brook reservoirs. Their main characteristics and storage capacity in cubic feet are shown by the following tabulation:

Name of reservoir	Catchment area, square miles	Distance to Erie canal, miles	Storage depth, feet	Average surface area, acres	Storage capacity, cubic feet
(1)	(2)	(3)	(4)	(5)	(6)
Hatch lake	....	36	10	134	58,370,400
Eaton brook	10.6	38	50	254	553,212,000
Bradley brook	....	35	25	134	145,926,000
Leland pond	....	25	8	173	59,287,000
Madison brook	9.4	29	40	235	460,647,000
Kingsley brook	....	33	20	113	98,445,600
Total storage	....	......	......	....	1,375,887,000

In examining tables Nos. 76 and 77 it will be seen that the runoff of Oriskany creek is considerably larger than the adjacent Sauquoit creek, but on making the proper deductions for these reservoirs the two will be found to be substantially the same.

Geologically this stream lies in the horizon of the Hamilton shales, crossing the Helderberg and Salina groups.

TABLE No. 76 — RUNOFF OF SAUQUOIT CREEK AT NEW YORK MILLS FOR THE WATER YEARS 1899–1900, INCLUSIVE

(Catchment area = 52 square miles)

MONTH	1898			1899			1900			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	......	......	......	57	1.26	1.10	29	0.64	0.56	......	......	......
January	......	......	......	58	1.29	1.12	72	1.61	1.40	......	......	......
February	......	......	......	58	1.16	1.12	146	2.94	2.83	......	......	......
March	......	......	......	111	2.48	2.15	84	1.90	1.65	......	......	......
April	......	......	......	127	2.75	2.47	138	2.99	2.68	......	......	......
May	......	......	......	38	0.85	0.74	49	1.09	0.95	......	......	......
Storage period	......	......	......	75	9.79	1.45	85	11.17	1.65	80	10.48	1.55
June	......	......	......	23	0.50	0.45	32	0.69	0.62	......	......	......
July	......	......	......	20	0.45	0.39	32	0.71	0.62	......	......	......
August	......	......	......	16	0.36	0.31	22	0.49	0.43	......	......	......
Growing period	......	......	......	20	1.31	0.38	25	1.89	0.56	23	1.60	0.47
September	27	0.58	0.52	14	0.29	0.26	15	0.32	0.29	......	......	......
October	56	1.24	1.08	17	0.38	0.33	*37	*0.81	*0.71	......	......	......
November	57	1.23	1.10	26	0.56	0.50	*42	*0.90	*0.80	......	......	......
Replenishing period	48	3.05	0.90	19	1.23	0.36	31	2.03	0.60	25	1.63	0.48
Yearly mean or total	......	......	......	47	12.33	0.91	57	15.09	1.11	52	13.71	1.01

* No record — Mean of corresponding months in previous years.

TABLE No. 77—RUNOFF OF ORISKANY CREEK AT ORISKANY FOR THE WATER YEARS 1899–1900, INCLUSIVE

(Catchment area = 144 square miles)

MONTH	1899			1900			MEAN		
	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile	Cubic feet per second	Inches on the catchment	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(3)	(4)
December	327	2.61	2.27	89	0.71	0.62	.....	.....	.....
January	295	2.35	2.04	199	1.59	1.38	.....	.....	.....
February	291	2.10	2.02	378	2.72	2.62	.....	.....	.....
March	342	2.73	2.37	386	3.07	2.67	.....	.....	.....
April	466	3.60	3.23	488	3.77	3.38	.....	.....	.....
May	119	0.95	0.83	136	1.08	0.94	.....	.....	.....
Storage period	306	14.34	2.13	276	12.94	1.92	291	13.64	2.02
June	99	0.77	0.69	95	0.73	0.66	.....	.....	.....
July	180	1.44	1.25	100	0.79	0.69	.....	.....	.....
August	186	1.48	1.29	103	0.81	0.71	.....	.....	.....
Growing	155	3.69	1.08	99	2.33	0.69	127	3.01	0.88
September	126	0.97	0.87	73	0.57	0.51	.....	.....	.....
October	91	0.72	0.63	85	0.68	0.59	.....	.....	.....
November	360	2.77	2.49	255	1.99	1.78	.....	.....	.....
Replenishing period	191	4.46	1.33	137	3.24	0.95	164	3.85	1.14
Yearly mean or total	239	22.49	1.66	197	18.51	1.37	218	20.50	1.51

Discharge measurements of Eaton and Madison brooks in 1835. Eaton and Madison brooks are in the central-eastern part of Madison county and tributary to Chenango river. The catchment area of Eaton brook is given at 6800 acres, or 10.6 square miles, and that of Madison brook at 6000 acres, or 9.4 square miles.

TABLE NO. 78—RAINFALL AND RUNOFF OF EATON BROOK

MONTH (1)	Rainfall (2)	Rainfall for 6,800 acres (3)	Runoff from 6,800 acres (4)	Percentage of runoff to rainfall (5)
1835	*Inches*	*Cubic feet*	*Cubic feet*	
June	6.72	165,876,480	59,407,394	35.8
July	2.74	67,634,160	27,994,240	41.4
August	2.86	70,596,240	13,547,058	19.2
September	1.34	33,076,560	9,586,513	29.0
October	3.0	74,052,000	20,694,651	27.2
November	2.20	54,304,800	23,772,620	43.8
December	0.96	23,696,640	36,525,544	54.1
June to December, inclusive	19.82	489,236,880	191,528,020	39.2
June to October, inclusive	.....	411,235,440	131,229,856	31.9

TABLE NO. 79—RAINFALL AND RUNOFF OF MADISON BROOK

MONTH (1)	Rain fall (2)	Rainfall for 6,000 acres (3)	Rnnoff from 6,000 acres (4)	Percentage of runoff to rainfall (5)
1835	*Inches*	*Cubic feet*	*Cubic feet*	
Snow of November-December, 1834, on ground	.....	87,120,000	....	....
January	2.17	47,262,600	23,192,079	49.1
February	2.50	54,450,000	35,377,594	64.9
March	1.03	22,443,400	43,284,656	192.8
April	5.0	108,900,000	80,776,974	74.1
May	1.98	43,124,400	58,013,176	134.5
June	8.05	175,329,000	20,138,006	11.5
July	3.87	84,288,600	23,141,302	27.4
August	3.06	66,646,800	23,725,060	35.6
September	0.88	19,166,400	19,158,957	99.9
October	3.86	84,070,800	19,544,880	23.2
November	2.10	45,738,000	18,232,372	39.9
December	0.76	16,552,800	19,401,364	117.2
January to December, inclusive	35.26	855,092,800	383,986,420	44.9
January to May, inclusive	.....	363,300,400	240,644,479	66.2
June to October, inclusive	.....	429,501,600	105,708,205	24.6

The following statements in regard to these measurements are abstracted from Mr Jervis's report:[1] From the Eaton brook results it appears that the average runoff from June to December, inclusive, was 39.2 per cent of the rainfall and from June to October, inclusive, 31.9 per cent of the rainfall. The minimum monthly runoff was in August, which shows only 19.2 per cent of the rainfall. The rainfall in the month of June, 1835, on Eaton brook was 6.72 inches and in July 2.74 inches. The percentage of runoff to rainfall for June was 35.8, whereas for July it was 41.4, which would indicate that the bulk of the June rain must have been at the end of the month.

From the measurements of Madison brook it appears that in 1835 the average runoff for the whole year, including the snow on the ground on January 1, was 44.9 per cent, or nearly one-half of the rainfall. Mr Jervis points out that on account of the storage of the reservoir, the Madison brook record can not be taken for the summer months, but that the year should be divided into two periods. For the first period he gives the results from January to May, inclusive, during which the runoff was 66.2 per cent of the rainfall, and for the second from June to October, during which the runoff was 24.6 per cent of the rainfall. During the second period, June to October, inclusive, Eaton brook gave a runoff of 31.9 per cent of the rainfall. Mr Jervis explains these different results by the different characters of the two districts drained. Eaton brook valley is narrow, the area drained steep, with a close-textured soil. Madison brook valley, on the other hand, is wider, with easy slopes, and the soil is more porous than that on Eaton brook. Mr Jervis concludes his discussion with the remark that Eaton brook valley would afford more than

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[1] For Mr Jervis's original report see appendix F to Ann. Rept. Canal Com., 1835, Ass. Doc. No. 65, pp. 55-60. Mr Jervis's tables, with extracts from the report, are also quoted in the following documents:

(1) Report of F. C. Mills, Chief Engineer Gen. Val. Can., in appendix D to Ann. Rept. Can. Com., 1837, Ass. Doc. No. 80, p. 81.

(2) Report of W. H. Talcott, Res. Eng. Gen. Val. Can., 1840, Ass. Doc. No. 96, p. 51.

(3) Report of the Regents of the University, 1838, Sen. Doc. No. 52, pp. 208-211.

(4) Documentary History of the New York State Canals by S. H. Sweet, Dep. State Eng. and Sur., 1863, Ass. Doc. No. 8, pp. 203-204.

an average runoff over a large district of country, including the usual varieties of soil, while Madison brook would probably not differ materially from the general average in this State.

In his documentary history of the New York State canals,[1] S. H. Sweet analyzes Mr Jervis's measurements of discharge of Eaton and Madison brooks and points out several probable errors, specially in the Madison brook result, where because the measurements indicate only what was actually discharged through the sluice pipes each day instead of what drained off from the valley, he concludes that the real drainage of the Madison brook area in 1835 was about 0.518 of the rainfall, instead of 0.449, as given by Mr Jervis. Inasmuch as the Eaton brook and Madison brook measurements have only historical interest at the present time, this branch of the subject is not here pursued at length. So far as can be learned the measurements of these two streams by Mr Jervis were the first systematic measurement of the runoff of streams in the United States.

Geologically Eaton and Madison brooks lie in the horizon of the Hamilton shales.

MAXIMUM AND MINIMUM FLOW OF STREAMS

The maximum flow of a stream is merely another name for flood-flow, and since floods are very destructive in New York the general causes may be briefly considered.

A typical New York stream rises in the hills and mountainous country at the sides of the valleys and flows down, with declivities steepest at the headwaters and in its lateral tributaries, the main stream growing flatter toward its mouth. The profile of nearly all New York streams is therefore roughly concave in form.

Streams having a concave profile are ordinarily divided into three portions, as follows:

1) The upper or torrential portion, where erosion is active and in excess of deposition.

2) The normal portion, where erosion and deposition are about equal and the stream is neither lowering nor raising its bed.

3) The alluvial portion, where deposition exceeds erosion and the bed is gradually being raised, and where also this raising of

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[1] Ann. rept. State Engineer and Surveyor for 1862.

the bed, together with the alluvial banks, permit of sudden and extensive changes in channel location at times of floods. This concavity of profile, with its resulting diminution of velocity, is one of the potent factors in the causation of floods, since it permits flood waters to be brought to points having sharp concavities of profile or abrupt flattening of grades more rapidly than the channel will carry the same away, producing at such points temporary accumulations of water with an attendant overflow.

It is not to be understood that the profile of any stream is a perfectly smooth concave curve, nor that the grades grow progressively flatter without interruption as one passes down stream. Local causes interfering with regularity of flow, and geological formations interfering with the vertical erosion of channels, cause interruptions in the regularity of the concave profile. The Genesee river is a characteristic type of this interruption by geological causes. Whatever the regularity or irregularity of the profile may be, however, it is safe to expect that if floods occur at all on a stream, they are more certain to occur where the stream slope grows suddenly or decidedly flatter or where extensive local obstructions or restrictions occur.[1]

In order to correct the excessive flows produced by the foregoing conditions the stream may be trained or regulated in a number of ways; such training is commonly called river regulation or river conservancy.

Antiquity of river regulation or conservancy. River regulation, or river conservancy, is very old, and there is scarcely a phase of it that has not been considered at some time in the Old World. The Chinese rivers, particularly the Hoang-ho, were regulated by dykes and embankments over 4000 years ago. The same is true of the Euphrates and many other rivers on which were situated the cities of the ancient world. This statement is specially true of the river Tiber, at Rome. In the year 53 B. C.—1957 years ago—a proposition was brought forward in the Roman senate for moderating the frequent inundations of this stream, which resulted in the appointment of five senators as a river conservancy commission, to whom was assigned the task of so regulating the volume of water in the river that there might be " no deficiency

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[1] Abstract from the Report of the Water Storage Commission.

in summer and no injurious excess in winter."[1] So far as known this was the earliest river conservancy commission. This commission does not appear to have regulated the river very effectively, since many inundations occurred afterwards, and in 1495 A. D. an accurate record of overflows was commenced. The flood of 1495 was, with a few exceptions, one of the heaviest known. Since that time serious floods have occurred on the Tiber in 1530, 1557, 1598, 1606, 1637, 1660, 1686, 1702, 1750, 1805, 1843, 1846 and 1870.

The town of Ostia, when founded, in 633 B. C., was at the mouth of the Tiber and soon had 80,000 inhabitants. In the course of years Ostia was deprived of its port by the silt carried down by the Tiber. Thereupon the Emperor Claudius, about the beginning of the Christian era, presented to the Roman senate a project for forming a port three miles from the original mouth. A basin, with two moles, a breakwater, towers and a lighthouse, was executed and a canal opened to connect with the river. This canal silted up towards the end of the first century. The Emperor Trajan repaired the port, adding an internal basin. The canal which still forms the navigable mouth of the Tiber was opened about 110 A. D. Plutarch, in his life of Julius Cæsar, states that Cæsar intended to remedy the evil by deepening the mouth of the Tiber, but that his death prevented the accomplishment of this task.

An extraordinary inundation of the Tiber is mentioned by the younger Pliny, in his letter to Micrinus, as occurring in the reign of Trajan, who, as already stated, built a canal which still exists. The present length of this canal is about two and one-half miles.[2]

In reference to the reason why the Roman senatorial river conservancy commission did not succeed there is but one remedy which can be applied to a river in order that there may be no deficiency in summer and no injurious excess in winter, namely, water storage. The valley of the Tiber does not present the proper conditions for applying this remedy. In its lower reaches the Tiber flows through a broad plain, while in its upper reaches,

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[1] The Tiber and Its Tributaries, by S. A. Smith, 1877, p. 60.

[2] W. Shelford, on Non-tidal Rivers, Proc. Inst. C. E., Vol. LXXXII, pp. 7-8; and The Tiber and Its Delta, by Prof. Ponzi, Proc. Inst. C. E., Vol. XLVII, pp. 342-344.

the valleys are narrow, with steep slopes, accordingly rendering it impossible for large quantities of water to be stored.

So far as known, aside from Black river, Raquette river and one or two others in this State, there are no rivers anywhere on which the task assigned to the Roman river conservancy commission could be successfully applied. On Black river it is not difficult to construct a single reservoir, which practically controls 1889 square miles of catchment area. The Raquette river can also be thus controlled by a single dam at Tupper lake. If it were not for the location of towns near the water level, the Seneca river could be controlled by a series of dams at the foot of the Finger Lakes.

River regulation on the Seine. The Seine is the most important river of France, not only on account of its being the highway for a flourishing inland trade, but in consequence of engineering works which have been carried out for its improvement. On this stream, the same as on others, the occurrence of high floods is due to the concentration of the rainfall at special periods of the year. The rainfall is considerably greater in the summer than in the winter months, but owing to evaporation the rains of summer have comparatively little influence upon the flow of the river, although a heavy rain during the winter months falling upon a saturated soil, when evaporation is inactive, causes a flood of which the hight depends upon the amount of saturation of the basin by previous rains and the duration of the rainfall. Daily readings of the hight of the river have been kept at Paris since 1732. During this time, thirty-one ordinary floods, twelve extraordinary, and two exceptional floods, in December, 1740, and in January, 1802, have occurred. A list is also given of five exceptional floods occurring between 1649 and 1732. In 1658 a severe flood followed the breaking up of the ice in the river after severe cold weather lasting five weeks. Of the forty-five large floods recorded since the commencement of the daily observations in 1732 only three occurred in the warm season, two of them appearing in the month of May and one in the month of September. The foregoing shows that regular floods of the Seine at Paris are almost wholly confined to the cold season.[1]

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[1] The River Seine, by L. F. Vernon-Harcourt, Proc. Inst. C. E., Vol. LXXXIV, p. 210.

A record of floods has also been kept on a number of other important French rivers, as the Garonne, of which special studies were made over forty years ago, the Loire and the Rhone, all of which are the subject of special extended memoirs.

A number of rivers of Germany and Austria have been studied carefully for from 50 to 100 years, but in the United States substantially nothing had been done until about twenty years ago, from whence it results that river conservancy is a new subject here, many persons supposing that nothing has ever been done anywhere.

Definition of river regulation or conservancy. The term river regulation or conservancy may be considered as comprising the following objects:

1) The preservation and improvement of a stream for domestic, sanitary and industrial purposes.

2) In the case of navigable streams, their maintenance and regulation for navigation.

3) The culture and preservation of fish.

4) The effectual drainage of the district through which a stream runs.

5) The abatement of injury to lands by floods.

The cause of floods is, broadly, excessive and irregular rainfall, although very heavy rainfalls may occur without causing a flood. General statements of why this is so have been made in the preceding paragraph regarding the river Seine. Indeed, an investigation into rainfall shows that the intensity of floods is due only very remotely to the amount of rainfall. On the contrary, floods are very closely related to hight of ground water. On Genesee river, in August, 1893, when as the result of a serious summer drought ground water was very low, a rainfall of several inches only produced a slight flood of about 4000 cubic feet per second, whereas in July, 1902, preceded by rain enough to fill the ground with water, about the same amount of sudden rainfall produced a devastating flood of from 20,000 to 30,000 cubic feet per second.[1] Many other examples could be

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[1] Floods on Genesee river vary greatly in intensity. A flood of from 30,000 to 40,000 cubic feet per second at Mount Morris is not likely to produce, owing to temporary storage on the flats, a flood of more than 20,000 cubic feet per second at Rochester. The preceding statement considers the flood as measured at Mount Morris.

cited of this general truth, but, as the object at present is not specially to multiply proof on this point, a single one is sufficient, although it is proper to remark that the same phenomenon has been observed on many other streams.

Torrential and gently flowing rivers. In addition to the classification as to concavity of profile, given on a preceding page, rivers may be divided into two classes; (1) torrential, and (2) gently flowing rivers. The rivers of the first class have considerable fall and usually flow over impermeable strata, while those of the second class flow over alluvium. Many of the streams of New York State belong to both classes—in their upper reaches they are torrential, while in their lower they are gently flowing. This distinction is important to bear in mind in treating of the question of floods, because the floods of torrential rivers, while high, are of brief duration. Gently flowing rivers, on the contrary, have lower floods, but they continue for a longer time and are therefore likely to be much more injurious. In New York State the torrential streams generally flow through deep valleys and in many cases present excellent opportunities for water storage. Usually the valleys of gently flowing streams are not suitable for storage reservoirs—the cost of the necessary barrage would in many instances, at any rate, prove insuperable.[1]

General principles of river regulation as defined by von Wex. Perhaps as interesting a paper as any is one by Gustav Ritter von Wex, Privy-Councilor to the Emperor of Austria, in which the governing principles of river regulation are so clearly set forth that one can hardly do better than to give an extended extract therefrom. Von Wex's memoir is limited to a brief general summary of the first principles requisite to the successful regulation of intractable rivers. The quotation follows:

> In every case, first of all the upper course of the river must be dealt with separately, and then the lower portion of it, together with its mouth, whether it empties itself into an estuary or into the open sea.
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> From long experience it has been ascertained that every river or stream, following its natural course through wide tracts

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[1] The Conservancy of Rivers, by Wm. H. Wheeler and Arthur Jacob, Proc. Inst. C. E., Vol. LXVII, pp. 201 and 233.

of level country, invariably, if the banks consist of deposits of earth or gravel, attacks them, the lighter particles being carried away, the heavier being deposited in the bed of the stream, so that in course of time its width increases while its depth decreases, and at the same time islands, sandbanks, bends, creeks and by-channels are formed.

In rivers thus left to nature, the fall, mean velocity and force of the current are continually decreasing while the riverbed is rising; this naturally raises the general water-level relatively to the adjoining country, and exposes it to frequent inundation, the effects of which are disastrous floods and the formation of innumerable branches and by-channels which intersect the whole country, flooding and swamping it at every rise of the river, and rendering it in time unfit for habitation by either man or beast. Instances of this kind are at the present time to be met with in many parts of the world, notably in Asia, Africa and America.

In order to deal effectually with such cases, namely, to abate the floods, and to prevent disasters accompanying them, as well as the ultimate formation of trackless swamps, the following procedure is recommended:

1) A new channel following the course of the valley should be carefully laid down by the superintending engineer, either in a direct line or with easy bends, and when excavated, the entire body of water should be admitted into this new channel, the old bed and all by-channels being filled up.

2) Having carefully determined—

a) The discharge per second at low, mean high water level of a cross-section of the river, either immediately above or immediately below the portion to be regulated, and

b) The increased fall which the new channel will afford; then the sectional area of the new bed must be fixed, according to approved hydraulic formulas, so as to allow of the passage of either an ordinary or an extraordinary volume of water.

3) The water having been admitted, the next thing is to protect the banks by random rubble or by stone pitching in order to prevent the action of the current injuring them, or forming bends or creeks.

4) After the completion of the above, the old river bed and by-channels should be filled up, the land thus reclaimed should by degrees be brought under cultivation; in the same manner the marshy tracts exposed hitherto to inundation, and fertilized by the deposit therefrom, should be raised by a coating of rich soil.

5) If exceptionally high floods still overflow the banks and inflict loss and damage to the freshly cultivated valley, dykes at

suitable distances apart will be necessary to confine such floods, and enable them to flow off gradually without causing damage.

From forty-eight years' observation and experience of extensive works undertaken for the improvement of rivers, the author can confidently affirm that by careful attention to the points above recommended, even the most tortuous rivers and the swampiest valleys have, generally within a few years, but in some cases only after many years, yielded the most satisfactory results, as for instance—

a) The increase of fall due to the more uniform section and more direct course, and the concentration and confinement of the stream within a single channel provided with firm banks, considerably increases the force and velocity of the current, which tend to deepen the channel, and to carry away the material thus scoured out as well as that brought down from above.

b) By lowering the bed of the river, in some cases to the extent of from 3 to 6 feet, the general water level, both of the river and of the ground springs in the neighborhood, is proportionately lowered, so that the adjoining country is less liable to inundation, and the swamps are more easily drained and brought under cultivation.

c) The velocity being accelerated in the new channel, as shown by (a), floods pass off more rapidly and do not rise so high, consequently the low country is seldom or never under water, or at any rate not to the same extent as before. If, however, these lesser and lower floods are to be entirely prevented, dikes parallel to the course of the river must be added.

d) In rivers exposed to the action of frost, floating ice is apt to accumulate in the unregulated portions of its course, especially at sharp bends, and on shallows and sandbanks, occasionally to such an extent as entirely to obstruct the flow of the stream, and to raise the water in the river to such a hight that it overflows the banks, inundates the neighboring country, and spreads ruin far and wide.

When once a river has been regulated this can not take place, as there would then be nothing to hinder the free passage of floating ice, and should a temporary stoppage occur, the concentrated force of the current would soon overcome every obstacle, by raising the blocks, and bearing them away without causing any flood.

e) It is a matter of general experience that even in a deep river following a winding course and dividing into numerous branches navigation is often obstructed to such an extent that the river becomes all but impassable, yet when the same river has been regulated, a direct channel is provided, facilitating traffic and commerce, and increasing the prosperity of the country already improved by drainage and cultivation.

f) On the banks of many rivers left to nature but a scanty population exists, invariably affected and often decimated by epidemics, and generally exhibiting an imperfect physical and mental development. After regulation, and by draining and cultivating the adjoining country, these evils disappear, the inhabitants improve in health, strength and intelligence, the population increases, new villages spring up, and prosperity reigns where before disease and poverty were rife. The government earns the hearty thanks of all thus benefited, and has at the same time fully recouped the capital laid out on the works by the increased revenues derived from the improved condition of the country.

Where such an improvement of the waterway has been rationally executed, in accordance with the particular nature and requirements of the locality, most, if not all, of the above advantages have been secured; as may be proved by numerous instances of works of the kind executed years back in France, Germany, Austria, Switzerland and Italy. Moreover, the fact that the chambers of deputies of these states have, during the last few years, repeatedly devoted hundreds of millions of florins to the completion of works already begun, and to new undertakings of the same kind, is a proof that the importance and advantage of such improvements are fully recognized.

As a complete description of even the most important works of this kind would far exceed the limits of a short paper, the author must confine himself to a brief review of those successfully accomplished on the Rhine.

The Rhine, between Basle and Mannheim, has for centuries followed a tortuous course, abounding in sharp bends and dividing into many branches, through a valley between 5000 and 6000 metres broad. Having further repeatedly shifted its course, the whole valley became cut up by old channels; to a considerable extent, too, its natural fall was lost, owing to its sinuous course, and consequently the rate and force of the currents were so much diminished that deposit accumulated everywhere, raising the bed of the river and mean water-level to such a degree that the adjoining country was little better than a swamp. The bed of the Rhine being thus elevated, and its course so irregular, the flood-water could not flow off rapidly enough, but spread abroad, inundating the neighborhood, and destroying whole villages and townships.

The riverside communities had in all ages attempted, by dams and other protective works, to abate these evils, but with little success, as, owing to the winding course of the river, the floods confined at one point escaped at another, and took their defenses in reverse. This deplorable condition of the Rhine valley continued until the commencement of the present century, when the population, already greatly reduced by poverty and disease, was daily decreasing owing to emigration to America.

Colonel Tulla, of the engineers, an eminent authority on hydraulics at that time, by repeated and unremitting exertions, induced the government, in 1817, to undertake a thorough survey of the entire Rhine valley. Upon that survey was based the project for the radical regulation of the Rhine bed, which was approved and ratified by treaty between the border states of France, Bavaria and the Grand Duchies of Baden and Hesse, and according to which the regulation of the Rhine was carried out during the years 1819-1863.

The work consisted in regulating the course of the river and making it more direct. This necessitated the excavation of twenty-three considerable cuts, which reduced the distance by river between Mannheim and Basle from 252 to 169 kilometres, and increased the fall 30 per cent. Further, the stream was confined to a uniform channel of suitable section, both banks were substantially protected, the old river bed and all branches were filled in, and the land thus reclaimed was for the most part brought under cultivation.

The above mentioned regulation of the Rhine may be considered one of the most extensive and interesting undertakings of the kind ever attempted in Europe. It is proved that the following advantages have been secured:

a) The river has undeviatingly followed the new course provided for it; has deepened its bed to the extent of two metres in some places, and lowered the mean water-level proportionately. Flood-water also has been passed more quickly.

b) The general water-level being thus reduced in hight, extensive tracts of swampy ground have been laid dry and converted into fertile arable land. Further, more than 20,000 hectares of old river bed, water-holes and sandbanks have been reclaimed, and brought in a great measure under cultivation; and lastly, the low-lying tracts are now no longer exposed to inundations.

c) The sanitary condition of the Rhine valley has visibly improved, and the general prosperity of the inhabitants materially increased.

d) According to the concurrent reports of experts, government officials and local authorities, the benefits derived from the regulation of the Rhine are so considerable that the capital laid out has been amply repaid. Wherefore, in grateful recognition of the eminent services rendered by Colonel Tulla, the original promoter of the scheme, a statue has been erected in his honor at Maxau on the banks of the river.

In one respect only has the regulation of the river not fulfilled the expectations of its promoters, viz. the extensive sandbanks formed at the confluence of its tributaries have rendered inter-communication with them both difficult and dangerous, because these feeders to the main stream enter it across bars little more than 0.60 or 1.50 metre below low-water level.

Had the hydraulic engineers in 1817 correctly determined the minimum discharge of the Rhine, and at the same time anticipated a probable decrease of the same, they would have diminished the waterway, and thereby considerably reduced the deposit formation of such sandbanks so that the channels of communication between the Rhine and its tributaries would have remained more open to navigation.

In addition to the foregoing general principles, applying more particularly to the non-tidal portion of rivers, rivers emptying into the sea, or into an arm of the sea, may require special treatment, and while, aside from the Hudson river, there are few such in this State, and although the improvement of this stream has been assumed by the Federal government, nevertheless it is proper to briefly consider the general principles governing such an improvement.

Generally speaking, the regulation of rivers flowing into the sea is more costly than that hitherto treated of, because the volume of water is greater and the yielding nature of the silt forming the beds and banks, together with the violence of the stream and force of the waves, render it necessary that whatever the form of protection, it shall have solid foundations and be executed in the most substantial manner.

The works necessary for the perfect regulation of such a river consist of:

1) Rendering the course as nearly straight as possible in order to increase the fall.

2) Inclosing the river at or near its outfall by means of dykes or jetties, and continuing the same beyond the bar and far enough out to sea to enable the current to carry the sand and mud away, thus preventing the formation of a bar at the mouth.

3) In order to protect the adjoining country from tidal inundation, it will be necessary to construct on either bank, dykes at such distances that at ebb tide the force of the river will be sufficient to carry out to sea the silt, etc., deposited during the inflowing of the tide.

The foregoing principles of river regulation are general in their character, and apply in some degree to every river in the United States.[1]

In regard to the definition of river conservancy as given on a preceding page, it may be mentioned that the third head—the culture and preservation of fish—has already been fully cared for by the Forest, Fish and Game Commission of this State, and in regard to the second head—the maintenance and regulation of streams for navigation—this phase of the subject has been undertaken by the Federal government and is therefore not specially considered here. The first head—the preservation and improvement of a stream for domestic, sanitary and industrial purposes—the fourth head—the effectual drainage of the district through which the stream runs—and the fifth head—the abatement of injury to lands by floods—are specially considered. The three heads are interrelated and the discussion may proceed without further special subdivision.

Flood overflows not necessarily injurious. Flood flows, when occurring either late in the fall or early in the spring, are not only not necessarily injurious, but may be a source of considerable benefit to agriculture. Streams carry, when in flood flow, a large amount of silt which is valuable for manure, which enriches land, and when the inundation is annual, it may be a source of unending fertility. To cite one case, the river Nile has maintained the fertility of its valley from time immemorial from this source. The same thing is true on the Mohawk and Genesee rivers, and many other streams of this State.

It is also true that floods in the late spring or early summer, after crops have been planted, may be a source of very serious damage. During the summer of 1902 very serious floods occurred in the month of July. Probably the damage from such floods in

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[1] The Regulation of Rivers and Waterways, With a View to the Prevention of Floods, by Gustav Ritter von Wex, Proc. Inst. C. E., Vol. LXIX, p. 323.

New York State exceeded, in 1902, $3,000,000. If damages of every kind could be reckoned they would amount to at least $1,000,000 in any year.

Irrigating streams. There is a class of streams which, through the tendency to elevate their beds and widen their channels, noted in a previous section, have actually raised themselves several feet, and in some cases twenty to thirty feet, above the surrounding country, so that whenever there is an overflow from the main channel, the water runs away from the streams, considerably complicating the construction of permanent regulation works. But there are, fortunately, only a few such streams in this State and none of those very important. The Missouri, Mississippi, Red and other rivers may be cited as streams of this character. The writer also remembers the case of the Clear fork of the Brazos river, in Texas, where a railway bridge crossing the stream was set level, with a down grade to the east for one half mile of 20 feet, or the country one-half mile east of the stream was about 20 feet lower than at the stream. There was also a down grade to the west of from 20 to 30 feet per mile, for one and one half miles. The writer's recollection is that two miles west the country was about 30 feet lower than at the stream.

Insufficient waterway of bridges. One main reason why bridges are so frequently carried away in floods is because of insufficiency of the waterways. Every student of hydrology understands that the catchment above a bridge should be ascertained, and a waterway, large enough to allow for all contingencies, provided. Nevertheless, under the system of building bridges by road commissioners, this is hardly ever done. Economy seems to be the sole consideration. The result is that bridges are carried away, and the writer ventures the opinion that enough money has been spent in the State of New York on renewal of highway bridges alone in the last ten to twenty years to make permanent bridges over every stream in the State. So long as the fact remains as it is, the writer can not but think that the carrying away of such bridges is due rather to the lack of definite knowledge on the part of the road commissioners than to severity of floods.

Before designing a permanent bridge, the catchment area above the proposed location should be ascertained, together with the heaviest rainfall. In case there happens to be gagings of the stream, the maximum runoff may be obtained from the gagings, but thus far there are gagings of comparatively few of the New York streams, and probably the flood-flow will require to be computed. As to just how this is accomplished is foreign to the purpose of this report, but it may be simply stated that there is no special difficulty, provided that the data of catchment and rainfall, together with the steepness of slope, length of catchment, etc. are known, in computing a flood-flow from which a bridge opening may be ascertained that will be large enough to carry the maximum flood.

Lack of data a source of difficulty. One difficulty in designing regulation works arises from lack of data and in order to render data of this character accurate within 2 or 3 per cent there should be a record about thirty years long. Such a record should include rainfall, maximum, or flood-flows, and minimum, or low-water flows. In this way only can accurate knowledge of the regimen of streams be gained.

River conservancy in England, Germany and France. In England, largely due to the prevalence of the common law rule that every riparian proprietor owns to the thread of the channel, river conservancy has not made the progress which it should. The taxpayers have generally insisted that all who are to be taxed have a voice in determining the kind of regulation to be carried out. The result is that many important works have not been undertaken, and on many streams the work has been carried out piecemeal, thus greatly increasing the expense, with ineffectual results.

In Germany the system is quite different. Here the State assumes control of the main and navigable rivers, defraying the expenses of their management out of tolls collected from those using the streams for navigation, mill power and other purposes. The State claims absolute ownership in the waters and prevents any interference, even with tributary streams. In some cases the riparian owners may combine for purposes of draining lands and flood protection. On application to the government they are constituted a conservancy authority, armed with powers to compel those who fail in their duty to construct the necessary protection works, or to maintain them. They may also tax all those who are benefited, but have no power to tax those occupying lands outside of the reach of floods. The State contributes a portion of the cost of protection works where such works have the effect of improving land and increasing its taxable value, on the principle that such increase is a source of profit to the State. The State also grants aid to townships, and if it becomes evident that nothing will cure the evil of flooding but a diversion of a part of the water, the State, by virtue of its property in the water, executes the work gratuitously.

The system of river conservancy in France is somewhat different from the German. In this country the general government has always undertaken the conservancy of navigable streams, and has recouped itself from navigation dues and other charges, but latterly taxation of this kind has been mostly abolished, and the government is now chargeable with nearly all the expenses connected with the conservancy of rivers, though in certain cases the owners are also taxed in proportion to their interests. In May, 1858, it was enacted that the State should undertake works for the protection of towns from inundation, providing also that the departments, communes and owners should contribute to the cost of the works in proportion to their respective interests. There is an inland navigation system on nearly every river of any importance in France, which has, perhaps, to some extent, influenced the action of the State.[1]

The storage dam on the Furens river, at Saint-Etienne, was built to protect the city of Saint-Etienne from floods. About 64 per cent of the total cost was paid by the city of Saint-Etienne, and the balance was paid by the department. The cost of construction of the Terney dam, also in France, was borne by the State, town and manufacturing interests. A number of other storage dams have been built in France in recent years by a combination of the general government, department government, local or municipal government and private interests benefited.

The cause of floods. While, broadly, the cause of floods has been stated as irregularity in the rainfall, we may now go some-

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[1] The Conservancy of Rivers, Wheeler and Jacob, Proc. Inst. C. E., Vol. XLVII, pp. 246 and 311.

what further into the detail than this statement implies. The clearing up of lands and drainage of towns, together with farm drainage, are all efficient causes for floods. In a general way, the water falling in the form of rain or snow runs off by these various means quicker than formerly. In the meantime the channels of rivers have not been correspondingly enlarged to meet the increased demands upon them, with the result that overflows frequently ensue. An examination of rainfall statistics shows that as a whole the rainfall is no greater now than formerly, and the increased frequency of floods must therefore be ascribed to not only irregularity in the rainfall, but to the greater rapidity with which water runs off. Broadly, we may say that the higher the degree of civilization, the more quickly will surface water be discharged, and hence, without there is a corresponding increase in the discharging capacity of streams, floods will become more frequent, with their attendant evils.

Frequency of floods. This matter has been referred to in a preceding chapter, discussing floods on the Tiber and Seine. Very serious floods have occurred on these streams as often as about once in thirty to fifty years. In the United States there are no records long enough to show certainly how often floods may be expected, but probably their periods will not be materially different from these streams—in some cases, heavy floods have occurred on the Tiber only a few years apart and it is intended to indicate here only very general averages.

Are storage reservoirs effectual in preventing floods? There is considerable doubt about storage reservoirs being a universal remedy for floods. On some streams excessive cost would preclude their use—that is to say, the benefits received would not be commensurate with the expense. On other streams their use may be of the greatest value. On the Genesee river, 41 per cent of the total catchment area can be controlled by a reservoir; on Salmon river, 55 per cent; on Black river, 90 per cent, and on the upper Hudson river, 50 per cent. On all these streams the percentage of control is large enough to prevent destructive overflows.

Views of French engineers. The utility of storage reservoirs in diminishing damage from floods was taken under consideration in France in 1856. Investigations made in the valleys of the Seine, the Rhone, the Loire, the Garonne and other important rivers resulted in a decision not to carry out the numerous reservoirs which had been proposed, owing to the uncertainty and doubtful efficacy of their action in floods.

Further investigations were made after the inundations of 1875. These latter observations show that in the case of the Garonne, a reservoir capacity of about 20,000,000,000 cubic feet would be required to protect Toulouse, and one of 50,000,000,000 to 60,000,000,000 cubic feet to protect Agen and the rest of the basin. Unfortunately, the capacity of the reservoirs which could be constructed in the upper valley of the Garonne would amount to only about one-sixth of that required for protecting Toulouse. The investigations led to similar conclusions in the case of the lower Garonne, and the other principal river basins in France.[1]

In one particular the French engineers seem to have been far from right in their investigation of the utility of storage reservoirs. Thus the statement is made that such reservoirs, to be useful against floods, must be kept empty throughout the whole season when floods may occur. This, perhaps, may be true in France, but it is not true, under the different conditions of rainfall, in a number of cases in the State of New York. Possibly, the French engineers overlooked the moderating effect of a reservoir, with large water surface, upon a flood even when the reservoir is filled to the flow-line. The writer has discussed this question extensively in his several reports to the State Engineer and Surveyor, and also in his report to the Board of Engineers on Deep Waterways, and a computation is given in connection with floods on Genesee river which shows that even under the adverse condition of water at the crest, the temporary storage on the water surface is in most cases great enough to practically double the time of a flood and hence to greatly decrease its destructive effect. The conclusion on this head, therefore, is that an extreme flood, which would not be effectually mitigated, even though a reservoir were full, would occur not oftener than once in a century.

Flood warnings. Since the flood wave in a river is progressive, some idea can be formed in advance as to the stages of

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[1] Annales des Ponts et Chaussees, sixth series, Vol. II, 1881, p. 5, translation in Proc. Inst. C. E.

water that will occur along the lower reaches of a river when the stages at points higher up are known. Judgment as to such cases is based upon the observed hight in previous years. Hence, the value of a record of water stages in determining the relation between the wave crest at various points along a river; but the relation between these will not be identically the same in all cases—it will depend upon the distribution of the rainfall and other causes over the catchment basin of a river. The average of a great many cases gives a result which, though sometimes in error, is in most cases nearly right.

Predictions as to the hight of floods based on the preceding general method have been kept in France since 1854, and in the United States on the Mississippi, Missouri, Ohio and other tributaries of the Mississippi for the last fifteen to twenty years. Generally the rivers of New York State are not long enough to make such predictions specially reliable, although on some of the longer rivers they may be successfully applied. At Cincinnati, Louisville and Cairo predictions may be made from two to six days in advance of a destructive flood.

This matter is merely mentioned here as one of the practical outcomes of the study of floods in large streams. It is extensively discussed in Russell's Meteorology[1] to which the reader is referred for more extended information.[2]

Maximum Flow of Streams in New York

We will now take up a brief description of floods on the various rivers of the State, following the same order as previously used in discussing the classification of streams. Since there is no information as to floods on many streams, only those will be mentioned where information is available.

Floods in Buffalo river. This stream is formed by the junction of Cayuga creek, Buffalo creek and Cazenovia creek, which unite near Buffalo. The catchment areas of these various streams are given on page 205. The slope of Cazenovia creek is steeper in its

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[1] See chap. 10, River Stage Predictions, in Meteorology, Weather and Methods of Forecasting and River Flood Predictions in the United States, by Thomas Russell. A general résumé of the cause of floods is also given in chap. 9 of the same work.

[2] Abstract from Report of the Water Storage Commission.

lower reaches than either Buffalo or Cayuga creek. It results, therefore, that floods in Cazenovia creek reach Buffalo several hours earlier than those in Buffalo and Cayuga creeks. The channel in the lower portions of all these streams is irregular and sinuous, which, together with the flattening of slopes, produces the usual flood congestion in the lower reaches. The annual occurrence of floods in these streams has long been a source of damage and has been a bar to the development of the city of Buffalo towards the southeast. The Buffalo engineers have been for several years making studies of floods in these streams in order to devise plans for their prevention. Serious floods have occurred at the following dates:

January 5, 1890.
December 16, 1893.
January 14, 1894.
May 20, 1894.
March 30, 1896.
January 13, 1898.
February 16, 1898.
December 5, 1898.
December 22, 1898.
January 13, 1900.
February 9, 1900.
April 22, 1901.
December 14, 1901.
March 1, 1902.
July 7, 1902.

It is stated in the report of the Buffalo Flood Committee, made to the Water Storage Commission, that in the flood of March 1, 1902, the maximum discharge of the Buffalo river was about 23,000 cubic feet per second (catchment, 420 square miles), or at the rate of 55 cubic feet per second per square mile. This, however, was an unusual flood; the ordinary flood-flows are estimated at about 18,000 cubic feet per second, or at the rate of 43 cubic feet per second per square mile, although from the conclusions of the committee, given on page 442 of the Report of the Water Storage Commission, it is inferred that exceptional floods may exceed 25,000 to 28,000 cubic feet per second, or at the rate of about 66 cubic feet per second per square mile.[1]

Floods in Tonawanda creek. High floods have occurred in this stream in 1865, 1889, 1896 and 1902. The flood of March, 1865, is considered to be the extreme maximum, although the flood of

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[1] A large amount of information in regard to Buffalo river is given in the Report of the Water Storage Commission, at pp. 71-76 and pp. 422-443, inclusive.

March, 1896, was nearly as high. At this time water flowed over the State dam at Tonawanda, with a head of 4.82 feet, indicating a discharge of 9600 cubic feet per second. At the same time there was 3 feet of water flowing over a waste-weir directly into Niagara river and representing a discharge of about 1000 cubic feet per second, making the total discharge on March 30, 1896, of Tonawanda creek at Tonawanda 10,600 cubic feet per second (catchment, 610 square miles), or at the rate of about 18 cubic feet per second per square mile. This value of the flood discharge is probably due to the natural storage in the flat and swampy portions of the creek valley west of Oak Orchard dam, as well as to the diversion of some of its waters through the Oak Orchard cutoff during this flood—probably, the entire flood-flow on March 30, 1896, was from 20 to 22 cubic feet per second per square mile. In the upper reaches of this stream the flood-flows may be expected to approximate anywhere from 60 to 80 cubic feet per second per square mile.

Floods in Niagara river. As shown by table No. 45, the natural regulation of this river is so perfect that floods are unknown. During the entire year 1895 the flow of Niagara river varied from 195,578 cubic feet per second to 177,852 cubic feet per second, the extreme variation for the year being only 17,726 cubic feet per second.

Floods in Genesee river. The following account of early floods in this stream is mostly taken from the report on Genesee river storage surveys, dated January 1, 1897.

Great floods have occurred in this river in 1815, 1835, 1857, 1865 and 1896. At a number of times between 1865 and 1896 the river has also been very high, but at no time since 1865 as severe as in 1896.

Beyond the mere fact that a very severe flood occurred in 1815, which overflowed the flats in the valley between Avon and Mount Morris and the black ash swamp which then covered the area now included in the first and third wards of the city of Rochester, little is known as to the flood of that year.

The next great flood of which we have record occurred in 1835.[1]

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[1] See report of F. C. Mills, relative to the Genesee valley canal, Assembly Document No. 73, 1837, p. 69.

Considerable damage was done to the farms in the flats. According to statements made by Hervey Ely, a former citizen of Rochester, the flow of the river in the flood of 1835 amounted to about 36,000 cubic feet per second.

In February, 1857, a serious flood occurred in the Genesee river which carried away not only a number of buildings on the north side of the Main street bridge at Rochester, but also undermined the piers of that bridge and even finally swept away the greater part of the old structure. A new bridge was in process of construction at the time.

The great flood of 1865. March, 1865, was a period of general high water throughout western New York. Long continued cold weather and a heavy snowfall were followed by a sudden thaw, accompanied by rain, about the middle of March. On the sixteenth a freshet in the upper Genesee valley was reported, and on the seventeenth the water was very high at Rochester, but aside from the usual alarm manifested on such occasions, the situation was not considered specially serious. The river, however, continued to rise during the night of March 17th, until the banks of the Genesee valley and the Erie canals were overflowed, with the water pouring direct from the river into the canals. The river further rose above its banks until finally nearly the entire central portion of Rochester was under water. During the whole of the 18th and part of March 19th the only means of transportation throughout the entire business portion of Rochester was by boat. The gas supply was cut off early in the disaster, leaving the city in darkness. The New York Central & Hudson River Railroad bridge over the river was carried away, and traffic suspended on that railway for several days. The damage to property is stated to have exceeded $1,000,000.[1]

Rochester newspapers of March, 1865, give detailed accounts of the Genesee flood, from which it is gleaned that the damage must have been very severe, and may have even considerably exceeded $1,000,000.

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[1] The foregoing details of floods in the Genesee river up to and including 1865, have been mostly gleaned from Peck's History of Rochester. The newspapers of the day have also been referred to for particulars of the great flood of 1865.

Plate 10.

Great flood of 1865 at Rochester. Looking across the aqueduct from South St Paul street near where the New Osborne House now stands. Lumber from yards further up lodged against the piers.

The flood commission of 1865. Following the great flood the Legislature passed an act appointing commissioners to inquire into and ascertain the cause or causes of the inundation of the city of Rochester by the waters of the Genesee river in the month of March, 1865, and also to ascertain whether any, and, if any, what obstructions had been placed in said river which tended to cause or increase the extent of such inundation, and the nature and extent of such obstructions, and what measures, proceedings and remedies were necessary or proper for the purpose of guarding against or preventing a recurrence of such an inundation. The commissioners were Addison Gardner, Amos Bronson, Levi A. Ward, George J. Whitney and George E. Mumford. General I. F. Quinby was engineer to the commission.

The commission begins its report by stating that there is no record in the previous history of Rochester of any serious damage from overflows of the river, no former flood having to any important extent spread beyond the banks of the river. In view of this state of things the citizens of Rochester had felt it to be of the highest importance to ascertain the cause of the unprecedented extent of the 1865 flood, and, as far as possible, to guard against its recurrence.

As to the first cause, it is stated that by reason of a sudden change of temperature from winter to almost summer heat an immense body of snow, which had accumulated during the previous winter weather, was suddenly melted and thrown at once into the river channel within the space of three or four days instead of occupying a week or more, as in ordinary floods. Secondly, the effect of the flood was increased in consequence of the obstruction to free flow caused by the bridge and embankment of what is now the New York, Lake Erie & Western Railway at Avon. The openings in the embankment across the river valley, while adequate for ordinary floods, were entirely too small for the quantity of water flowing in March, 1865. The consequence was that at the time of greatest flow the water stood at least three feet higher on the upper side of the embankment than on the lower side. The embankment finally gave way, thus allowing a large quantity of ponded water to flow suddenly down the river, filling the channel at Rochester beyond its carrying capacity. As a third cause, the commissioners found that the channel of the river was obstructed through the city of Rochester in such manner as to cause overflows into the Erie and Genesee valley canals at that place. The remedy suggested was that the waterway through the city be considerably increased.

As regards the Erie canal aqueduct, the commissioners pointed out that the piers supporting the structure, instead of being built parallel with the stream, run partially across it, thereby materially increasing the amount of the obstruction by so changing the current that at least one half the river as it passes the aqueduct flows in the direction of the east bank above Main street bridge. The commissioners also pointed out that during the flood trunks of trees, logs and timber lodged against the aqueduct and closed a considerable portion of the waterway through the arches. Under these circumstances the flood rose to the copings, standing more than three feet higher on the south side than on the north. The commissioners also considered that Main street bridge presented considerable obstruction. In 1865, and for some years previous to that time more than two thirds of the eastern arch of the bridge had been closed by the wall of the building on the north side. This obstruction, however, was removed by the action of the flood, the building in question having been carried away. Since then the east opening has been left entirely free, but there is still in 1904 considerable obstruction to the west arch by a building erected since 1865.

The areas of the several openings of the arches of the Erie canal aqueduct at Rochester are as follows:

First opening, east side, 516.6 square feet; second opening, 681.4 square feet; third opening, 625.7 square feet; fourth opening, 641.3 square feet; fifth opening, 615.3 square feet; sixth opening, 625.7 square feet; seventh opening, 552.4 square feet; total, 4308.3 square feet.

The following are the total openings of the several river bridges: Court street, 5081 square feet;[1] Main street, 3367 square feet; Andrews street, 4511 square feet; Central avenue, about 4450 square feet.

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[1] This is the opening of the river arches below the level of the flood of 1865; in addition the arches over the Johnson and Seymour raceway have an opening of 790 square feet and the Erie canal arches of 498 square feet.

It will be noticed that the area at Main street, the first bridge below the aqueduct, is 941 square feet less than that of the Erie canal aqueduct.

The commissioners also gave some attention to the causes which made the flood of 1865 greater than that of any previous year, and expressed the opinion that the same causes might produce a still greater flood in the future.[1]

As a chief cause, the commissioners considered that cutting off the forests and clearing up lands were likely to lead to heavier floods from year to year. In view, therefore, of what seemed to the commissioners a constant source of danger, they arrived at the conclusion that a much larger waterway was imperatively necessary through the city of Rochester.[2]

A severe flood also occurred in the upper Genesee at Mount Morris in March, 1893, at which time large quantities of ice were left in the streets of the lower portion of that village.

Flood in Genesee river of May, 1894. It is very common for the flats in the vicinity of Mount Morris to be inundated, with great destruction of farms and growing crops. The flats between Mount Morris and Rochester were inundated May 20-23, 1894, the damage to growing crops at that time amounting to many thousand dollars. As interesting data we may discuss that flood, at which time the approximate discharge of the stream at Mount Morris (catchment, 1070 square miles), was as follows:

	Cubic feet per second
May 18, 7 a. m.	600
May 18, 6 p. m.	3,090
May 19, 7 a. m.	5,530
May 19, 6 p. m.	5,090
May 20, 7 a. m.	16,580
May 20, 12 m.	22,210
May 20, 6 p. m.	28,000
May 21, 3.30 a. m.	42,000
May 21, 7 a. m.	33,000

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[1] The report of the commissioners appointed to investigate the causes of the inundation of the city of Rochester in March, 1865, may be found in Assembly Document No. 117 of the Session of 1866.

[2] The waterway is still substantially the same as in 1865. If anything, it has been somewhat contracted by various constructions since that day.

	Cubic feet per second
May 21, 12 m.	30,730
May 21, 6 p. m.	26,500
May 22, 7 a. m.	15,650
May 22, 12 m.	13,650
May 22, 6 p. m.	10,720
May 23, 7 a. m.	7,300
May 23, 12 m.	6,700
May 23, 6 p. m.	5,690
May 24, 7 a. m.	5,390

The total runoff from 7 a. m. of May 18 to 7 a. m. of May 24 was over 7,000,000,000 cubic feet.

On the morning of May 21 the flats in the broad, level valley of the Genesee river and Canaseraga creek, between Dansville, Mount Morris, and Rochester, which have an area of from 60 to 80 square miles, were nearly flooded, in some localities to a depth of from 4 to 6 feet. On account of the large pondage by these flats, although the maximum runoff at Mount Morris was 42,000 cubic feet per second at 3.30 a. m. on the morning of May 21, at Rochester the maximum flow did not at any time exceed about 20,000 cubic feet per second. We have, then, a case where a large pondage has, by prolonging the time of runoff, modified a flood-flow over 50 per cent. As further illustrating the effect of a large reservoir, or, what is the same thing, the effect of a large pond

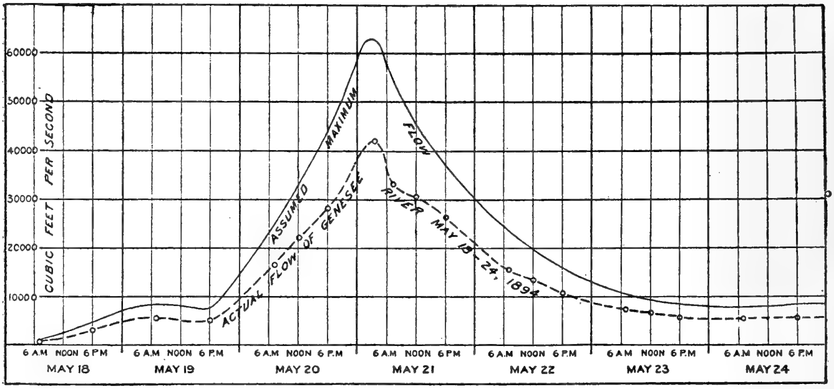
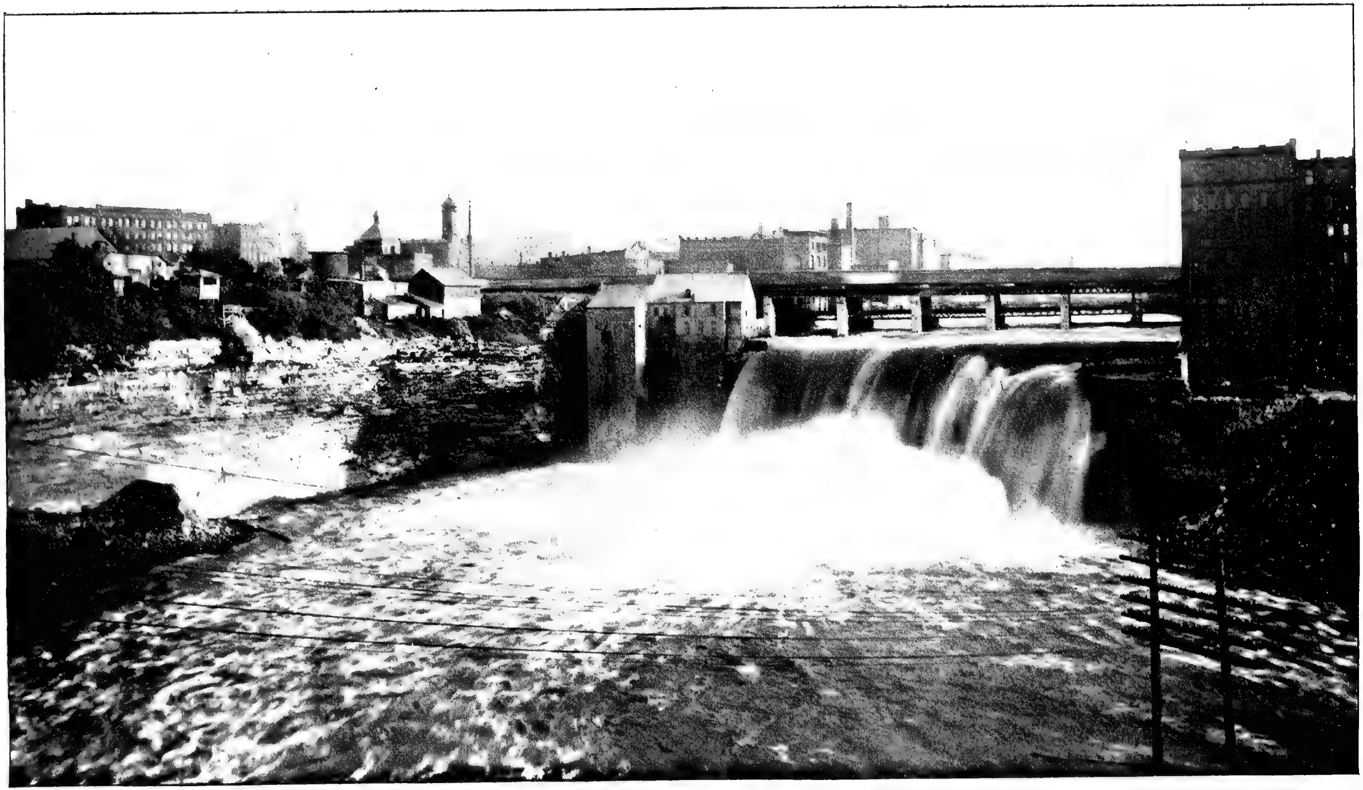


Fig. 35 Flood flow of Genesee river May 18–23, 1894.

Plate 11.



The upper fall at Rochester at time of flood flow.

area in modifying the effect of an extreme flood, reference may be made to fig. 35, in which, with time as abscissas and runoff as ordinates, the runoff record of Genesee river for May 18-23, 1894, has been plotted. The lower curve of that figure may be taken as representing approximately the law of the runoff of any generally distributed heavy rainfall on the catchment area of this stream. In making this statement it is not overlooked that flood-flows at other seasons of the year may differ somewhat in their movement from that of May, 1894. Inasmuch as the rapidity and intensity of the runoff of any given stream depend largely upon the topography, the statement may be made that the general law of movement of floods in the Genesee river is indicated by the lower curve of fig. 35. With this understanding we may assume any other runoff and construct the approximate curve by drawing it generally parallel to the curve of the actually observed case. In this way the upper curve of fig. 35, representing the curve of a flood one and one-half times greater than that of May, 1894, has been produced, slight irregularities of the lower curve having been neglected in projecting the upper one.

A flood-flow one and one-half times as great as that of May, 1894, which culminated in a maximum of about 42,000 cubic feet per second at 3.30 a. m. of May 21, gives a maximum of 63,000 cubic feet per second, the movement of which would be, under the assumptions, substantially as in the upper curve of fig. 35. As to the probability of a maximum flood-flow of 63,000 cubic feet per second on the upper Genesee catchment area, the case of the neighboring Chemung river may be cited, where a flood-flow of 67.1 cubic feet per second per square mile occurred in June, 1898. This figure applied to the upper Genesee would give a possible maximum runoff of 71,126 cubic feet per second.

Flood of 1896. The flood of April, 1896, came very near reaching the danger limit—so near, indeed, that it is now the opinion of many thinking citizens of Rochester that the regulation afforded by the proposed storage dam at Portage may not be sufficient to fully protect the city from a repetition of the disaster of 1865. If the river were to again rise to the hight attained in that year, the damage would inevitably be several times greater than occurred then.

Flood of March, 1902. On March 3 to 5, 1902, a flood occurred which, at Rochester, lacked but little if any of reaching the hight of the great flood of 1865. At Avon, twenty miles above, the high-water mark reached was eight inches below that of 1865. Owing to a fortunate combination of circumstances the damage resulting from this flood within the city of Rochester was much less than that in 1865, but only prompt and energetic measures on the part of city and canal officials and the rarest good fortune prevented the damage from exceeding that of 1865. This flood was due to the more common cause of floods on this catchment, namely, the general melting of the snows by warm rains. This flood reached its maximum hight at Rochester on the afternoon of March 3.

Flood of July, 1902. On July 6 to 13, there occurred a flood on the Genesee which, from the time of the year, the high stage of water in certain parts of the river, and the extent and severity of the damage arising from it on a certain portion of the catchment, is without precedent in the history of Genesee floods.

The rains over the catchment generally had been unusually heavy during the latter part of June and the early part of July, and the ground was thoroughly saturated with water. On July 6 the rainfall reached a climax which culminated in a so-called "cloudburst" in the region covering the northern central portion of Allegany county. At Angelica, within this district, the rainfall on July 6 amounted to 4.5 inches. Heavier rainfalls than this have occurred occasionally on the catchment area without producing severe floods. This fact, coupled with the fact that a number of private observers unofficially claimed much heavier precipitation than the Angelica office reports, raises some doubt as to whether the Angelica station itself may not have escaped the severe downpour, or whether the marked difference in the results may be due wholly to the difference of saturation of the ground. The former alternative is rather discounted by the fact that the catchment at Angelica creek itself, of which the station is not far from the center, suffered the most severe flood in its history. This remark in fact is true of the entire catchment of the Genesee in the aggregate down as far as Portage falls. It is well established by repeated evidence that the hight which the flood attained at Portage was several feet—variously estimated at from three to five feet—higher than the highest known preceding flood, and similar evidence exists for points on the Genesee up as far as Wellsville. This is not true, however, for the lower portion of the valley. At Mount Morris the flood hight attained was about that of previous floods, but at Rochester the river showed a discharge of only about 20,000 cubic feet per second against 36,000 to 40,000 or 42,000 cubic feet per second for the 1865 flood and the March, 1902, flood. The excessive precipitation, therefore, must have been confined to the headwaters of the river.

It must not be inferred that the maximum flood discharge at Portage was less than 20,000 cubic feet per second, the discharge at Rochester. On the contrary, there is good reason to believe that the discharge at Portage with only 40 per cent of the catchment area was very much in excess of that at Rochester, and the reasons for this are: (1) the flood hight at Portage was from three to five feet higher than during former extreme floods which gave flood discharges of 40,000 cubic feet per second at Mount Morris, which has only 7 per cent more catchment area; these former floods must therefore have discharged not much less than 40,000 cubic feet per second at Portage; five feet, or even three feet, added to the crest of these former floods indicate still greater discharges and leave little doubt that the discharge at Portage was nearly if not fully double that at Rochester; (2) an examination of the July flood at Rochester shows that the maximum stage of water was reached at Rochester during the afternoon of July 8, while the maximum stage at Portage occurred during the forenoon of July 6, indicating that the flood crest occupied more than two days in passing from Portage to Rochester. When we consider the topography of the valley between Mount Morris and Rochester, this time consumed in transit must have been accompanied by an elongation of the flood with a corresponding diminution of the discharge per second.

A careful study of the circumstances attending this flood of July, 1902, in conjunction with the other maximum floods in the Genesee, leads to the conclusion that the maximum flood at Rochester has not yet occurred, and that by a combination of circumstances which do not seem at all improbable a maximum flood in excess of 40,000 cubic feet per second may reasonably be expected.

Had the same precipitation which occurred in Allegany county occurred on the northern portion of the catchment area with reasonably high water from the southern district, the flood wave would not have been elongated as it was by its flow through the alluvial valley north of Mount Morris, and as a result the wave would have been shorter but with a higher maximum discharge.

This flood of July is unique in the matter of the date of its occurrence. The other great floods have occurred in March or April, with minor severe floods occurring later. Occurring, as this did, in July, with the crops well advanced toward maturity, the resulting damage was greatly in excess of what would have occurred under similar conditions in the early spring. The destruction of crops was in itself serious. But it was a greater disaster to agricultural interests that the season was then too far advanced to permit of replanting.[1]

The effect on floods of Genesee river flats. Considering Genesee river as a whole, the following conditions govern: Between Rochester and Mount Morris and between Mount Morris and Dansville, in the broad valley of the Canaseraga creek, there are extensive flats, amounting for the whole to from 60 to 80 square miles. The effective catchment area at Rochester is 2365 square miles, as against 1070 square miles at Mount Morris. The portion of the catchment area below Mount Morris also contains Honeoye, Canadice, Hemlock and Conesus lakes, which altogether provide a large volume of surface storage, while above Mount Morris there are few flats and only one small lake (Silver lake).

There are extensive flat areas in the catchment of Black and Oatka creeks, which are tributary below Mount Morris.

The preceding discussion shows that the upper section of the Genesee river has a rapid runoff and is subject to sudden and excessive flood-flows. These flood-flows are received in the extensive flats below Mount Morris, where they are partially retained and gradually delivered to the extreme lower river. The flood-flows at Mount Morris are greater than at Rochester, although the dry-weather flow at Rochester is, proportionately to catchment area, usually greater than at Mount Morris. The flats then act to decrease the flood-flow at Rochester and to increase the dry-weather flow there. At Mount Morris we may expect flood-flows of from

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[1] Abstract from the Report of the Water Storage Commission.

25,000 to 30,000 cubic feet per second nearly every year, while at Rochester 30,000 cubic feet per second is quite rare, even the great flood of 1865 probably did not materially exceed 45,000 to 54,000 cubic feet per second. About 30,000 to 35,000 cubic feet per second at Rochester gives a full river, and anything much beyond that figure will produce a disastrous flood. The flats then act to decrease in a very marked degree the violence of the spring freshet at Rochester. With the river in its natural state, and with the same character of catchment area throughout its whole course that we find to exist above Mount Morris, what is now the chief business portion of the city of Rochester would probably be submerged nearly every year.

This immunity of the city of Rochester is, however, purchased at the expense of the flats which act as an immense storage reservoir for the spring floods of the upper river.

From an economic point of view one marked effect of the annual inundation is largely to prevent the use of these flats for any agricultural purpose other than grazing. If they can be certainly relieved of the burden of that portion of the annual overflow which occurs in May, they will immediately become the most fertile agricultural lands in the State, and their value will be doubled. It is in line with the policy of all civilized governments to establish works for river conservancy wherever results are to be gained such as these, and the precedent of similar works by other governments is in view of the benefits to be derived by the Commonwealth in the way of increased valuation of property, the strongest possible argument that can be urged in favor of the Genesee river storage.

The question may be asked whether the annual inundation is not really a benefit rather than an injury, by reason of carrying a large amount of valuable silt fertilizing material over the entire submerged area, as in the case of the river Nile and other irrigating streams. The answer is that, by reason of a heavy May rainfall, occurring at a time when the ground water is high and before vegetation has become active, there is likely to be an overflow just at the planting season, which effectually prevents the putting in of crops. Frequently, too, the May overflow extends over into the early days of June. In May, 1893, the discharge at Rochester was at the rate of over 14,500 cubic feet per second, and on May 20th the mean discharge at Rochester was 12,900 cubic feet per second. Flood discharges of these amounts are sufficient to render farming operations impossible on a considerable portion of the flat area. On June 2, 1889, the discharge at Rochester was about 20,000 cubic feet per second, and from personal observations on that day it is known that nearly the whole flat area of the valley was flooded. The answer to the question as to the value of the annual overflow is, therefore, that in the case of the Genesee valley, the May overflow comes at such a time as to do only injury, without any opportunity to realize what would be, if the inundation came only in March or April, a great benefit.

The cash value then of so regulating the flow of the river as to do away with the May overflow can be estimated as an average of 80 square miles, at say $40 per acre, or the increased valuation of the whole area would be about $2,050,000.

Moreover, the flats above Rochester are a further benefit to the lower river by reason of an immense storage of ground water therein, which, as the flood level subsides, gradually runs out with the result of greatly decreasing the period of extreme low water.

Again, in case of excessively heavy rains, in the middle of the summer, from the effect of which the river channel is temporarily, partially or wholly filled, such an amount of water is stored in these flats as to keep the river comparatively well up during the fall.

This actually happened in the season of 1893, when on August 29, 1893, there occurred a rainfall of nearly three inches over the whole catchment area in a period of about 12 hours, which produced a flood-flow of 5800 cubic feet per second at Mount Morris and 3800 cubic feet at Rochester, an amount of water sufficient to partly fill the channel between these two places, but without any overflow of the adjoining flats. Previous to this heavy rainfall the mean flow at Rochester had been for a month about 300 cubic feet per second. At Mount Morris it had not averaged, for the same period, more than 125 cubic feet per second. The effect of this rain on the ground water of the flats is strikingly shown by comparing the flows at Mount Morris and Rochester, when it will be found that on September 3 the flow at Mount Morris was again down to 200 cubic feet per second, and remained below that figure, except for slight rises due to rainfall on September 7 and 8, and September 15 and 18, until October 15, when the flow rose to a little over 2000 cubic feet per second. At Rochester, on the other hand, the effect of the heavy rainfall of August 29, was to so far replenish the depleted ground water of the flats as, with the exception of a few days in the early part of October, when the flow dropped to about 600 cubic feet per second, to keep the flow up to about 800 cubic feet per second, for the balance of the year.

The storage value of the Genesee river flats. In order to further illustrate the great storage value of the flats, we may note that the catchment area at Rochester is 2.3 times that at Mount Morris; hence, for proportionate yields the flow at Rochester should be 2.3 times that at Mount Morris. During August, 1893, at a time of extreme dry weather, the flow at Rochester was 3.7 times that at Mount Morris, and after the extreme storm of August 29, which replenished the ground water of the flats, the flow at Rochester, during the entire replenishing period (September, October and November) was four times that at Mount Morris.

A knowledge of this constant accession of large quantities of water from the flats leads to another conclusion of great practical importance, namely, that we may expect to realize at Rochester the full value of all the water added from the storage at Mount Morris; that is, an addition of, say, 700 cubic feet per second at Mount Morris, in time of low water, will be likely to increase the flow at Rochester 700 cubic feet per second more than it would have been without such addition.

In order to show more strikingly the value of the flats for such storage, we will now compute the amount stored and held back therein.

Referring to Rafter and Baker's Sewage Disposal in the United States, page 165, we find a tabulated statement of the per cent of empty space in a number of soils, as follows:

	Per cent
In Illinois prairie soil, the voids are..................	55.2
In East Windsor, Connecticut, clay soil, the voids are...	48.3
In coarse river sand, the voids are from.........38.4 to	41.0
In subsoils, the voids are from ....34.6 to	42.6
In blowing sands, the voids are......................	44.7

From these figures we learn that an estimate of 33 per cent of void space in the soils of the flats would be very conservative. The mean low-water surface of the river channel is mostly from 15 to 20 feet below the surface of the flats. We will also assume that the water runs out of the upper 5 or 6 feet quickly, but that it is retained and delivered slowly from the balance. We have then 33 per cent of say 12.0 feet or 4.0 feet in depth over 80 square miles as the probable available ground-water storage of the flats. For 80 square miles this amounts to (80 x 640 x 43,560 x 4)= 8,921,088,000 cubic feet. If there were any way to control this ground-water storage of the flats it would by itself furnish an outflow of 800 cubic feet per second for four months, or 130 days.

During June and July, 1893, the rainfall was used up by the demands of growing vegetation, and the flow of the stream was that due to stored ground water only, except possibly a very slight effect from the rainfall on June 6. By July 24, what may be termed the high level rapid runoff ground water of the flats was entirely exhausted, and from that time on the flow was merely due to the deeper seated ground water of the whole area, assisted, however, by the relatively more rapid delivery of the flats. It may be remarked that the surface storage of the lakes of the lower-river system is usually about exhausted by July 24.

However, it should not be overlooked that in a long continued drought the storage of these flats becomes exhausted, and when this occurs there will be very low water at Rochester until this storage is renewed by copious rainfall.

As to the propriety of including in this discussion the area of the Canaseraga flats it may be mentioned that high water is stated by the inhabitants to only occur there when the Genesee is full to overflowing and is therefore mostly the result of backwater from the Genesee. The catchment area of the Canaseraga creek is 259 square miles, and although the creek channel has for several miles only slight declivity, it probably has capacity enough to discharge the ordinary flood-flows, provided the Genesee were kept within its banks.

The value of a reservoir on Genesee river in mitigating floods. The question will arise in storage projects as to the value of a reservoir in mitigating flood-flows. As this matter has been

TABLE NO. 80 — EFFECT OF FULL RESERVOIR IN MITIGATING EXTREME FLOODS.

h above crest in feet	Total depth in reservoir in feet	Storage =C in cubic feet	Intermediate values of C	Q at height h cu. ft. per sec.	Qp= means values of Q cu. ft. per sec.	Time t in seconds	Total time in seconds	Outflow in each period in cu. ft.	Total outflow in cu. ft.	Total inflow in cu. ft.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
0	130.0	0		0		0	0	0	0	
			51, 221, 000		230					
0.5	130.5	51, 221, 000		459		1720	1720	395, 700	395, 700	
			51, 297, 000		899					
1.0	131.0	102, 518, 000		1340		1763	3483	1, 583, 800	1, 979, 500	
			51, 374, 000		1864					
1.5	131.5	153, 892, 000		2388		1826	5309	3, 403, 500	5, 383, 000	
			51, 449, 000		3032					
2.0	132.0	205, 341, 000		3677		1908	7217	5, 784, 400	11, 167, 000	
			51, 526, 000		4408					
2.5	132.5	256, 767, 000		5139		2013	9230	8, 874, 900	20, 042, 300	
			51, 602, 000		5947					
3.0	133.0	308, 369, 000		6755		2145	11375	12, 757, 700	32, 800, 000	
			51, 678, 000		7634					
3.5	133.5	360, 047, 000		8512		2311	13686	17, 640, 000	50, 440, 000	
			51, 754, 000		9456					
4.0	134.0	411, 801, 000		10400		2519	16205	23, 822, 000	74, 262, 000	
			51, 830, 000		11405					
4.5	134.5	463, 631, 000		12410		2787	18992	31, 790, 000	106, 052, 000	
			51, 907, 000		13470					
5.0	135.0	515, 538, 000		14530		3140	22132	42, 298, 000	148, 350, 000	
			51, 983, 000		15655					
5.5	135.5	567, 521, 000		16780		3624	25756	56, 730, 000	205, 080, 000	
			52, 059, 000		17943					
6.0	136.0	619, 580, 000		19106		4318	30074	77, 473, 000	282, 553, 000	
			52, 135, 000		20338					
6.5	136.5	671, 715, 000		21569		5396	35470	109, 035, 000	392, 295, 000	
			52, 212, 000		22823					
7.0	137.0	723, 927, 000		24076		7275	42745	166, 035, 000	558, 330, 000	
			52, 287, 000		25389					
7.5	137.5	776, 214, 000		26702		11340	54085	287, 902, 000	846, 332, 000	
			52, 364, 000		28059					
8.0	138.0	828, 578, 000		29416		26980	81063	756, 972, 000	1, 603, 204, 000	2, 431, 782, 000
			52, 439, 000		30816					
8.5	138.5	881, 017, 000		32216						
			52, 516, 000		33658					
9.0	139.0	933, 533, 000		35100						
			52, 592, 000		36583					
9.5	139.5	986, 125, 000		38065						
			52, 668, 000		39588					
10.0	140.0	1, 038, 793, 000		41110						

worked out for Genesee river, the following is herewith included to illustrate the subject:

The most unfavorable case that can be assumed is that of the occurrence of an extreme runoff when the reservoir is full to the flow line. Even under such circumstances the reservoir will still act as a great mitigator of an extreme flood-flow, as may be seen by inspecting table No. 80, which has been prepared specially to illustrate the point in question. The following discussion will indicate the principle embodied in this table.

The efficiency of a storage reservoir as a flood moderator will depend upon the storage capacity in relation to the quantity of water flowing in from the catchment area. This capacity includes all storage space, whether above or below the crest of the overflow weir, which may be available at any time of heavy storm. Water is stored in the space above the crest only temporarily, but this space may still play an important part in reducing the maximum discharge below the reservoir, by extending the time within which the total surplus has to be passed down.

Inasmuch as extreme flood-flows are of short duration, we may neglect the effect of evaporation, absorption and leakage, whence it becomes evident that the discharge by the overflow weir or sluices will be equal to the quantity received, less the quantity retained, whether temporarily or otherwise.

We will assume that the water stands at the level of the crest at the instant when the inflow becomes equal to 30,000 cubic feet per second, and that the inflow remains constant at that figure for 24 hours, after which it gradually decreases. We desire to determine the length of time which will elapse before the outflow reaches 30,000 cubic feet per second, and the approximate time it will remain at about that figure. With the following notation:

$h =$ any given hight above the crest in linear feet and h_1, h_2, h_3, etc., successive equal hights.

$C =$ storage capacity corresponding to h, and C_1, C_2, C_3, etc., successive capacities.

$Q =$ discharging capacity of the overflow weir in cubic feet per second, as determined by the formula $Q = 3.33 \sqrt{h^3} \times L$ for the given values of h, h_1, h_2, h_3, etc.

Q_p = the mean discharge in cubic feet per second for any given period, as for instance, $Q = \frac{Q_{h_1} + Q_{h_2}}{2}$ and

$Q_{p_1} = \frac{Q_{h_2} + Q_{h_3}}{2}$, etc

S = inflow from catchment area, taken in the present case at 30,000 cubic feet per second; and

t = the time in seconds in which the water will rise to any given value of h above crest.

Whence we have the formula,

$$t = \frac{C}{S - Q_p} \qquad (41)$$

by which table No. 80 has been computed.

On referring to table No. 80 we learn:

1) That, with water surface in reservoir at level of crest of overflow weir and a constant inflow of 30,000 cubic feet per second, it will be about 6.5 hours before the outflow will reach 15,000 cubic feet per second.

2) That under the same conditions it will be about 24 hours before the outflow will reach approximately 30,000 cubic feet per second.

3) Inasmuch as the original assumption was that the inflow should only be at the rate of 30,000 cubic feet per second for 24 hours and then gradually decrease, we may therefore say that the flow at rate of about 30,000 cubic feet per second would only be for say two or three hours, instead of at least 24, as it would have been without the assistance of the surface storage of the reservoir.

4) The total inflow in 22.5 hours would be 2,431,782,000 cubic feet, of which 34 per cent of the whole would be stored during that time temporarily in the reservoir.

Other deductions can be made, but the foregoing are enough to show the value of such a reservoir as a moderator of floods even when entirely filled at the beginning of the maximum flow.

In the same way if we assume the reservoir full and an inflow at the rate of 40,000 cubic feet per second, we learn on making the numerical computation that about 19 hours would elapse before the outflow would reach approximately that amount, in which time a depth of ten feet would be reached on the crest. The total inflow in 19 hours would be 2,904,735,000 cubic feet, of which 1,865,942,000 cubic feet would flow out and 1,038,793,000 cubic feet, or nearly 36 per cent of the whole would be stored temporarily on the surface of the reservoir.[1]

Floods in Oswego river. The highest water reported in Oswego river is a depth of 4 feet on the crest of the dam at Fulton, the flow being 19,500 cubic feet per second, the ordinary spring flood amounting to 17,700 cubic feet per second. This figure is verified by the statement of the late Charles Rhodes, Esq. of the Oswego Canal Company, who studied Oswego river extensively and who, according to the Report on Water Power of the United States in the Tenth Census, considered that the ordinary flood discharge at Oswego was from 16,000 to 17,000 cubic feet per second, and that an excessive flood might be as large as 41,000 to 42,000 cubic feet per second, these latter figures probably being the discharge of the Oswego river in the great flood of March, 1865. Thus far exact figures have not been obtained of any flood exceeding about 21,000 cubic feet per second. This flow when computed in cubic feet per second per square mile does not much exceed 4 cubic feet, which is very small.

The catchment area of Oswego river at Oswego is 5002 square miles, and a very interesting question arises as to why a stream with so large an area as this, issuing from a region with a mean annual rainfall of from about 30 to 40 inches and with heavy snowfall, frequently melting suddenly at the end of winter, should not show greater flood-flows than a maximum of about 4 to 8 cubic feet per second per square mile. The answer to this may be found in considering the large temporary storage on the surfaces of the lakes, marshes and flat valleys of Oswego basin, as shown by the tabulation on page 111.

Floods in Seneca river. According to statements made by people at Baldwinsville, mill owners and others, ordinary high water in Seneca river is about 3 feet on the crest of the dam there and occurs nearly every spring. This gives a discharge

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[1] Abstract from Second Report on Genesee River Storage Project, dated April 1, 1894. For further account of Genesee river floods, see Report of Flood Committee appointed by Mayor of Rochester in 1904.

over the present dam and through the water wheels of 13,968 cubic feet per second. In 1865, which was a year of unusually high floods in central and western New York, it is stated that the water went higher than this, but no person has been found thus far who is able to give the exact hight. The flood of 1865 is estimated at the rate of 6.4 cubic feet per second per square mile.

All statements agree that floods seldom occur in the fall of the year in the Seneca river.

Floods in Chittenango creek. This stream is tributary to Oneida lake and, like many of the Oneida lake tributaries, has considerable flat area. The extreme measured flood is taken at 4105 cubic feet per second (catchment, 307 square miles), or at the rate of 13 cubic feet per second per square mile.

Floods in Oneida creek. Kenwood, where the records are kept on this stream, is pretty well up from Oneida lake, of which Oneida creek is a tributary. This stream has a rapid descent from the hills above the point of gaging, and shows a maximum flood of about 3930 cubic feet per second (catchment, 59 square miles), or at the rate of 41 cubic feet per second per square mile, while ordinary spring floods are at the rate of about 15 cubic feet per second per square mile.

December 15, 1901, there was a flood in this stream with a discharge of 2075 cubic feet per second, or at the rate of 35 cubic feet per second per square mile.

Floods in Wood creek. The catchment area of this stream above the point of gaging is mostly flat, level country. The highest flood reported was in the spring of 1895, when the discharge was about 2630 cubic feet per second (catchment, 126.5 square miles), or at the rate of about 21 cubic feet per second per square mile.

Floods in west branch of Fish creek. The swamp and marsh area of this stream is large enough to distribute the flood-flows, thus keeping the maximum, which is reported as having occurred in 1884, as measured at McConnellsville, down to 6170 cubic feet per second (catchment, 187 square miles), or about 33 cubic feet per second per square mile. The ordinary flood-flows, as taken from high-water marks on McConnellsville dam, indicate 18.4 cubic feet per second per square mile.

The following data relative to flood-flows in this stream were obtained for the United States Board of Engineers on Deep Waterways:

Location	Catchment area, square miles	Date	ESTIMATED MAXIMUM DISCHARGE Cubic feet per second	ESTIMATED MAXIMUM DISCHARGE Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(5)
Williamstown	16.2		500	30.9
Williamstown	16.5		561	34.0
West Camden	47.5	Spring 1884	1,620	34.1
Camden	61.4	June, 1889	1,475	24.1
Camden	61.5		1,417	23.0
Camden	61.5		1,456	23.5
Camden	68.8		1,335	21.9
McConnellsville	187.0	1884	6,170	32.7
Taberg station	387.0	March 14, 1898	5,875	15.2
Fish Creek	533.0	March 15, 1898	7,597	14.2
Point Rock[1]	104.3	Fall, 1897	8,400	80.5

[1] On east branch of Fish creek.

Floods in Mad river. This stream is tributary to the west branch of Fish creek at Camden. Maximum flood-flows from well-defined high-water marks, as measured at this place, are 922 cubic feet per second (catchment, 47 square miles), or at the rate of 20 cubic feet per second per square mile. As measured at the gristmill dam, just below the preceding, with one mile additional catchment area, they are 1030 cubic feet per second, or at the rate of about 22 cubic feet per second per square mile.

Floods in east branch of Fish creek. The catchment area of this stream above Point Rock, where the gaging station is established, is quite different from that of the west branch of Fish creek above McConnellsville. The stream rises very rapidly and the surface soil is such as to give large runoffs. The maximum flood is reported as having occurred in the fall of 1897, with a total runoff of 8400 cubic feet per second (catchment, 104 square miles), or 80.5 cubic feet per second per square mile. Ordinary floods, as determined from high-water marks, are about 37 cubic feet per second per square mile.

Floods in Beaver Dam creek. This stream is reported as having given (date uncertain) a flood-flow as measured near Altmar of 2300 cubic feet per second (catchment, 21 square miles), or at the rate of 111 cubic feet per second per square mile.

Floods in Salmon river, west. This stream has a catchment area of 190.5 square miles above Henderson's mill, of which 10 to 20 square miles are flats, the balance of the area having rather sharp slopes. The soil is sandy. The maximum flood is reported as occurring in the summer of 1888 and was due to heavy summer rains. The figures are 5670 cubic feet per second, or at the rate of 30 cubic feet per second per square mile. The ordinary floods do not exceed about 20 cubic feet per second per square mile. The upper part of the catchment is mostly primeval forest.

Data from flood hights were also obtained at Altmar, three miles below Henderson's mill, as follows: Maximum, 6100 cubic feet per second (catchment 221 square miles), or at the rate of 28 cubic feet per second per square mile.

Floods in Trout brook. This stream is reported as having given a flood-flow at Centerville (date uncertain), of 1166 cubic feet per second (catchment, 23 square miles), or at the rate of 51 cubic feet per second per square mile.

Floods in Skinner creek. This stream is reported as having given in the summer of 1891 a flood-flow at Mansville of 790 cubic feet per second (catchment, 6 square miles), or at the rate of from 125 to 130 cubic feet per second per square mile.

Floods in south branch of Sandy creek. In December, 1898, this stream gave a flood-flow at Adams of 3840 cubic feet per second (catchment, 110 square miles), or at the rate of 35 cubic feet per second per square mile. At Allandale a flood-flow is reported in 1890 or 1891 of 6000 cubic feet per second (catchment, 68 square miles), or at the rate of 88 cubic feet per second per square mile. Ordinary flood-flows in this stream average perhaps 35 cubic feet per second per square mile.

Floods in north branch of Sandy creek. A flood-flow was measured in this stream at Adams in the winter of 1897 of 7410 cubic feet per second. The catchment area is the same as that of the south branch at this place, or 110 square miles. Hence, the flow was at the rate of 67 cubic feet per second per square mile. Ordinary flood-flows are at the rate of about 30 to 35 cubic feet per second per square mile.

Floods in Black river. Heavy floods have occurred in Black river in 1807, 1833, 1850, 1857, 1862, 1866, 1869 and 1896. The flood of April 20–24, 1869, was specially heavy, there being a heavy snowfall over nearly the entire catchment area, which melted rapidly that year. In addition to the ground being heavily covered with snow, about 2.2 inches of rain fell in some parts of Black river catchment basin from April 17-23, though this quantity of rain, which was only over a portion of the catchment area, hardly explains the severity of the flood. The greater portion of the water evidently came from rapid melting of snow.

Flood in Black river in April, 1869. On April 21, 1869, the banks of North lake reservoir, a structure maintained by the State for the purpose of storing water for the Black river and Erie canals, gave way, precipitating into the heavily swollen stream about 350,000,000 cubic feet of water. This accident was made the basis of large claims for damages against the State, which were tried before the Canal Appraisers in the summer and fall of 1869. The testimony in this case, which included two large octavo volumes of over twelve hundred pages, is the source of the following information as to flood-flows of Black river and its tributaries in the spring of 1869:

The Black river flood of April, 1869, was studied by David M. Green, Samuel McElroy, William J. McAlpine, L. L. Nichols and other hydraulic engineers of that day. The testimony may, therefore, be referred to as furnishing unusually good flood data.

Mr Nichols stated that he not only measured the lengths of the crests of the dams on the several streams for which flood-flows were given, but that he also instrumentally determined the hight of flood marks above the crests. This work was done within a few months after the flood while the matter was fresh in the minds of everybody. He further stated that the tabulated flood-flows were obtained by computing with Francis's formula for discharge over sharp-crested weirs with clear overfall. The dams, however, on which the flood-flows were measured were of such a form as to indicate the use of Cornell experiments Nos.

1 or 2 as giving more nearly the actual flows, and accordingly the flows have been computed by the use of the said coefficients. By way of showing the relation between the flows as per Francis's formula and by Cornell experiments Nos. 1 and 2, the following tabulation is submitted, the last column giving the difference between Francis's formula and the mean of experiments Nos. 1 and 2 as a per cent of the flow by Francis's formula:

HEAD ON CREST Feet	CUBIC FEET PER SECOND PER FOOT OF CREST		Difference of columns (2) and (3)	Difference as a per cent of flow by Francis's formula
	Cornell experiments Nos. 1 and 2	Francis's formula		
(1)	(2)	(3)	(4)	(5)
0.5	*1.17	1.18	0.01	0.8
1.0	*3.44	3.33	*0.11	3.3
1.5	*6.59	6.12	0.47	7.7
2.0	10.50	9.42	1.08	10.4
2.5	14.59	13.16	1.43	10.8
3.0	19.12	17.30	1.82	10.5
3.5	24.20	21.90	2.30	10.5
4.0	29.66	26.64	3.02	11.3
4.5	35.40	31.78	3.62	11.4
5.0	41.46	37.20	4.26	11.5

* Mean taken

In passing, it may be remarked that the flood-flows of Black river have been computed by either Bazin's coefficients or by the coefficients deduced from the Cornell University experiments.

In its course from the headwaters in Hamilton county to Lake Ontario at Dexter, Black river has topographically three distinct subdivisions: (1) The upper valley above Lyon Falls; (2) the middle valley stretch from Lyon Falls to Carthage, and (3) the lower valley with rapid fall from Carthage to Black river bay. The second division, from Lyon Falls to Carthage, is a broad, flat valley.

The catchment area of the whole river above Dexter is 1930 square miles; above Carthage, 1812 square miles, and above the mouth of Moose river, 463 square miles. The following are the areas of the principal tributaries: Deer river at mouth, 102 square miles; Beaver river at mouth, 337.5 square miles; Moose river at mouth, 415.5 square miles; Woodhull creek at mouth, 108 square miles; Otter creek, above Casler's dam, 63 square miles; Independence creek, 99 square miles.[1]

The descent of the river above Lyon Falls, as well as below Carthage, is very rapid. At North lake reservoir the elevation is 1821 feet above tidewater; at Forestport, 1126 feet; at Lyon Falls, above the dam, 799 feet, and at Carthage, 723 feet. At Dexter, at Lake Ontario level, the elevation is 247 feet.[2]

Throughout the flat portion of the stream, between Lyon Falls and Carthage, the river at ordinary stages ranges from 250 to 300 feet wide, increasing to about 500 feet above the Carthage dam, which is 966 feet long. In a powerful freshet like that of 1869 the flats on each side are overflowed to a great width and considerable depth, the quantity of water accumulated in large floods being computed at from 4,000,000,000 to 6,000,000,000 cubic feet. If we take into account the water held in the interstices of the soil, the temporary storage is considerably higher than indicated by these figures. In this reach of the river, which is alluvial in its formation, there are now two dams of 4 feet each, with locks for facilitating navigation.

The river has no affluents of any magnitude below Carthage, but a few miles above that place, on the west side, Deer river comes in. There are also a number of secondary creeks between Deer river and Lyon Falls. On the east side the chief affluents are Beaver river, Independence creek, Otter creek and other secondary creeks below Lyon Falls, with Moose river flowing in just above Lyon Falls. All of these streams between Carthage and Lyon Falls have rapid descents, with consequent large flood-flows.

The following tabulation gives the catchment area of Otter and Independence creeks, as well as of Beaver and Deer rivers and Black river, including Moose river above Lyon Falls, together with

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[1] For statement in more detail of the Black river catchment area and elevations, see pages 221–222.

[2] The fall in Black river from the foot of Lyon Falls to Carthage is 9 feet in a distance of about 30 miles in a straight line. The distance by the meander of the river is considerably greater than this. This intermediate flat stretch of river is due to a rocky barrier at Carthage.

the flood-flows for April, 1869, the flows having been corrected by the use of the Cornell coefficients in the manner already described:

Name of stream	Catchment area, square miles	Flood flow, cubic feet per second
Otter	63.0	1,944
Independence	93.2	6,200
Beaver	322.3	5,382
Deer	101.0	7,881
Black	878.5	40,400
Total	1458.0	61,807

From the preceding tabulation it appears that a catchment area of 1458 square miles yielded a maximum flood-flow about April 22, 1869, of 61,807 cubic feet per second, or at the rate of 42.3 cubic feet per second per square mile. The total area above Carthage, however, is 1812.2 square miles. Assuming the same average flow from the balance of the catchment area as from the 1458 square miles included in the streams tabulated, it follows that the total inflow to the pond area between Carthage and Lyon Falls was at the rate of 75,830 cubic feet per second. The greatest flow at Carthage, which occurred April 23, 1869, was only 39,529 cubic feet per second, the effect of the temporary pondage above that place having been to reduce the flood from about 76,000 cubic feet per second to about 40,000 cubic feet per second.

Inasmuch as there are no affluents to the stream below Carthage, there is no special reason why the flood-flow below that place should have any higher rate than at Carthage. The reported flow at Watertown in April, 1869, of 39,696 cubic feet per second is, therefore, considered as fairly justifying the Carthage figure. A comparison of the two shows at any rate that the error is not likely to be more than a few per cent.

On April 21, 1900, the calculated discharge over the Huntingtonville dam was 30,150 cubic feet per second (catchment, 1889 square miles), or at the rate of about 16 cubic feet per second per square mile. December 15, 1901, there was a flood with a calculated discharge of 37,000 cubic feet per second, or 19.2 cubic feet per second per square mile.

Floods in Woodhull creek. The flood-flow of this stream at Hill tannery in April, 1869, was 4040 cubic feet per second (catchment, 108 square miles), or at the rate of 37 cubic feet per second per square mile.

Floods in Moose river. The flow of this stream at Ager's paper mill in April, 1869, was 12,644 cubic feet per second (catchment, 407 square miles), or at the rate of 31 cubic feet per second per square mile.

Floods in Otter creek. The flow of this stream at Casler's paper mill in April, 1869, was 1944 cubic feet per second (catchment, 63 square miles), or at the rate of 31 cubic feet per second per square mile.

Floods in Independence creek. The flow of this stream at Crandall's paper mill in April, 1869, was 6200 cubic feet per second (catchment, 93 square miles), or at the rate of 67 cubic feet per second per square mile.

Floods in Beaver river. The flow of this stream at Beaver Falls in April, 1869, was 5382 cubic feet per second (catchment, 322 square miles), or at the rate of 17 cubic feet per second per square mile.

Floods in Deer river. The flow of this stream at Deer River in April, 1869, was 7881 cubic feet per second (catchment, 101 square miles), or at the rate of 78 cubic feet per second per square mile.[1]

Floods in Oswegatchie river. The highest flood reported in the Oswegatchie river at Ogdensburg (date unknown) gave a depth of 5.5 feet on the crest of the dam. This depth corresponds to a discharge of 15,500 cubic feet per second (catchment, 1609 square miles), or to 10 cubic feet per second per square mile.

Above the Black lake inlet the flood discharge estimated from highwater marks is 9000 cubic feet per second (catchment, 900 square miles), or at the rate of 10 cubic feet per second per square mile. At Town Line bridge the flood discharge of Indian river on September 28, 1900, was 29 cubic feet per second.

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[1] The foregoing in regard to the flood-flows in 1869 in Woodhull creek, Moose river, Otter creek, Independence creek, Beaver river and Deer river is taken from the evidence relating to the Black river claims.

A considerable number of the foregoing flood-flows are from table No. 124, in the report to the Board of Engineers on Deep Waterways, to which reference may be made for detail not given here.

Floods in Raquette river. The estimated flood discharge of Raquette river at Piercefield about May 1, 1900, was 7000 cubic feet per second (catchment, 700 square miles), or at the rate of about 10 cubic feet per second per square mile. Owing to a large amount of lake storage, probably the flood-flows of Raquette river do not often exceed this, although they may occasionally rise somewhat higher.

Floods in Hudson river. The maximum flood of this stream is stated to have occurred in the spring of 1869, and at Mechanicville amounted to about 70,000 cubic feet per second (catchment, 4500 square miles), or was at the rate of 15.5 cubic feet per second per square mile. Gagings have been made at Mechanicville for sixteen years, the highest flood during the period having been 59,400 cubic feet per second on April 9, 1896. The large pondage on natural lakes and ponds on the headwaters of the Hudson tends to reduce the severity of the floods. On April 18, 1896, the water stood on the crest of the Fort Edward dam at the hight of 8.16 feet, giving a computed flow of 41,675 cubic feet per second (catchment, 2800 square miles), or 14.7 cubic feet per second per square mile.

The ordinary floods at Fort Edward, as determined from the last seven years' record, may be taken at about 25,000 cubic feet per second, or 9.2 cubic feet per second per square mile. The following tabulation shows the flood-flows at Fort Edward since the establishment of the station in the fall of 1895. As stated on a preceding page these flows may be 25 per cent in error.

Date	MAXIMUM DISCHARGE	
	Cubic feet per second	Cubic feet per second per square mile
April 18, 1896	42,620	15.2
November 7, 1896	24,550	8.7
April 12, 1897	23,732	8.5
June 12, 1897	23,242	8.3
December 17, 1897	27,920	10.0
March 16, 1898	29,856	10.7
April 25, 1898	32,159	11.5
April 23, 1900	43,900	15.7
April 23, 1901	42,820	15.3

Hudson river has a catchment area of about 12,200 square miles in New York, 200 square miles in New Jersey, 320 square miles in

Massachusetts and 300 square miles in Vermont, or over 13,000 square miles in all. It drains about one-fourth of the land area of the State. Above Troy it is a normal stream of varying inclination, gradually increasing as we go toward the source. The crest of Saratoga dam, 180 miles from the mouth of the river, is at an elevation of 102 feet, giving a grade for 30 miles of 3.2 feet per mile. At the Fort Edward railway bridge, 190 miles from the mouth, the hight above the sea is 118 feet, giving a grade for 10 miles of 1.6 feet per mile. At the crest of the Glens Falls feeder dam, a distance of 197 miles from the mouth, the hight of the river above the level of the sea is 284 feet, giving a grade for 7 miles of 23.7 feet per mile. At the mouth of Sacandaga river, 216 miles from the mouth, the hight above sea level is 536 feet, giving a grade for 19 miles of 13.3 feet per mile; and so on, until finally, at the extreme head, in Lake Tear of the Clouds, 300 miles from the mouth of the river, the hight above sea level is 4322 feet, and the average grade for the preceding 34 miles is 84.4 feet per mile. This condition of steep grades in the upper reaches, with flat grades in the lower reaches, while true of all streams, is markedly true in the case of New York State streams.

The main tributaries of the tidal portion of the Hudson are the Croton, with a catchment of 365 square miles; Fishkill, draining 204 square miles; Rondout creek, including the Wallkill, draining 1148 square miles; Esopus creek, draining 417 square miles; the Catskill, draining 394 square miles, and the Kinderhook, draining 304 square miles. The Croton is regulated by storage reservoirs for the water supply of New York city, and most of the other tributaries mentioned have been studied with reference to their availability for municipal water supplies.

Broadly, such studies indicate that while these streams are controllable by storage reservoirs, their topography is such as to make development very costly. Generally they would be too expensive for flood prevention merely. Above the tidal portion, which terminates at the Troy dam, the conditions are different. The Mohawk river, with a catchment area of 3500 square miles, joins the Hudson at Cohoes. Higher up the Hoosic, the Battenkill and Fish creek enter. At Hadley the Sacandaga, with a catchment area of 1057 square miles, enters, and at Thurman the Schroon river, with a catchment of 570 square miles. Farther north the Indian and Cedar rivers join.

Serious flood conditions exist in the upper part of the tidal portion of the Hudson from Troy to Coxsackie, a distance of about 30 miles. The channel is shallow, crooked and narrow and the full effect of floods in the Mohawk and upper Hudson, which come together near the head of the tidal section, are concentrated here. At the ordinary low stage the current is intermittently reversed by the tide, but upon the occurrence of a flood in the Mohawk and upper Hudson the water rushes into this upper portion of the tidal section until a cross-section, slope, and velocity are acquired sufficient to carry the flood-flow, whatever it may be.

The flood conditions are greatly intensified in winter and early spring by ice, which forms more solidly in the tidal section than in the steeper tributaries. Whenever a winter flood occurs the breaking up of ice in the upper part of the tidal section, retarded by the field below, continually increases in volume along the crumbling upper edge of the latter, and finally grounds in some shallow or narrow part of this section, creating an ice dam, to which the most disastrous floods of this part of the river are attributable. These dams form at various points in the shallow section—sometimes between Troy and Albany, but usually between Albany and Coxsackie. It is the floods accompanied by these ice dams that have inflicted the most serious damage upon this section of the river.

Hudson river floods at Albany. The following from the report of a Committee of the Albany Chamber of Commerce on Freshets in the Hudson River will serve to show the extent of Hudson river floods for twenty-five years:

FRESHETS AND ICE GORGES IN THE HUDSON RIVER

Year	Month	Elevation above M. L. W. 1876	Remarks
(1)	(2)	(3)	(4)
1876	Feb. 16...........	14.0	
1877	March 30.........	....	No bad dam formed so far as known.
1878	March 5..........	....	No bad dam formed so far as known.
1879	March 27.........	....	No bad dam formed so far as known.
1880	Feb. 14, Jan. 28...	....	Trains on Susquehanna R. R. could not start from depot on account of high water. Heavy rainfall; river rose 11 feet in 36 hours.
1881	Feb. 12, Mar. 1, 18	....	Gorge formed between Stuyvesant and lower Kinderhook light.
1882	Feb. 14..........	....	River 12 feet above mean tide.

FRESHETS AND ICE GORGES IN THE HUDSON RIVER (*couclucled*)

Year	Month	Elevation above M. L. W. 1876	Remarks
(1)	(2)	(3)	(4)
1882	March 1–8	....	Ice gorge formed at Douw's point.
1883	March 28	....	No dam formed so far as known.
1884	Feb. 8, 14, 15, 18, 22, 24 and 26	15.45	Ice dam at Van Wie's point; dam at Four-Mile point.
1885	April 1–4	....	Ice gorge at Van Wie's point and Quay street submerged.
1885	January 1	....	Ice lodged on the "Overslaugh."
1886	March 14–26	17.89	Ice dam at Pleasure island, Troy inundated.
1886	Jan. 4–8, Feb. 13	....	Ice dam between Castleton and Coeymans.
1887	April 11–May 5	....	Docks and R. R. tracks submerged. People's Line boats could not land at their docks until after May 5. Ice gorge at Nuttenhook.
1888	Dec. 18, Apr. 1–7	....	Docks submerged. State and Dean streets covered.
1889	....	....	No dam formed so far as known.
1890	....	....	No dam formed so far as known.
1891	February 27	....	Ice dam formed south of Albany and remained until March 14.
1892	Jan. 15	....	Water in cellars on Broadway. No bad dam formed so far as known.
1893	March 14	19.00	Ice piled to a depth of from 20 to 30 feet. Some of the ice nearly 3 feet thick.
1894	March 7	16.12	Ice dam from Cedar Hill to N. Coeymans.
1895	April 10	16.54	Melting snow and rain.
1896	March 1	17.78	Much damage done to railroad by water and ice which flooded the tracks as far as Stockport. Ice finally stopped at Four-Mile point and remained until some time in April.
1897	....	....	Ice moved out easily.
1898	March 13	13.80	No bad dam so far as known.
1899	March 6	12.45	Gorge at Van Wie's point opposite Castleton and below North Coeymans.
1900	Feb. 14	19.96	Gorge below Kinderhook Upper light, between Coeymans—north end of Castleton U. S. Government dike to Cow Island light.
1901	December 12	13.56	Gorge below Stone House bar.
1902	March 3	18.26	Gorge below Stone House bar.

It seems doubtful whether with the present irregularity of flow in the Hudson there is either any practicable means of preventing the formation of ice dams in this part of the river, or of removing them by artificial means when once formed. In order to prevent their formation it would be necessary to have a channel through the ice broken before the flood arrived. The fact that (1) floods are to be apprehended at any time during the four months from December to April; (2) that tidal action at low stages of the river would prevent the broken ice from passing rapidly away, and (3) that floods frequently come with little warning, means that to certainly prevent ice dams the ice must be continually broken during these months, a condition involving heavy cost for furnishing and operating powerful ice-breaking steamers. Moreover, when we consider that ice dams sometimes obstruct the river for several miles in extent, the impracticability of removing them by mechanical means seems sufficiently obvious.

While it is doubtless possible to mitigate floods in this section of the river by isolating the flooded districts by dykes or levees, which would necessitate intercepting sewers, as well as the pumping of the surface and sewer drainage whenever there is a slight freshet in the river, nevertheless the most rational treatment is believed to be by storage of the flood-flow in the upper tributaries of the stream.

The opinion has been expressed that storage should be developed proportionate to the catchment area on the several tributaries of the Hudson above Troy, and while this is theoretically true, the writer imagines that the question of cost will finally come in, very greatly modifying any purely theoretical deductions based on this view. To show how material an element in the problem cost may become, it may be mentioned that reservoirs have been at various times considered costing from about $20 per million cubic feet stored, to as high as $200 or $300 per million cubic feet. The cost of such reservoirs as compared with the cost of reservoirs for municipal purposes, even at these prices, is very low, the cost per million gallons frequently rising higher than the cost per million cubic feet here proposed. But nobody is likely to expend a large amount of money in order to meet the theoretical requirement of equal storage in all parts of a catchment area when considerably less money will build a storage reservoir of equal capacity elsewhere. Practically, therefore, it is impossible to regulate as large a catchment as that of the Hudson river to anything like a uniform flow throughout all of its tributaries. The mere matter of cost alone will militate against such a conclusion. In a few words the conditions are that in the upper Hudson, above Glens Falls, very extensive storage reservoirs may be constructed, either on the main river or its chief tributaries, Sacandaga, Schroon and Cedar rivers, which were estimated in 1895, for the whole system, to cost something like $60 per million cubic feet of water stored. Probably at the present time they will cost somewhat more, but for water storage merely they will not exceed $75 or $80 per million cubic feet. On the Mohawk and its tributaries conditions are much less favorable. Reservoirs there are likely to cost from $200 to $300 per million cubic feet. Hence, as a financial proposition, the Hudson river above Mechanicville is likely to be more thoroughly regulated than the Mohawk river and its tributaries, the more specially since water storage has not only value here for preventing floods, but is also of considerable value for water power. The same is true on the Mohawk river, but the limit of cost of water power in comparison with steam power will be much sooner reached on this stream than on the upper Hudson. Since this phase of the subject is extensively discussed in the first report on the upper Hudson storage, it is merely referred to here.

Floods in Croton river. The catchment of the Croton river consists of a broken, hilly country with its surface soil composed principally of sand and gravel. Clay, hardpan and peat, while found in a few localities, are for the whole area only present to a limited extent. The rock formation consists generally of gneiss, although strata of limestone, some micaceous and talcose slates, with veins of granite, serpentine and iron ore, occur in a few places. The catchment area is about 339 square miles, above the old Croton dam, at which point daily gagings of the stream have been taken since 1867. According to J. J. R. Croes there is a well-attested case of a maximum flood of 25,376 cubic feet per second, or 74.9 cubic feer per second per square mile. In reference to these figures it may be remarked that probably they have been obtained by the use of Francis's formula. The profile of the old Croton dam, however, shows a rounded crest which, according to Bazin's coefficient, series No. 193, would give, with about 5 feet depth on the crest, a discharge from 37 to 38 per cent higher than Francis's formula. The maximum flood of the Croton may, therefore, be from 30,000 to 35,000 cubic feet per second, or possibly as high as 103 cubic feet per second per square mile.

January 7-8, 1841, a severe flood occurred which washed away the earthen bank of Croton dam. At that time the ground was covered with eighteen inches of snow, and rain falling continuously for forty-eight hours, with high temperature, produced a serious flood. The overflow weir was insufficient to discharge the large volume, although part of the water was discharged through the aqueduct to the waste-weir at Mill river, fifteen miles below Croton dam. The water rose in Croton lake at the rate of fourteen inches per hour. The earthen bank remained intact until the water nearly reached its top, when it flowed between the frozen and unfrozen earth, twenty inches below its crest, forming a breach. The large amount of ice in the river demolished the protection wall and the whole embankment was washed away. At the time of the accident, on January 8, the water flowed over the weir to a depth of 15 feet.

Another severe flood occurred in November, 1853, while in April, 1854, after unprecedented rains, the worst freshet was experienced which has yet been recorded. The depth on the crest of the Croton dam was 8.25 feet.

Floods in Fishkill creek. This stream is subject to severe floods, although there is not a great deal known about them. The following tabulation, calculated from high-water marks observed for a number of years at the Groveville dam, embodies practically all the information. The dam is of masonry faced with plank, with a straight horizontal crest, 4 feet wide and 134 feet long. The discharge has been calculated by coefficients derived from Cornell University experiment No. 11.

Year	Month	Depth on crest, feet	DISCHARGE	
			Cubic feet per second	Cubic feet per second per square mile
(1)	(2)	(3)	(4)	(5)
1882	September 24	6.3	7,700	38.5
1888	March 22	5.0	5,200	26.0
1888	December 18	4.5	4,400	22.0
1891	January 12	6.3	7,700	38.5
1891	January 13	4.0	3,650	18.3
1891	January 22	4.0	3,650	18.3
1891	January 23	6.9	8,800	44.0
1893	March 10	5.0	5,200	26.0
1893	March 11	4.3	4,000	20.0
1893	March 12	5.5	6,100	30.5
1893	March 13	5.0	5,200	26.0
1893	March 14	4.0	3,650	18.3
1896	February 7	6.7	8,300	41.5
1896	March 1	4.5	4,400	22.0
1896	March 20	6.7	8,300	41.5
1902	March 1	9.5	13,700	68.5

Floods in Wallkill river. Very little information is available as to the flood-flows of this stream any further than that on August 7, 1901, the discharge at New Paltz was 7365 cubic feet per second (catchment, 736 square miles), or at the rate of 10 cubic feet per second per square mile. The extreme flood must be much higher than this. Mr Vermeule states that high-water marks on Clove river, one of the tributaries of the Wallkill river, indicate a maximum discharge of 67 cubic feet per second (catchment, 0.7 square mile), or at the rate of 96 cubic feet per second per square mile.[1] This catchment is perhaps rather small for final conclusions.

Floods in Esopus creek. According to the statement of M. E. Evans in a report to the Saugerties Manufacturing Company, the maximum flood in Esopus creek at Saugerties occurred on December 10, 1878. This flood resulted from a snowfall of six inches, followed by excessive and continuous rain for three days. The extreme depth on the crest of a dam 330 feet in length was 14 to 14.5, feet, indicating a flood discharge of from 50,000 to 60,000 cubic feet per second (catchment, 417 square miles), or at the rate of from 120 to 145 cubic feet per second per square mile.

Floods in Rondout creek. The most severe flood in this stream was that of March 1, 1902, when there was a discharge as measured at Rosendale of about 14,000 cubic feet per second (catchment, 365 square miles), or the flow was at the rate of 38 cubic feet per second per square mile.

Floods in Catskill creek. This stream is of rapid descent and subject to wide variation in flow. From high-water marks at Woodstock dam the flood-flow in the spring of 1901 has been computed at 21,000 cubic feet per second (catchment, 210 square miles), or at the rate of 100 cubic feet per second per square mile.

Floods in the Normans kill. So far as can be learned, the only information in regard to flood-flows of this stream is given in a report of the Water Commissioners of Albany to the Common Council in 1891 as to the advisability of utilizing this stream for a water supply for the city of Albany. In this report the catchment area above French Mills is stated at 111 square miles. From measurements taken in February, 1891, the flow was 1240 cubic

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[1] Report on Water Supply, Water Power, the Flow of Streams and Attendant Phenomena, by Cornelius C. Vermeule, Vol. III of the Final Report of the State Geologist of New Jersey, p. 149.

feet per second, or at the rate of 11 cubic feet per second per square mile. The maximum flood hight on the Harden dam at Normanskill is stated at 4 feet. This would indicate a flood discharge of 16 cubic feet per second per square mile. The maximum flood hight on the dam just above the highway at Kenwood is stated at 8 feet, indicating a discharge of 22.0 cubic feet per second per square mile.

Floods in Schroon river. Owing to the regulating effect of Schroon lake, serious floods are unknown in this stream. The usual extreme flows are about 8000 cubic feet per second at Warrensburg (catchment, 563 square miles), or at the rate of 14 to 15 cubic feet per second per square mile.

Floods in Mohawk river. Flood-flows of the Mohawk river have been measured at Dunsbach Ferry, with a catchment area of 3440 square miles, as follows:

Date	ESTIMATED DISCHARGE Cubic feet per second	ESTIMATED DISCHARGE Cubic feet per second per square mile
March 14, 1898	47,000	13.8
November 11, 1898	47,000	13.8
November 27, 1900	24,700	7.2
March 27, 1901	36,200	10.5
April 8, 1901	34,200	9.9
April 22, 1901	46,100	13.4
December 16, 1901	52,400	15.3

In 1892 the Mohawk at Rexford Flats flowed at the rate of 78,350 cubic feet per second (catchment, 3385 square miles), or 23 cubic feet per second per square mile. On February 14, 1900, the flow here was 45,000 cubic feet per second, or at the rate of 14 cubic feet per second per square mile. Ordinary floods at this place are from 30,000 to 35,000 cubic feet per second.

The maximum discharge of the river at Rocky Rift dam was in March, 1901, and is estimated to have been 23,150 cubic feet per second (catchment, 1337 square miles), or at the rate of 17 cubic feet per second per square mile. The flow has been calculated from Cornell University experiments.

In 1890 the flow at Little Falls is stated to have been about 22,000 cubic feet per second (catchment, 1306 square miles), or at the rate of 17 cubic feet per second per square mile. In February, 1891, there was a flood estimated at 26,260 cubic feet per second, or 20 cubic feet per second per square mile. On March 14, 1898, the flow was at the rate of 23,749 cubic feet per second, or 18.2 cubic feet per second per square mile. Since the gaging record has been kept at Little Falls the following freshets have occurred:

Date	Discharge	
	Cubic feet per second	Cubic feet per second per square mile
April 15, 1899	13,000	10.0
April 20, 1900	15,240	11.7
November 27, 1900	15,669	12.0
March 27, 1901	19,538	14.9
December 16, 1901	26,280	20.1
March 1, 1902	27,000	20.7

Ordinary floods at Little Falls are from 12,000 to 15,000 cubic feet per second.

The following information in regard to floods at Utica is mostly from a report made in 1900 by Stephen E. Babcock to the Mohawk River Straightening Commission of Utica. A few flood hights determined in 1901 and 1902 have also been added. The topographical elevations are plus tidewater:

Date	Elevation	Estimated Discharge	
		Cubic feet per second	Cubic feet per second per square mile
(1)	(2)	(3)	(4)
Mean low water	394.64	355	0.7
Freshet, November 22, 1900	398.49	1,470	2.1
Freshet, November 27, 1900	405.44	8,000	16.0
High water of 1890	405.68	8,800	17.4
High water, February 26, 1891	407.22	17,300	34.6
High water, 1892	406.44	12,500	25.0
High water, 1893	406.37	12,100	24.2
High water, 1894	405.62	8,600	17.2
High water, 1895	406.32	11,900	23.8
High water, 1899	405.52	9,300	18.6
High water, March 27, 1901	406.19	11,100	22.2
High water, December 15, 1901	406.75	14,300	28.6
High water, March 1, 1902	407.14	17,200	34.4

The foregoing flood elevations have been deduced from current-meter measurements and, as there is no very satisfactory place for making such measurements at Utica, are subject to considerable error. The catchment area at Utica is 500 square miles.

In the spring of 1888, the Mohawk at Ridge Mills gave a flow of 7030 cubic feet per second (catchment, 153 square miles), or at the rate of 46 cubic feet per second per square mile. On March 12, 1898, the flow at the same point was 5266 cubic feet per second, or at the rate of 35 cubic feet per second per square mile.

In the foregoing at Ridge Mills and Little Falls the data have been computed in accordance with the Cornell University coefficients. The ratio of the catchment area at Little Falls to that of Ridge Mills is 8.56. If we assume the flow of the several tributary streams above Little Falls to have been the same as that of the main Mohawk river above Ridge Mills, the maximum discharge of the entire catchment area is found by multiplying 5266, the flow in cubic feet per second at Ridge Mills on March 12, 1898, by 8.56, the ratio of the catchment areas. This gives a maximum inflow into the Mohawk river above Little Falls of about 45,000 cubic feet per second. Probably, however, this assumption is too large for the special case under consideration, as the flow of Oriskany creek at Oriskany on March 12, 1898, was only 600 cubic feet per second, or 4.1 cubic feet per second per square mile.

If, however, we assume that at some time the total flow from the tributary streams above Little Falls will approximate about 35 cubic feet per second per square mile, it follows that we may expect an inflow into the valley above Little Falls of certainly 45,000 cubic feet per second, although probably in March, 1898, it did not reach that figure. As to why such a flow is possible, we may consider (1) that tributary streams all have a rapid descent from the adjacent high ground, and (2) the large temporary storage of the flats above Little Falls.

By way of showing the character of the inflowing streams the following data relative to the descent of a number of the more important ones are cited. In the following tabulation we have the name of the tributary, distance from headwaters to mouth, and elevation of the headwaters, the elevation being taken not at the extreme, but usually at some point where the stream branches, within a short distance of the extreme headwaters:

Name of stream	Distance from headwaters to mouth, miles	Elevation of headwaters above tide
Mohawk river, above Ridge Mills....	23	1,066
Nine Mile creek..................	10	760
Oriskany creek....................	19	1,000–1,240
Sauquoit creek....................	15	1,200
Sterling creek....................	6	1,000
Mayer creek.......................	7	1,260
West Canada creek.................	64	2,300
East Canada creek.................	19	1,600
Canajoharie creek.................	15	1,350
Cayadutta creek...................	12	800
Schoharie creek...................	75	1,860
Cobleskill (tributary to Schoharie creek)	20	1,177
Batavia kill (tributary to Schoharie creek)	17	2,000
Chuctenunda creek.................	8	800
South Chuctenunda creek...........	11	1,100
Alplaus kill[1].....................	12	600

As further showing that the upper Mohawk—the portion above Little Falls—must be, so far as delivery in the broad level valley is concerned, a relatively rapid stream, we may consider that this division of the catchment area is quite narrow, being at the extreme western end about 45 miles and at Utica about 25 miles. On the north side of the valley Black river canal, following the general course of the river and its chief tributary above Rome, the Lansing kill, rises to an elevation of 1200 feet on the Boonville summit in a distance of 25 miles. To the south of Utica the abandoned Chenango canal, following a circuitous route, reaches an elevation of 1126 feet on the Bouckville summit in a distance of about 24 miles.

The mean elevation of the Mohawk valley proper, from a short distance above Little Falls to Rome, may be taken from about 380 to 420 or 430. At Rome, above the feeder dam, the elevation of the water surface above mean sea level is 430.5 feet; at the New York

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[1] This is the present corrupted spelling of the stream originally called Aalplaatz—a good place for eels.

Central & Hudson River railroad crossing, four miles east of Rome, it is 418.4 feet; at the crossing three miles east of Utica the water surface is 393.3 feet; at the mouth of Schoharie creek it is about 270 feet, and at the New York Central & Hudson River railroad crossing at Schenectady it is 214 feet. The foregoing tabulation, which includes streams below Little Falls as well as above, indicates that rapid flood delivery is the marked characteristic of all the tributary Mohawk streams.

The area of the flats between Little Falls and Rome as computed from the United States Geological Survey topographic sheets is about 21 square miles, this area including in effect the flats between the 400 and 420 contours. Adding thereto somewhat for nearly level area above the 420 contour, we may take the total area on which temporary pondage may exist during flood-flows at something like 30 square miles. The effect of this pondage, so long as the present natural conditions are maintained, will be to considerably lengthen the period of flood runoff at Little Falls, thus decreasing the maximum at that place.

The Mohawk river flood of August 24-26, 1898, may be mentioned. On August 23 and 24 very heavy thunderstorms occurred throughout the central and eastern portions of the State. They were specially severe about Utica, with the result, so far as can be learned, of yielding a nearly unprecedented summer flood in the Mohawk. The Mohawk flats between Herkimer and Rome were so far covered with water as to do great damage to standing crops. The water was still standing on the flats on the afternoon of August 27, but was down into the channel again on the afternoon of the 28th.

On August 25 Nine Mile creek, at Stittsville, flowed approximately 7820 cubic feet per second (catchment, 63 square miles), or at the rate of 124.9 cubic feet per second per square mile.

On the same date West Canada creek, at Middleville, gave a flow of about 12,950 cubic feet per second (catchment, 519 square miles), or about 24.9 cubic feet per second per square mile, while East Canada creek, at Dolgeville, flowed 6330 cubic feet per second (catchment, 256 square miles), or at the rate of 24.7 cubic feet per second per square mile.

Probably these flows were for very short periods—perhaps two or three hours—because the highest flow over the middle dam at

Little Falls where the gagings were made was about 4 feet to 4.5 feet in depth, equivalent to a flow of from 12,000 to 14,000 cubic feet per second, the temporary storage of the flats reducing the quantity at Little Falls very greatly.

By way of showing the quantity of rainfall causing the flood of August 24-26, 1898, the following precipitations at a number of points in the central and eastern portions of the State are cited from the monthly report of the New York State Weather Bureau:

	Rainfall in inches		
Name of Place	August 23	August 24	Total
Cooperstown	1.96	1.40	3.36
Oneonta	1.10	2.18	3.28
Gloversville	1.24	1.30	2.54
Little Falls (near city)	0.64	0.56	1.20
Little Falls reservoir (8 miles north)	1.68	2.78	4.46
Number Four	1.71	0.88	2.59
Kings Station	0.35	2.36	2.71
Albany	0.50	1.86	2.36
Greenwich	1.16	1.58	2.74
Rome	1.20	1.40	2.60
Saratoga Springs	0.23	1.79	2.02
Watertown	1.45	0.43	1.88

Taking all the facts into consideration, there seems to be no reasonable doubt but that the streams tributary to the Mohawk river above Little Falls for a short time on August 24 or 25 delivered water into the flat area at the rate of perhaps 40,000 cubic feet per second. By way of illustrating further why this large inflow did not produce a greater flow at Little Falls, we may consider that for from thirty to fifty days previous to August 23 the rainfall on and in the vicinity of the Mohawk catchment area had been rather low. The total for the Mohawk valley in July, 1898, as deduced from Weather Bureau stations at Little Falls, Canajoharie, St Johnsville and Rome was 3.93 inches, 2.53 inches of this having fallen on July 18 and 19. The concentration of the rainfall of the month into these two days had the effect of sending a very large portion of it into the streams, only a small portion going to replenish ground water. On August 1 the Mohawk valley record shows 1.18 inches precipitation, the total for that month being 7.12 inches. We may assume, therefore, that ground water was rather low August 23. Hence, Mohawk flats were in shape to absorb a considerable portion of the water delivered upon them into the interstices below the surface. Assuming, as already stated, 30 square miles to be more or less effected by such an inflow, and further assuming the interstices of the soil of this 30 square miles to be for the first 8 or 10 feet of depth about 30 per cent to 40 per cent of the whole volume, we reach the conclusion that the temporary storage of the flats may have been as much as 3,000,000,000 to 4,000,000,000 cubic feet, which sufficiently explains why the outgo at Little Falls did not exceed 12,000 to 14,000 cubic feet per second.

The foregoing figures do not take into account the extreme maximums which may be expected on this stream. So far as can be now seen, from 40,000 to 50,000 cubic feet per second delivery into the flats above Little Falls is rather common. The extreme maximum must be considerably greater than this. Without being able to cite specific floods proving the statement, the writer is nevertheless disposed to say, taking into account the known maximum floods of other streams of the State—Chemung, Genesee and Croton rivers—that at some time the Mohawk river above Little Falls may yield something like 60,000 to 70,000 cubic feet per second, or at the rate of perhaps 46 to 54 cubic feet per second per square mile.

A study of the flood-flows of the Mohawk river would be incomplete without some reference to the surface geology of the catchment area. The main trough of the valley lies entirely within the horizon of the Hudson river and Utica shales, where the soils, aside from immediately in the flat, level valley, are heavy and compact. On the north side, beyond the horizon of the shales, Trenton limestone and calciferous and sand-rock appear. At Little Falls, St Johnsville and Amsterdam these formations extend down into the valley to the thread of the stream. To the north of the Trenton limestone and calciferous sand-rock the Laurentian granite appears, the headwaters of West and East Canada creeks lying in this formation, while the less extended streams on the north side terminate either in the shale or limestone and sand-rock horizons. In the vicinity of Fonda, Johnstown, Gloversville and Mayfield the shale formations extend for some distance to the north of the trough of the valley, as also they do farther east, to the north of Schenectady.

To the south of the trough of the Mohawk valley we have first the shales, followed in ascending series by the Medina and Oneida sandstones, the shales and limestones of the Clinton formation, the Niagara limestones, the rocks of the salt group, the Helderberg limestone, the Oriskany sandstone, the Onondaga limestone, and finally the extended area covered by the Catskill and Chemung sandstones. The headwaters of Schoharie creek issue mostly from the Catskill formation, although the extreme headwaters flow from off the Oneonta sandstone, which, however, is closely allied to the Catskill. The shorter streams on the south side issue from the horizon of the Hudson and Utica shales, the same as short streams to the north.[1]

The soils of a considerable portion of the Mohawk river catchment area are consequently heavy and impermeable, and further tend to give heavy runoffs at time of flood-flow.

As regards flood-flows in the lower Mohawk river, the stream divides naturally at Little Falls. Below that point the flat area is relatively more restricted, and the flood-flows probably larger in volume than at Little Falls. We have already given particulars of the highest flood at Rexford Flats, where the catchment is 3385 square miles. According to the Report on Water Power in the Tenth Census, in an extreme flood which occurred about 1860 to 1865 there is stated to have been a depth of 12 feet of water on the Cohoes dam, which is 1400 feet in length. If such a depth actually occurred, the discharge may have been over 200,000 cubic feet per second or at the rate of over 59 cubic feet per second per square mile. The information at hand does not indicate a flow over about 78,350 cubic feet per second or 23 cubic feet per second per square mile at the Rexford Flats dam. The maximum, however, in view of the foregoing, may be placed at a considerably higher figure than this.

Floods in Cayadutta creek. The maximum flood of this stream near Johnstown is stated to have occurred in the spring of 1896, at which time the flow was 2895 cubic feet per second (catchment, 40 square miles), or at the rate of 72 cubic feet per second per square mile.

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[1] Also see statements regarding geology of Mohawk valley on p. 411.

Floods in Schoharie creek. The flow of this stream at Fort Hunter in 1892 was 41,715 cubic feet per second (catchment 947 square miles), or at the rate of 44 cubic feet per second per square mile.

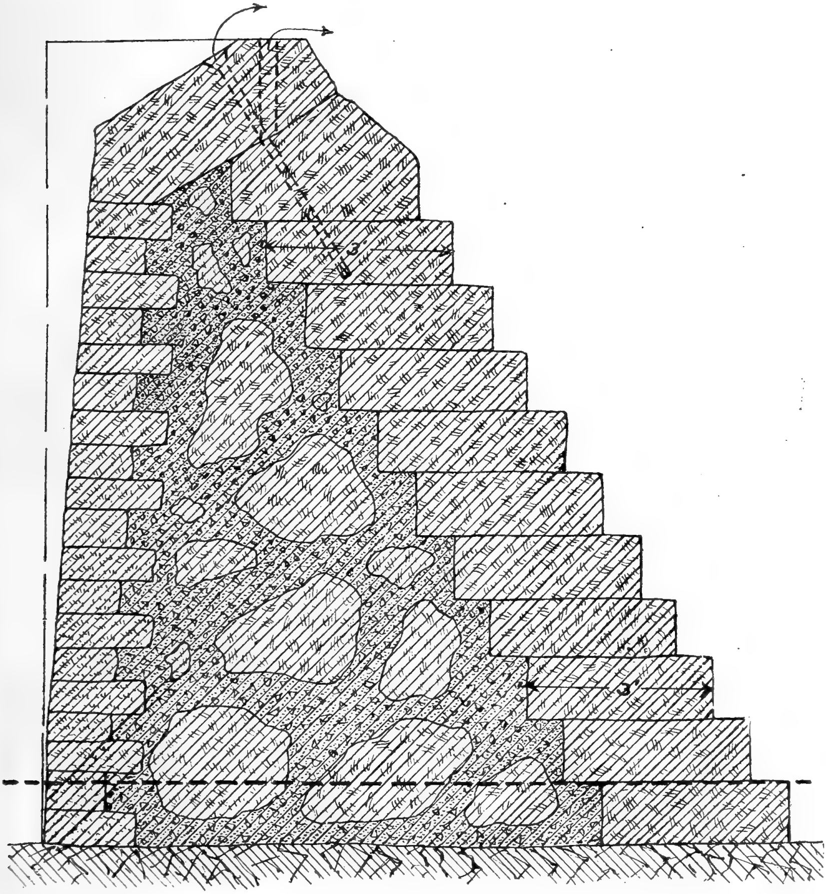

Fig. 36 Cross-section of dam of Empire State Power Company at Schoharie falls.

In 1899 and 1900 the Empire State Power Company erected a dam and power plant on Schoharie creek at Schoharie falls, seven miles from the city of Amsterdam. The crest of this dam was originally 380 feet in length. During a flood on March 21, 1901, the water attained a depth on the crest of 11.2 feet. The calculated discharge was 49,600 cubic feet per second (catchment, 930 square miles), or at the rate of 53 cubic feet per second per square mile.

This flood is stated to have been due to an ice gorge farther upstream.

On April 22, 1901, there was a flood of 38,400 cubic feet per second, or at the rate of 41 cubic feet per second per square mile. This flood is stated to have resulted from heavy rainfall.

The flood-flows of this stream are very heavy, and probably the extreme maximum may be taken at from 60 to 65 cubic feet per second per square mile.

The headwaters of Schoharie creek issue from the horizon of the Catskill group, which is closely allied to the Chemung, from whence it is probable that like the Genesee river, in the western part of the State, floods are not only frequent, but very heavy. Exceedingly heavy floods are ascribed to Schoharie creek by tradition.

Floods in Garoga creek. A flood of 16 cubic feet per second per square mile is, so far as can be learned, the highest flood in this stream. The stream rises in the Garoga lakes and Peck pond.

Floods in East Canada creek. The maximum flood in this stream at Dolgeville is reported as having occurred on August 25, 1898, at which time the flow was 6330 cubic feet per second (catchment, 256 square miles), or at the rate of 25 cubic feet per second per square mile. The flow at Dolgeville on April 18, 1900, was 5385 cubic feet per second, or at the rate of 21 cubic feet per second per square mile.

In reference to the moderate flow of August 25, 1898, it may be remarked that probably the heavy rainfall of August 23 and 24 did not extend over the greater part of this catchment. At North lake the rainfall of these two days was only 0.89 inch.

On December 15, 1901, there was a flow at Dolgeville of 12,150 cubic feet per second, or at the rate of 47.4 cubic feet per second per square mile.

Floods in West Canada creek. The maximum flood in this stream as measured at Trenton Falls dam occurred on December 15, 1901. It is estimated at 36,300 cubic feet per second (catchment, 375 square miles), or at the rate of 97 cubic feet per second per square mile. It is probable that this flood was considerably increased by the failure of the Hinckley dam, a short distance upstream. The flood was caused by heavy rains falling on frozen ground.

A high-water mark at the Newport dam indicates a flood discharge on August 25, 1898, of 22,000 cubic feet per second (catchment, 472 square miles), or at the rate of 47 cubic feet per second per square mile.

At Middleville the flood of August 25, 1898, is estimated to have discharged 12,950 cubic feet per second (catchment, 519 square miles), or the flow was at the rate of 25 cubic feet per second per square mile.

In August, 1874, a flood at Hinckley is estimated at 21,100 cubic feet per second (catchment, 360 square miles), or at the rate of 59 cubic feet per second per square mile. It is probable that flood flows as high as from 60 to 70 cubic feet per second per square mile are rather common in West Canada creek.

Floods in Sauquoit creek. The figures for this stream are not very definite, but so far as they go they indicate that floods of 50 cubic feet per second per square mile are not uncommon.

Floods in Oriskany creek. In the spring of 1888 a flood is reported in this stream as measured at Coleman of 7830 cubic feet per second (catchment, 141 square miles), or at the rate of 56 cubic feet per second per square mile.

In the spring of 1896 a flood is also reported in this stream, as measured at Oriskany, of 7510 cubic feet per second (catchment, 144 square miles), or at the rate of 52 cubic feet per second per square mile. Ordinary floods in this stream range from 18 to 25 cubic feet per second per square mile.

Floods in Nine Mile creek. On August 25, 1898, there was a flood-flow at Stittsville for a short time of 7820 cubic feet per second (catchment, 63 square miles), or the stream flowed at the rate of 125 cubic feet per second per square mile.

On March 12, 1898, the flow at Stittsville was 1800 cubic feet per second, or at the rate of 29 cubic feet per second per square mile.

Floods in Allegheny river. Nothing is known in regard to the flood-flows of Allegheny river and its tributaries any further than that the tributaries in their upper portions have heavy flows. As an estimate, purely, many of them may be placed at from 60 to 70 cubic feet per second per square mile, but like streams in other parts of the State, they need to be studied on their merits.

Floods in Susquehanna river. By common consent the highest flood experienced in this stream within the historical period was in March, 1865, but aside from the fact that considerable damage ensued, little is known in regard thereto. The entire region drained by the Susquehanna river in New York State, as well as in Pennsylvania, is not only mountainous, but largely denuded of timber. The flood-flows of the stream are, therefore, large. The catchment area above Chenango river is 2400 square miles. There is a State dam, formerly used in connection with Chenango canal, across this river at Binghamton, and S. E. Monroe, City Engineer of Binghamton, has compiled a map on which he has placed high-water elevations during the flood of March, 1902, together with a plan elevation and cross-section of dam. The figures show that the depth on the crest of this dam was 13.1 feet, with a difference of elevation above and below the dam of two feet. Computing the flow over this dam as a submerged weir, and making various corrections, including one for the water flowing through the lock at the south side of the river, it is found that the flood-flow in March, 1902, was about 70,000 to 80,000 cubic feet per second, or possibly at the rate of something over 33 cubic feet per second per square mile. A flow at this rate is less than might reasonably be expected; accordingly it may be assumed that the flood of March, 1902, was not the largest flood likely to occur on the Susquehanna river. Comparing it with other similar streams, there seems reason for supposing that at some time there may be a flood here of at least 50 cubic feet per second per square mile. Such extreme floods, however, do not occur more than once or twice in a century. The flood of March, 1865, which is the largest known,

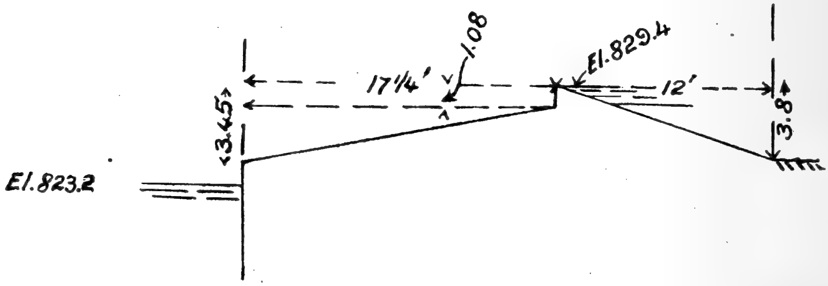

Fig. 37 Outline section of State dam at Binghamton.

probably approximated these figures. Probably the headwaters of this stream will give flood-flows of 60 to 70 cubic feet per second per square mile.

Chenango river. The serious flood which occurred at Binghamton on March 1-3, 1902, was mostly due to the overflow of Chenango river. A flood committee appointed by the Mayor of Binghamton has reported the total damage resulting from this flood at $16,720.

The committee also submitted a detailed statement, with names of individuals, showing a total decrease in valuation of property of $44,800.

The flood-flow of Chenango river is estimated at from 40,000 to 45,000 cubic feet per second (catchment, 1582 square miles), or at the rate of possibly 30 cubic feet per second per square mile. It is probable that the smaller tributaries towards the headwaters have flood-flows of 50 to 60 cubic feet per second per square mile.

Floods in Chemung river. The Chemung river, as well as its tributaries, the Cohocton and the Canisteo, is a gently flowing or alluvial river. The third tributary, the Tioga, is torrential for the greater portion of its length.

The city of Corning is situated on the Chemung river, about two miles below the junction of the Tioga and the Cohocton. A large portion of the city is built directly in the valley below flood level, from whence it results that Corning has suffered seriously from floods, but the city has recently carried out a system of improvements which thus far has prevented these inundations. The river flows near the south side of the valley, with the greater portion of Corning lying on the alluvial strip to the north—the balance of the city extends up the abrupt hill, flanking the valley on the south. The greater part of the floods occur on the northern side of the river, though there have been some which were more severe on the south side, owing to the denser population. In 1892 an act was passed by the legislature creating a Board of River Commissioners with authority to carry out the needed improvements and to issue bonds to pay for them. This act was amended in 1895, extending the authority to issue bonds to $150,000. The improvement was begun in 1896 and completed in 1897. The general plan was to enlarge the river channel through and below the city and to raise the banks by artificial dykes.

The minimum cross-section allowed through the bridges is 10,500 square feet. The dykes have a total length of 4.9 miles and vary in hight from 4 to 19 feet. These dykes not only extend along the river front opposite the city and for a considerable distance downstream, but also extend for nearly two miles along the westerly bank of Post creek, a torrential tributary reaching the river from the north. Several streams and a number of surface-water drains are provided for in different ways—some were carried in closed conduits which extend above high-water mark on the land side; others were carried through the dyke by cast-iron pipes, with gate valves and automatic flap valves at the river end.

The foregoing river improvement, although inaugurated and carried out as a city measure, did not include a reach of the south bank of the river, which was protected by an embankment and slope wall built a number of years before by the State of New York. In the course of time this embankment has deteriorated so that the portion of the river front protected by it is now in an unsatisfactory condition. During the floods of 1902 the high water was only kept from going over this old embankment by temporary work. Formerly, the State appropriated funds to maintain this embankment, with the result that the local authorities consider that the burden of maintaining it now rests with the State.

The city of Elmira lies on the Chemung river, about twenty-five miles above where it joins the Susquehanna. Floods are common here the same as at Corning, fifteen miles above. Within the historical period the most severe flood is that of June 1, 1889. At this time, according to a report made by Francis Collingwood, the stream flowed at the rate of 138,000 cubic feet per second (catchment, 2,055 square miles), or 67 cubic feet per second per square mile.

Mr Collingwood submitted a report of his investigations, together with a map of the river with flood profile for June 1, 1889. This profile shows obstructions to flood-flow are caused by a dam extending across the river near the west city line and by several bridges spanning the river below this dam. In addition to these specific obstructions the general condition of the channel through the city is unfavorable to a free discharge of floods. The river channel is characterized by breadth and shallowness, with abrupt changes of width and depth. This condition has been brought about by the fact that the river approaches Elmira with a high velocity, due to rapid descent for some miles above. It therefore reaches the city loaded with sediment and moving large amounts of detritus along its bed, but on reaching the flatter grades the velocity is checked and the stream is no longer able to move this material, which is left in the channel, gradually accumulating with each successive flood. The shoaling of the channel, due to such accumulation of material, encourages the erosion of banks, with the result that the channel increases in width and becomes shallower. During the flood of 1889 the river rose to a hight of 14 feet above low water mark, and a number of floods since that time have approached this in severity. In March, 1902, about thirteen hundred acres within the business and residence portions of the city were inundated and the flood damage in that year has been estimated at $155,000.

Mr Collingwood prepared five alternative plans for flood prevention, differing in the extent of protection to be secured and the permanence and character of the improvement. The first of these is estimated to cost $700,000; the second, $640,000; the third, $376,000; the fourth, $336,000, while in the fifth scheme an immediate expenditure of $133,000 is suggested, with moderate annual expenditure until the desired result is finally reached.

In this connection, Mr Collingwood suggests that the city should buy its own dredging plant. The total cost of a suitable plant would be about $25,000. In order to prevent the gradual filling up of streams, raising them more and more with each flood, Mr Collingwood suggests that the material should be taken from the bed of the streams.

Without knowing the condition fully, the writer doubts whether any scheme of partial dyking on Chemung river can be permanently effective. The whole river should be considered before any actual work of construction is undertaken.[1]

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[1] The facts in regard to floods at Elmira have been obtained from the Report on the Protection of the City of Elmira, N. Y., against Floods, by Francis Collingwood, dated February 12, 1890. The balance of the information in regard to floods on Chemung river is from the Report of the Water Storage Commission.

Floods in Canisteo river. This stream is subject to severe floods from which the city of Hornellsville has suffered greatly in the past. The fall of Canisteo river for two miles above the mouth of Canacadea creek is 2 feet per mile, while below the mouth of that creek it is 8 feet per mile. Above the mouths of Bennett and Stephens creeks the fall is 3½ feet per mile and 10 feet per mile below their mouths. These facts illustrate the effect of torrential tributaries of a stream in flattening slopes above their confluence and increasing them below.

Flood in Cohocton river. Conditions similar to those stated for the Canisteo river apply on the Cohocton river.

Floods in Delaware river. Very little is known about flood-flows in this stream, although they are undoubtedly high, in many cases no doubt approximating from 70 to 80 cubic feet per second per square mile. The valleys are narrow and do not, generally speaking, offer any great opportunity for water storage.

Summary of information as to maximum flows in New York. Concluding the subject of flood-flows in New York, on Oswego river and tributaries, where there is extremely large lake pondage, the flood-flows do not exceed 6 to 8 cubic feet per second per square mile.

On the Hudson river, with considerable lake pondage, the extreme floods are 15 to 16 cubic feet per second per square mile.

On the Black river, below Carthage, flood-flows of 16 to 20 cubic feet per second per square mile are about the maximum; above Lyon Falls, 25 to 40 cubic feet per second per square mile, and in the tributaries, generally from 30 to 60 cubic feet per second per square mile.

On the Mohawk river, with steep torrential tributaries, floods are from 20 to 50 cubic feet per second per square mile, and in the upper sections they may be as high as about 60 cubic feet per second per square mile.

On the Genesee river the extreme maximum thus far observed at Rochester, above which place there is an extensive pondage area, is 18 to 24 cubic feet per second per square mile, while at Mount Morris and Portage floods rise to over 40 cubic feet per second per square mile. On this latter portion of the stream a possible maximum may be expected of 60 to 70 cubic feet per second per square mile.

On the Allegheny, Susquehanna and Delaware rivers and their tributaries floods may rise to 50 to 60 cubic feet per second per square mile, and on torrential streams generally, throughout the State, they may at times be from 80 to 100 cubic feet per second per square mile. In a few cases on streams of small catchment areas they may rise to 125 cubic feet per second per square mile. The latter flows, however, are not very common.

Minimum Flow of Streams in New York

Whatever the purpose for which an inland stream is to be utilized, the first question asked is with regard to the minimum flow. If for power development, the minimum flow will determine the amount of power which can be insured on a given head; if for the water supply of a town, the minimum flow will indicate at once the number of people which may be supplied without storage. From every point of view, therefore, a knowledge of minimum flow is a matter of the first importance. Below are given the minimum flows of the inland streams of the State of New York, so far as information is at hand.

Minimum flow of Niagara river. According to table No. 45, the minimum discharge of Niagara river was in November, 1895, when the flow for the entire month averaged only 177,852 cubic feet per second (catchment above Niagara Falls, 265,100 square miles), or the flow was at the rate of 0.67 cubic foot per second per square mile.

Minimum flow of west branch of Canadaway creek. In the summer of 1883 measurements were made of the west branch of Canadaway creek in Chautauqua county from July 18 to September 2 of that year. This stream, which is the source of the water supply of the village of Fredonia, has a catchment area above the point of measurement of 4.3 square miles. The valley is deep cut for a distance of 3 miles from the measuring point to its extreme headwaters. Small springs issue frequently throughout the valley. On July 18, 1883, the stream was flowing at the rate of 541,620 gallons in 24 hours, or 50.2 cubic feet per minute, and very gradually decreased to 270,000 gallons, or 25 cubic feet per minute, on July 22. Rains between July 22 and July 29 brought the stream up to a discharge of 1,319,000 gallons per day, or 122.1 cubic feet per minute, on the latter date. The flow then gradually decreased during the month of August until, on August 26, it was only 216,000 gallons per day, or 20 cubic feet per minute, which was the lowest point reached during the summer of 1883.

This stream can not be considered a good water yielder. A mean discharge of 216,000 gallons in twenty-four hours from a catchment area of 4.3 square miles represents a yield of 0.334 cubic foot per second, or, what is the same thing, 0.078 cubic foot per second per square mile. It is apparent, therefore, that even a spring-fed stream with a deep valley in Chautauqua county may at times furnish a very small outflow, though it should not be overlooked that the flow of 0.078 cubic foot per second per square mile was the extreme minimum for one day only. The relations of this extreme minimum to the daily flows during the period covered by the measurements may be easily gathered from an inspection of table No. 81. The gradual falling in water yield from August 1 to 26 is the most interesting fact revealed by these measurements.

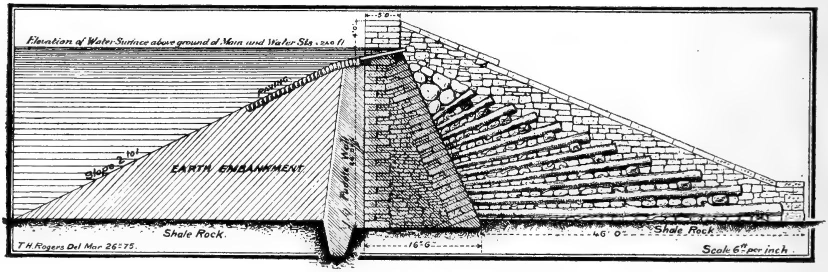

Fig. 38 Cross-section of dam near Fredonia on west branch of Canadaway creek.

The following was the rainfall at the point of measurement during the month of August, 1883:

	Inches
August 3	0.04
August 13	0.10
August 20	0.05
August 23	0.05
August 28	1.98

TABLE NO. 81

DAILY MEAN DISCHARGE IN CUBIC FEET PER MINUTE OF WEST BRANCH OF CANADAWAY CREEK, NEAR FREDONIA.

[Catchment area=4.3 square miles.]

DAY.	July.	August.	September.
1	......	56.5	47.6
2	......	50.3	45.0
3	......	46.2	....
4	......	45.4	....
5	......	39.8	....
6	......	36.9	....
7	......	36.0	....
8	......	34.1	....
9	......	34.1	....
10	......	33.2	....
11	......	31.7	....
12	......	30.2	....
13	......	30.2	....
14	......	32.4	....
15	......	27.0	....
16	......	27.9	....
17	......	31.7	....
18	50.2	28.4	....
19	49.3	29.3	....
20	45.7	31.7	....
21	44.0	33.2	....
22	25.0	22.9	....
23	......	25.6	....
24	......	....	....
25	......	22.1	....
26	......	20.0	....
27	......	21.3	....
28	......	105.1	....
29	122.1	321.9	....
30	......	101.7	....
31	62.4	60.0	....

Minimum flow of Genesee river. The following tabulation gives the mean monthly flows of the Genesee river at Mount Morris and Rochester for several low months of the year 1895, the catchment area above Mount Morris being 1070 square miles and that above Rochester, 2365 square miles:

Month	Mount Morris			Rochester	
	Cubic feet per second	Cubic feet per second per square mile	Inches on the catchment	Cubic feet per second	Cubic feet per second per square mile
May	174	0.163	0.19	385	0.380
June	128	0.119	0.13	283	0.226
July	105	0.099	0.11	232	0.165
August	115	0.108	0.12	254	0.169
September	100	0.093	0.10	221	0.106
October	104	0.097	0.11	230	0.093

Comparing the foregoing figures for Mount Morris with those for Rochester for the month of October, 1895, it is seen that the proportion of runoff at Rochester was somewhat less for that month than at Mount Morris, although for the previous months it appears to have been larger. The explanation of this is that there are between Rochester, Mount Morris and Dansville extensive flats aggregating from 60 to 80 square miles. The temporary ground-water storage of these flats acts to sustain a somewhat more equable flow at Rochester than at Mount Morris, above which point there are proportionately smaller areas of flats. There are nevertheless some exceptions to this general proposition, as when, in a long-continued dry time, the flats become exhausted of moisture, and to some extent act like a sponge, taking up water from the river, thereby decreasing, in a measure, the outflow at Rochester.

In the summer of 1846 Daniel Marsh made a series of measurements in order to determine the low-water flow of that year. As the result of nine measurements made at various times in July and August he placed the minimum flow at Rochester in 1846 at 412 cubic feet per second.[1]

At Middlebury Academy, Wyoming county, in the catchment area of Oatka creek, the rainfall for the water year 1845 was, for

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[1] For these low water gagings of Genesee river in detail, see pp. 182-3.

the storage period, 12.59 inches; growing period, 4.82 inches; replenishing period, 8.60 inches; total for the year, 26.01 inches. The record for the year 1846 at Middlebury is not given. It is clear, therefore, so far as we have any definite meterological record, that the measurements made by Mr Marsh in 1846 were at a time of very low water.

A number of years ago gagings of the minimum flow of the Genesee were kept at the raceway of the Genesee Paper Company, in the north part of the city of Rochester, where it is possible to turn the entire flow of the river through the raceway. These gagings showed that for several months the minimum flow did not exceed about 160 cubic feet per second, and as this included perhaps 10 cubic feet per second flow of sewage, we may conclude that the minimum flow of this stream at Rochester is as low as 150 cubic feet per second (catchment, 2365 square miles), or at the rate of 0.064 cubic foot per second per square mile. These measurements were verified during the summer of 1903, when at Elmwood avenue bridge in the south part of the city the flow was even somewhat less than this, as determined by current-meter measurement.

These statements apparently indicate that the minimum summer flow of the Genesee river has decreased from 412 cubic feet per second in 1846 to about 150 cubic feet per second in 1903. As to the reason for this decrease, it is believed that the extensive deforestation of the catchment area which has taken place since 1846 offers full explanation. In 1846 the upper Genesee catchment was still very largely in forest. Probably of the entire area above Rochester the virgin forest was from 65 per cent to 70 per cent of the whole. We have therefore apparently a marked case where the deforestation of a large area has materially reduced the minimum runoff.

The foregoing minimum flows of Genesee river show conclusively that in its present condition it is not a good mill stream. The great variation in runoff is conclusive on this point. The figures show that the runoff of the stream may be exceedingly slack for several months during the summer and fall.

Minimum flow of Oatka creek. The catchment area of this stream above the point of measurement is 27.5 square miles. The mean flow for the month of August, 1891, was 6 cubic feet per second; for September, 5.83 cubic feet per second; for October, 5.8 cubic feet per second. Expressed in cubic feet per second per square mile, the foregoing results are 0.218 cubic foot for August, 0.212 cubic foot for September, and 0.211 cubic foot for October. Expressed in inches on the catchment, the runoff of this stream for August to October, 1891, was from 0.24 to 0.25 inch per month. For several days during the months of August to October, 1891, the flow of Oatka creek was down to about 4.2 cubic feet per second, or to about 0.151 cubic foot per second per square mile. On September 26, 1891, the recorded mean flow for the day was 3.77 cubic feet per second, or 0.137 cubic foot per second per square mile.

As a general proposition, statements of minimum flows of streams ought not to be based on the records of single days, specially on streams where there are mill ponds above the point of measurement, because such accidental circumstances as the holding back of the water may vitiate the result; from this point of view an average extending over as long a period as possible should be taken.

The measurements of Oatka creek from August to October, 1891, illustrate well the nearly universal tendency of streams to run either at approximately a fixed rate or to decrease only very slowly after the tributary ground water has become well drawn down. For several days at a time the records show only slight variation.

Minimum flow of Morris run. The result of a measurement of Morris run, a tributary of Oatka creek, the source of a part of the water supply of the village of Warsaw, Wyoming county, made from July 4 to December 26, 1894, is shown by table No. 82. The measured catchment area is 156 acres, but it may, by reason of the peculiar topography be somewhat greater than this. The water issues along the thread of the short valley in the form of springs. The measurement was made by a thin-edged notched weir at a point just below the lowest spring. As may be observed, the flow varied greatly at different times, the minimum being 77,630 gallons per day or 7.2 cubic feet per minute, in October. On July 8 the discharge was 238,580 gallons, or 22.1 cubic feet per minute for twenty-four hours. There is a popular impression that springs do not vary their flow at different seasons. The measurements of Morris run are valuable, therefore, as illustrating that even a spring-fed stream will gradually decrease during a dry season.

TABLE NO. 82—DAILY MEAN DISCHARGE IN CUBIC FEET PER MINUTE OF MORRIS RUN NEAR WARSAW, IN 1894.

[Catchment area = 0.24 square mile.]

DAY.	July.	August.	September.	October.	November.	December.
1	....	16.0	10.4	......	10.9	......
2	....	17.3	......	......	......	......
3	....	16.7	8.3	......	......	10.0
4	19.4	18.3	8.0	7.8	......	......
5	17.8	......	7.8	8.2	......	......
6	19.5	16.2	......	......	9.4	......
7	20.9	14.9	......	6.7	......	......
8	22.1	......	......	......	......	......
9	21.2	......	......	......	......	......
10	21.3	......	......	......	......	......
11	20.8	......	......	9.4	......	21.9
12	20.6	......	......	7.8	......	......
13	19.7	......	......	......	......	16.2
14	20.1	......	......	......	......	......
15	19.7	......	......	8.8	......	14.9
16	19.3	......	8.8	......	8.2	......
17	18.7	......	8.2	7.8	......	......
18	18.3	......	19.0	7.8	......	13.4
19	17.5	......	......	7.2	8.2	......
20	17.9	......	......	......	......	13.6
21	21.2	......	11.1	7.2	8.2	......
22	20.6	......	8.8	......	8.8	......
23	20.0	......	......	7.2	......	......
24	20.4	......	8.8	53.8	8.2	13.6
25	18.7	......	......	......	......	......
26	17.8	......	......	8.8	8.2	13.6
27	17.3	......	......	7.8	......	......
28	17.1	......	8.8	......	......	......
29	17.8	......	8.8	7.2	......	......
30	16.3	......	......	7.2	......	......
31	16.5	11.7	......	19.0	......	......

Minimum flow of Hemlock lake. According to a report made by Henry Tracy,[1] the minimum flow of Hemlock lake is 5 cubic feet per second (catchment, 43 square miles), or 0.116 cubic foot per second per square mile.

Table No. 49 gives the quantity of water passing out of Hemlock lake for the period covered and without reference to the natural flow. In order to obtain the approximate natural flow for the year we must take into account the mean elevations of lake surface. Thus, for the water year 1880 the mean elevation of the first month, December, was —1.67, while for the last month, November, it was —1.24. The difference (0.43 foot) represents the gain in depth of storage for the year. Computing for the value of this storage in inches on the catchment area, we have 0.28 inch, which, added to the quantity of water passing out of the lake (3.07 inches), gives as the approximate total runoff for the year 3.35 inches. Since 1880 was a very dry year, we may compute the flow for the entire water year to be 10.3 cubic feet per second, which again amounts to 0.24 cubic foot per second per square mile.

For the five-year period included in this tabulation the total rainfall and runoff are as follows:

	Rainfall, inches	Run-off, inches
1880	21.99	3.07
1881	24.27	8.38
1882	25.46	14.51
1883	32.24	9.29
1884	26.74	12.57
Add for rise in level	......	0.40
Total	130.70	48.22

For the five-year period the total runoff was therefore only 36.9 per cent of the rainfall. In 1880 the runoff was only 15.2 per cent of the rainfall. The corrections for rise in lake level are included in these statements.

Minimum flow of Oswego river. Previous to 1897 there were no records of any long-continued measurements of the flow of

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[1] Report on the Cost and Policy of Constructing Reservoirs on Conesus, Hemlock, Honeoye and Canadice lakes. Senate document, No. 40, 1850.

Oswego river, of which the catchment area at the mouth is 5002 square miles. The minimum flow of this stream has been the subject of judicial inquiry. In August, 1875, in the case of Michael J. Cummings against owners and lessees of the water of the Varick canal at Oswego, it was decreed:

(1) That the average flow of water from the Oswego river into the Varick canal in low water in the summer months is about 45,000 to 50,000 cubic feet per minute; (2) that in extreme low water in the summer, and which usually occurs in the month of July or August, it is about 35,000 cubic feet per minute; and (3) that the average flow of the whole three summer months is about 75,000 cubic feet per minute.

Varick canal is entitled to receive one-half the total flow of the river, less the amount of water required for navigation purposes. Hence the average summer flow, according to the decree, is from 90,000 to 100,000 cubic feet per minute (1500 to 1670 cubic feet per second). The extreme low-water flow is placed at 70,000 cubic feet per minute for the whole flow of the river, or at 1170 cubic feet per second, while the average flow of the whole three summer months is given at about 150,000 cubic feet per minute, or 2500 cubic feet per second. From the foregoing figures we deduce an extreme minimum of perhaps 0.23 of a cubic foot per second per square mile, with an average of low water in the summer months of about 0.30 to 0.33 of a cubic foot per second per square mile.

The following measurements may, however, serve to show that the minimum figures just stated may be modified somewhat.

Beginning in April, 1897, a record of the flow of Oswego river has been kept at High dam, two miles above the city of Oswego. This record is, however, somewhat uncertain as to the low water, but it is given for what it is worth in table No. 50. This record does not include diversion for the use of the Oswego canal.

For seven days in September, 1897, the flow was at the rate of about 900 cubic feet per second and during the entire month of September, 1898, the mean flow was 925 cubic feet per second. For twenty-five days in September, 1898, the mean flow was only 795 cubic feet per second (catchment, 5000 square miles), or at the rate of a little less than 0.16 cubic foot per second per square mile.

In July, 1899, the flow for the month was 748 cubic feet per second; for August of that year, it was 612 cubic feet per second; for September, 615 cubic feet per second, and for October, 585 cubic feet per second.

In August, 1900, the mean flow was 669 cubic feet per second; September, 670 cubic feet per second, and in October, 853 cubic feet per second.

It may be again remarked that these flows do not include diversion for the Oswego canal, which, however, probably did not exceed 100 to 150 cubic feet per second.

The following tabulation gives the minimum flows of Oswego river at Fulton during 1900, as determined by a measurement through openings in the sides of the bulkhead, the discharge being calculated by the formula for orifices, using a coefficient of 0.62. These figures only apply to the year 1900, which, on reference to the rainfall tables, is shown to have been a wet year.

	Minimum Daily Flow	
	Cubic feet per second	Cubic foot per second per square mile
October 29	1,225	0.25
October 30	1,111	0.23
October 31	1,201	0.24
November 1	1,132	0.23
November 2	1,760	0.36
November 3	1,540	0.31
November 4[1]	......	......
November 5	1,201	0.24
November 6	1,309	0.27
November 7	1,357	0.28
November 8	1,539	0.31
November 9	1,193	0.24
November 10	1,293	0.26

Minimum flow of Seneca river. In July, 1899, the mean discharge for the month, of Seneca river at Baldwinsville was 776 cubic feet per second; in August, it was 455 cubic feet per second; in September, 481 cubic feet per second, and in October, 637 cubic feet per second.

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[1] Sunday.

In July, 1900, the mean flow was 720 cubic feet per second; in August, 551 cubic feet per second, and in September, 471 cubic feet per second.

Since the catchment area at Baldwinsville is 3103 square miles, the flow for the entire month of August, 1899, of 455 cubic feet per second was at the rate of less than 0.15 cubic foot per second per square mile. For several days in August and September, 1899, the flow was very much smaller than the average, but it does not seem proper to consider the flow of single days in estimating the minimum flow of a stream like Seneca river. The small summer flows in this stream are largely due to heavy evaporation from the marsh areas above Baldwinsville.

Minimum flow of west branch of Fish creek. In July, 1900, the mean flow of this stream for the entire month at McConnellsville was 60 cubic feet per second, and in August it was 57 cubic feet per second (catchment, 187 square miles), or the flow for these two months was at the rate of about 0.3 cubic foot per second per square mile. Undoubtedly the extreme minimum flows of this stream are less than 0.2 cubic foot per second per square mile, since for six days in December, 1900, the mean flow was only 36 cubic feet per second or at the rate of 0.19 cubic foot per second per square mile. It is possible that the extreme minimum may perhaps be placed as low as 0.12 cubic foot per second per square mile for a week at a time.

Minimum flow of Salmon river west. The lowest recorded flow of this stream is 75 cubic feet per second for five days in September, 1900. Since the catchment area at Pulaski, where the measurements are made, is 264 square miles, this flow would be at the rate of 0.28 cubic foot per second per square mile. Probably the extreme minimum flow of this stream will go as low as 0.22 cubic foot per second per square mile.

There are a number of streams to the north of Salmon river, between there and Black river, as for instance the north branch of Sandy creek, of which the minimum flows are exceedingly small. As observed by the writer in the fall of 1898 these streams were substantially dry, the flow of several of them not exceeding 20 cubic feet per second. Their minimum flows are as low as 0.05 cubic foot per second per square mile. Their headwaters lie in a deforested country in the horizon of the Hudson river shales and Trenton limestone.

Minimum flow of Black river. The catchment area of this stream at Huntingtonville dam, where the measurements are made, is 1889 square miles. Previous to 1897, aside from measurements made by engineers in the employ of the State at the time of construction of the Black river canal and a few made by Frank A. Hines in 1875, there had been no measurements taken of the flow. In February, 1897, the Board of Water Commissioners of Watertown began a record of the daily flow of the river, from which the following statements of minimum flows are taken.

In July, 1897, the mean flow for the entire month was 940 cubic feet per second; for two days it was about 582 cubic feet per second; one day, 630 cubic feet per second, and one Sunday is given at 480 cubic feet per second. In August, 1897, the mean flow for August 6 was 782 cubic feet per second; for August 7, 630 cubic feet per second; August 8 (Sunday), 362 cubic feet per second; August 9, 536 cubic feet per second; August 10, 630 cubic feet per second; August 25, 522 cubic feet per second; August 26, 566 cubic feet per second; August 27, 582 cubic feet per second, and August 28, 322 cubic feet per second.

In 1898 the minimum month was July, in which the mean flow was 1128 cubic feet per second, although for five days in August the flow was about 900 cubic feet per second.

The mean flow for the month of August, 1899, was 897 cubic feet per second and for September, 990 cubic feet per second. For a short period in August the flow fell to about 700 cubic feet per second, and on one day it was 522 cubic feet per second. In considering these statements of minimum flow in Black river, the fact that there is a leakage estimated at 250 cubic feet per second should be taken into account; 520 cubic feet per second, which with one exception is the lowest, is at the rate of 0.27 cubic foot per second per square mile. The daily record of this stream shows that it is a good water yielder, as indeed might be expected. There are a large number of reservoirs at the headwaters and it flows from an area largely in primeval forest. It is doubtful, therefore, if Black river will, while present forestry conditions are maintained, go below about 0.3 cubic foot per second per square mile for more than a few days at a time, although it is claimed to have been less than this for some time in 1849.

Minimum flow of Oswegatchie river. From a current meter measurement of the low-water flow of this stream made a few miles above Ogdensburg September 25, 1900, the discharge was estimated at 614 cubic feet per second (catchment, 1535 square miles), or at the rate of 0.4 cubic foot per second per square mile. There is not enough information about this river to determine whether or not this is the extreme minimum flow, but taking into account the rainfall of 1900, it is probable that the minimum flow is somewhat lower than this.

Minimum flow of Raquette river. Only two measurements of the flow of this stream have been made. The first of these was a current meter measurement made at Potsdam, where the catchment area has not been determined, by W. C. Johnson, on August 28, 1898, on which day the flow of the stream was 755 cubic feet per second.

A current meter measurement was also made near Massena, October 2-3, 1900, showing the low-water flow of Raquette river to be 934 cubic feet per second (catchment, about 1200 square miles), or at the rate of 0.78 cubic foot per second per square mile.

There is very large pondage area on the various lakes at the headwaters of this stream, but probably the low-water flow will go lower than the preceding figures—how much, there is no way of stating at the present time.

Minimum flow of Hudson river. Measurements of the flow of the Hudson river have been kept at Mechanicville since October, 1887, the record of which to November, 1902, inclusive, is presented in tables Nos. 60, 61 and 62. The natural flow of this stream is somewhat obscured by a considerable number of lumbermen's reservoirs on its headwaters, the total storage of which aggregates 4,000,000,000 cubic feet, as well as by two reservoirs on Hoosic river in Massachusetts. In 1898-9 Indian lake reservoir was constructed with a storage capacity of about 5,000,000,000 cubic feet. The water stored in Indian lake is usually let out in the months of August, September and October, assisting the low-water flow materially, while the water from the lumbermen's dams is let out in the spring, and tends to increase floods somewhat.

The month of minimum runoff for the whole period covered by the measurements was August, 1899, the mean for the month being 1393 cubic feet per second (catchment, 4500 square miles), or at the rate of 0.31 cubic foot per second per square mile. The flow for one day during this month was 993 cubic feet per second, and for one day 979 cubic feet per second. In September, 1899, the flow for one day was 711 cubic feet per second. For short periods the flow has been less than for August, 1899. Thus, August 14-19, 1890, the mean flow was 1080 cubic feet per second, and October 2-6, inclusive, 1891, the mean flow is also given at 1080 cubic feet per second, or at the rate of 0.24 cubic foot per second per square mile. Taking the diversion for the supply of the Champlain canal into account, we have about 0.29 cubic foot per second per square mile as the actually observed flow.

The figures show, however, that the flow of 0.29 cubic foot per second per square mile has occurred for only two periods—one of six days and the other of five days—a total of eleven days for the whole period covered by the measurements. For July, 1888, the mean flow, including the diversion which was then occurring for the supply of the Champlain canal, may be taken at 0.37 cubic foot per second per square mile. For October, 1891, the mean flow for the whole month was 1472 cubic feet per second, or, including the diversion to the Champlain canal, 0.36 of a cubic foot per second per square mile. In July, 1890, the mean flow for the month was 1950 cubic feet per second, and in several other months, as July, 1893, July, 1895, and September and October, 1895, the mean monthly flow varied from about 2600 to 2700 cubic feet per second. Hence we may say that for any business where it is not absolutely indispensable to have permanent power, water power on Hudson river may be developed up to the limit of about 0.4 of a cubic foot per second per square mile, with a prospect of not being interrupted on account of low water more than a few days in each year. For electric power, however, or any application of water power requiring a permanent power every day in the year, the development ought not to be based, under present conditions, on more than about 0.24 to 0.25 of a cubic foot per second per square mile, these latter figures relating specially to that portion of the river from which water is diverted for the supply of the Champlain canal. As is shown in the section on the water power of the Hudson river, nearly all of the plants on that stream are developed far beyond these figures.

Above the mouth of the Hoosic and Battenkill rivers somewhat different conditions obtain from those occurring at Mechanicville. The Hoosic and Battenkill rivers flow from eastern Vermont and Massachusetts, and frequently there are rainfalls in this region when there are none on the Hudson river above Fort Edward. This fact renders it impossible to predicate what will happen on this part of the stream from the record at Mechanicville.

A record of the flow of the river has been kept at Fort Edward from December, 1895, to the present time, which is given to November, 1902, inclusive, in table No. 63. In August, 1899, the mean flow for the month at Fort Edward was 714 cubic feet per second (catchment, 2800 square miles), or at the rate of 0.26 cubic foot per second per square mile. For fourteen days in September, 1899, the mean flow was at the rate of 661 cubic feet per second or 0.24 cubic foot per second per square mile. Probably, in some extreme dry time, the flow at Fort Edward will not exceed 0.2 cubic foot per second per square mile, as the evidence is clear that 1899, while exceedingly dry, was not the minimum dry year. The statements in regard to the reliability of the gagings, made on a preceding page, may, however, be taken into account in considering the minimum flows at this place.

Minimum flow of Croton river. The daily record of this stream is not available, the flows being given for an entire month. The following are the monthly means for the lowest flows:

In August, 1869, the flow for the entire month was 90 cubic feet per second; in September of that year, it was 54 cubic feet per second. The mean flow, therefore, for two months was 72 cubic feet per second (catchment, 339 square miles), or at the rate of 0.21 cubic foot per second per square mile.

In September, 1870, the mean flow was 97 cubic feet per second and in October, 111 cubic feet per second.

The following are the flows for the growing period of 1877:

	Cubic feet per second
June	159
July	130
August	127
Mean	138

The flow for September, 1877, was 93 cubic feet per second.

In the water year, 1880, the flow for the growing and replenishing periods was as follows:

	Cubic feet per second
June	138
July	138
August	132
September	132
October	130
November	152
Mean	137

The flow for the following month of December was 138 cubic feet per second. The entire flow for the water year 1880 was 365 cubic feet per second.

In the year 1881 the mean flow for the replenishing period was 129 cubic feet per second.

In the year 1883 the mean flow for the entire year was 363 cubic feet per second. Attention may be directed to the fact that the flow of the storage period will chiefly determine whether the mean flow for the whole year is large or small. Thus, in 1880, the mean flow for the storage period was 592 cubic feet per second and in 1883, 572 cubic feet per second. The maximum flow of the storage period from 1868–1899, inclusive, occurred in 1888 and was 1137 cubic feet per second. In 1888 the mean flow for the entire year was 838 cubic feet per second, which is the maximum mean yearly flow for the entire period covered by the gagings.

The lowest mean monthly flow for the entire period was in September, 1869, and was 54 cubic feet per second, or at the rate of 0.16 cubic foot per second per square mile. Probably the flow of the Croton river for several days during these periods did not exceed 0.1 cubic foot per second per square mile.

According to J. J. R. Croes, the minimum flow of the west branch of the Croton river, with a catchment area of 20.4 square miles, is 0.02 cubic foot per second per square mile.

Minimum flow of Fishkill creek. The lowest flow of this stream thus far observed was on August 26, 1902, and was at the rate of

0.24 cubic foot per second per square mile. There seems little reason to doubt but that this stream will go as low as from 0.10 to 0.15 cubic foot per second per square mile.

A measurement of Clove creek, the largest tributary of Fishkill creek, was made September 24, 1902, when the discharge was 3.5 cubic feet per second (catchment, 20 square miles), or at the rate of 0.18 cubic foot per second per square mile.

Minimum flow of Rondout creek. The low-water flow of this stream is estimated at from 0.05 to 0.1 cubic foot per second per square mile.

Minimum flow of Wallkill river. The lowest flow thus far observed on this stream at New Paltz is 124 cubic feet per second (catchment, 736 square miles), or at the rate of 0.17 cubic foot per second per square mile. This flow is from a single current meter measurement on July 17, 1902. The minimum flow of this stream will go as low as from 0.05 to 0.1 cubic foot per second per square mile.

Minimum flow of Esopus creek. The flow of this stream at Kingston on August 5, 1901, was 40 cubic feet per second (catchment, 312 square miles), or at the rate of 0.13 cubic foot per second per square mile. This stream will at times go as low as 0.05 cubic foot per second per square mile. In June, 1899, the mean flow for the entire month was only 0.24 cubic foot per second per square mile.

Minimum flow of Catskill creek. The available data show that this stream will in dry time run down to 0.05 cubic foot per second per square mile.

Minimum flow of the Normanskill. The lowest recorded flow of this stream occurred in September, 1891, and was 4.6 cubic feet per second (catchment, 111 square miles), or at the rate of 0.04 cubic foot per second per square mile. The mean flow for the entire month of September, 1891, was 8.9 cubic feet per second, or at the rate of 0.07 cubic foot per second per square mile. In October, 1891, the lowest flow was 4.9 cubic feet per second; in August, it was 5.9 cubic feet per second, and in November of the same year, it was 6.9 cubic feet per second. These figures show at once that this stream is a poor water yielder, and that probably the extreme minimum flow for several days will not exceed 0.02 to 0.03 cubic foot per second per square mile.

Minimum flow of Kinderhook creek. The mean flow of this stream at East Nassau for November, 1892, was 30 cubic feet per second (catchment, 120 square miles), or at the rate of 0.25 cubic foot per second per square mile.

In 1894 the minimum flow at Wilson's dam was 4 cubic feet per second (catchment, 68 square miles), or at the rate of 0.06 cubic foot per second per square mile. The minimum flow for August, 1894, at the same place was 5.2 cubic feet per second, or at the rate of 0.08 cubic foot per second per square mile.

Minimum flow of Schroon river. Gagings of this stream are kept at Warrensburg, but the natural flow is considerably obscured by the storage of Schroon lake, which is controlled by the Starbuckville dam. During the month of August, 1899, the mean flow at Warrensburg was taken at 150 cubic feet per second (catchment, 563 square miles), or at the rate of 0.27 cubic foot per second per square mile, but this is not very precise.

Minimum flow of Mohawk river. For four days in September, 1900, the flow of the Mohawk river at Dunsbach Ferry was 373 cubic feet per second (catchment, 3440 square miles), or at the rate of 0.11 cubic foot per second per square mile. Probably the extreme minimum would not exceed 0.07 or 0.08 cubic foot per second per square mile. In October, 1900, the flow at the same place was 373 cubic feet per second for two days; 457 cubic feet per second for three days; 625 cubic feet per second for seven days, and 541 cubic feet per second for one day.

The minimum flow of the Mohawk river as measured at Rexford Flats during September, 1899, was 228 cubic feet per second (catchment, 3385 square miles), or 0.06 cubic foot per second per square mile for fifteen days, followed by a flow of 278 cubic feet per second for ten days. The mean flow for the entire month of August, 1899, was 294 cubic feet per second, or at the rate of 0.09 cubic foot per second per square mile, while for the last three days of the month it was only 208 cubic feet per second. These figures include the amount of water diverted to supply Erie canal, or they are the total flow of Mohawk river at the point of gaging.

The minimum flow of Mohawk river at Schenectady as measured in September, 1899, was 420 cubic feet per second (catchment, 3321 square miles), or at the rate of 0.13 cubic foot per second per square mile, for twelve days. The entire flow of the stream is included in this measurement. The flow for the month of August, 1899, was at the mean rate of 524 cubic feet per second. In September, 1900, the mean flow for the entire month was 609 cubic feet per second.

The mean flow at Little Falls for the month of August, 1899, was 223 cubic feet per second, but this does not include diversion to the Erie canal, which may amount to about 150 cubic feet per second, or to a total flow of about 375 cubic feet per second (catchment, 1306 square miles), which is at the rate of about 0.28 cubic foot per second per square mile. In comparison with the flow for the month of August, 1899, at Rexford Flats, these figures show that the upper Mohawk river is relatively a better water yielder than the lower—the low flows from Schoharie creek and contiguous catchment areas, probably making the difference. The lowest water observed since gagings have been kept at Little Falls was in August, 1899, when the mean flow for nine days was but 120 cubic feet per second, or 0.07 cubic foot per second per square mile. This, however, does not represent the total flow of the stream, as nearly the entire river was being taken for the supply of Erie canal.

In September, 1901, the minimum flow of Mohawk river at Utica for two days was 70 cubic feet per second (catchment, 500 square miles), or at the rate of 0.14 cubic foot per second per square mile. These figures are somewhat indefinite.

The minimum flow of Mohawk river at Ridge Mills for September, 1899, was at the mean rate of 81 cubic feet per second for twenty-two days; for three days, the mean flow was 56 cubic feet per second, and for two days, 53 cubic feet per second (catchment, 153 square miles), or at the rate of 0.34 cubic foot per second per square mile.

Minimum flow of Cayadutta creek. In August, 1899, the mean flow of this stream at Johnstown for the entire month was 18 cubic feet per second; in September, 20 cubic feet per second, and in October, 21 cubic feet per second. For several days during these months it was from 14 to 16 cubic feet per second. In July, 1900, the mean flow was 17 cubic feet per second, and for several days it was from 12 to 14 cubic feet per second, which, for a catchment area of 40 square miles, is at the rate of about 0.3 to 0.35 cubic foot per second per square mile.

Minimum flow of Schoharie creek. The mean flow of this stream at Fort Hunter for the month of August, 1899, was 142 cubic feet per second (catchment, 947 square miles), or at the rate of 0.15 cubic foot per second per square mile. In July, 1900, the mean flow was 115 cubic feet per second, or at the rate of 0.12 cubic foot per second per square mile. For three days during this month the flow was 76 cubic feet per second and for one day 72 cubic feet per second.

Gagings of Schoharie creek were also made at Schoharie falls over a sharp-crested weir, 25 feet in length, during a portion of 1900 and 1901. According to these gagings the mean flow of the stream for August, 1900, was 89 cubic feet per second; for September, 32 cubic feet per second, and for October, 40 cubic feet per second. In February, 1901, the flow was 166 cubic feet per second. The catchment area at this point is 930 square miles. Hence, 32 cubic feet per second was at the rate of 0.04 cubic foot per second per square mile.

In May, 1900, the writer reported at length relative to the low-water flow of Schoharie creek. At that time, the Empire State Power Company was contemplating extensive developments on this creek and had procured reports from several engineers. These reports agreed that the minimum flow of this stream would not be less than about 400 cubic feet per second. In regard to this matter, it was stated that the minimum flow of Schoharie creek had been taken too high, as might be sufficiently appreciated by considering the figures derived from all the rivers of the State which had then been studied. Figures were given for Oatka creek, Genesee river, Hemlock lake, west branch of Canadaway creek, Oswego river, Black river, Mohawk river, Hudson river, Croton river and Niagara river, and the conclusion was arrived at from such comparison, based on general considerations purely, that the flow of Schoharie creek might go down to as low as 0.2 cubic foot per second per square mile, or to about 190 cubic feet per second. The following was the conclusion of this part of the report:

> If, therefore, we were to accept the idea that there is at least 0.4 cubic foot per second per square mile minimum flow in Schoharie creek, we should have about the best flowing stream in the State—better even than the Hudson and Mohawk. A stream,

too, without any lake pondage, with steep sharp slopes, and with everything against high flows. Obviously, then, the conclusion that Schoharie creek flows as high as 0.4 cubic foot per second per square mile is absurd. At present the writer does not feel justified in assigning to it, on the evidence, more than from 0.2 to 0.25 cubic foot per second per square mile. Such flows, however, probably do not continue very long, because the stream responds quickly to relatively small rains, which is certainly an advantage, the more especially because the rainfall is possibly slightly greater in the elevated highlands from which this stream issues than it is in less elevated regions.

It was also stated:

> In the absence of gagings of Schoharie creek the determination of the minimum flow is a matter of judgment, but taking into account all the evidence, the writer believes he has given Schoharie creek a liberal place.

Since that time definite gagings have been kept, showing that the low-water flow of this stream is lower even than estimated from general considerations in 1900; it is, in fact, shown to be an exceedingly poor water yielder, and it is clear that the writer's report of 1900 did not place the low water flow as low as it really is.

Minimum flow of East Canada creek. The mean low-water flow of this stream at Dolgeville for September, 1899, was 92 cubic feet per second. For eleven days it was 67 cubic feet per second (catchment, 256 square miles), or at the rate of 0.26 cubic foot per second per square mile. For August, 1899, the mean flow for the month was 97 cubic feet per second. For September, 1900, it was 133 cubic feet per second.

Minimum flow of West Canada creek. The mean flow of this stream at Middleville for September, 1899, was 221 cubic feet per second (catchment, 518 square miles), or at the rate of 0.42 cubic foot per second per square mile. For several days the flow was only 145 cubic feet per second, and for eleven days, September 2–12, inclusive, the mean flow was 183 cubic feet per second, or at the rate of 0.35 cubic foot per second per square mile. In the preceding month of August the mean flow for the month was 235 cubic feet per second. These figures show the superiority of both East and West Canada creeks over Schoharie creek as water yielders.

Minimum flow of Sauquoit creek. The mean flow of this stream at New York Mills for September, 1899, was 14 cubic feet per second (catchment, 52 square miles), or at the rate of 0.27 cubic foot per second per square mile; for August, 1899, it was 16 cubic feet per second, and for October, 1899, 17 cubic feet per second. For September, 1900, the mean flow was 15 cubic feet per second.

Minimum flow of Oriskany creek. The low-water flow of this stream is likely to occur during the months when canal navigation is closed, at which time the water flowing is only the natural contribution from the catchment area. For ten days in December, 1899, the mean flow at Oriskany was 53.5 cubic feet per second (catchment, 144 square miles), or at the rate of 0.37 cubic foot per second per square mile. For four days during this month the mean flow was 31 cubic feet per second, or at the rate of 0.22 cubic foot per second per square mile.

Minimum flow of Allegheny river and tributaries. So far as known, minimum flows have not thus far been determined for the Allegheny river and its tributaries. They are, however, small and may be placed at 0.05 to 0.1 cubic foot per second per square mile.

Minimum flow of Susquehanna river and tributaries. So far as known, minimum flows have not thus far been determined for Susquehanna river and tributaries. They are, however, small and may be placed at 0.05 to 0.1 cubic foot per second per square mile.

Minimum flow of Delaware river and tributaries. So far as known, minimum flows have not thus far been determined for Delaware river and tributaries. They are, however, small and may be placed at 0.05 to 0.1 cubic foot per second per square mile.

The preceding discussion of minimum flow is of considerable value in that it includes comparison of a number of New York streams for the year 1899, which, as shown by the rainfall statistics, was rather a dry year, although there is no reason for supposing it was the minimum dry year.

Summary of information regarding minimum flows. Summarizing the present knowledge of minimum flow of streams in New York State, we may say that in western New York for streams like Genesee river issuing from regions of heavy, compact soil, mostly deforested, the minimum flows will run as low as from 0.05 to 0.1 cubic foot per second per square mile. In extreme cases they may be even less than this. In the chapter on the classification of streams we have shown that Croton river properly classifies with the Genesee. It is also shown that this stream has low minimum flows. Spring-fed streams in western New York and those with considerable lake surface pondage may be expected to have somewhat greater minimum flows than the preceding.

In the central part of the State streams flowing from the south side of the Mohawk north into that stream have generally low minimum flows; they do not differ greatly from the Genesee river and tributaries. To the north of the Mohawk river the conditions are different and the flow of the streams is larger.

The Mohawk river and upper Hudson may be placed, while their present condition of forestation is maintained, at a minimum of about 0.2 to 0.25 cubic foot per second per square mile. Reservoirs on the Hoosic river in Massachusetts tend to increase the minimum flow of the Hudson at Mechanicville somewhat.

Streams issuing from the Catskill mountains, where conditions similar to those on the Genesee river obtain, have minimum flows of from 0.05 to 0.1 cubic foot per second per square mile.[1]

The streams of Long Island, issuing from sand plains, will give larger yields, the available measurements showing minimum runoffs as high as 0.5 cubic foot per second per square mile, but whether these runoffs would be maintained in a minimum dry year is uncertain; at present, it appears somewhat improbable. Moreover, it is proper to say that these measurements were made about fifty years ago and there is some doubt whether they are entirely reliable; probably an extended series would show perhaps 0.35 cubic foot per second per square mile as the minimum.

The streams of the northern part of the State, issuing from denser forests and with large lake storage, may be expected to give minimum yields somewhat in excess of 0.3 cubic foot per second per square mile, although until definite measurements are made this must be considered an inference merely.

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[1] Streams issuing from the Catskill region have not been gaged long enough to entirely settle the question of minimum flows. The difference in forestation may be taken into account in estimating these flows.

Nothing is known as to the minimum yields of streams tributary to the Allegheny, Susquehanna and Delaware rivers, aside from the measurements of Eaton and Madison brooks made in 1835. So far as can be learned, aside from those recently inaugurated by the United States Geological Survey, no measurements of any other of these streams have been made. It is probable that they will mostly be found substantially the same as Genesee river and streams issuing from the Catskill region.

Quantity of water which may be stored on the several plateaus. The foregoing treats of the yield of streams in a general way, but the practical summation of the preceding discussion is as to the quantity of water that can be safely stored on different catchment areas of New York in the year of minimum runoff. The tables of precipitation on the several plateaus show that the quantity which can be stored varies in different parts of the State and in some degree in proportion to the rainfall. It is also shown that when the rainfall is above a certain minimum amount, the excess quantity of runoff is roughly in proportion to the rainfall. In order to emphasize the preceding propositions, we have the following as the mean rainfalls of the ten plateaus into which the area of New York is divided for the twelve water years 1891-1902, inclusive, together with the low rainfalls of 1895 and 1899.

	Mean of 12 years, inches	1895, inches	1899, inches
Western plateau	37.03	29.76	27.65
Eastern plateau	40.30	32.87	35.26
Northern plateau	44.03	36.67	35.79
Atlantic coast	46.71	40.77	44.54
Hudson valley	42.59	35.74	37.98
Mohawk valley	42.13	31.30	35.31
Champlain valley	37.06	32.95	33.85
St Lawrence valley	36.18	33.75	28.51
Great Lakes	35.65	29.13	28.67
Central Lakes	34.46	27.31	27.83

The difference in the average precipitation of the Atlantic coast and the Central Lakes regions is 12.25 inches. We may expect, therefore, about 10 to 11 inches more average runoff in the Atlantic coast region than in the region of the Central Lakes.

The preceding mean rainfalls are for a period of 12 years only, which is not long enough for perfectly safe averages. Moreover, while these 12 years have included the minimums of 1895 and 1899, these minimums were not as well defined on some of the plateaus as on others.

Since the precipitation of the storage period largely determines the runoff of that period, let us for a moment consider the relation between precipitation in the storage period of the Atlantic coast and Central Lakes regions. The minimum precipitation in the storage period of the Atlantic coast region for the 12-year period included in the tables was for the year 1896, and amounted to 19.70 inches. The minimum precipitation of the Central Lakes region for the same period was in 1895 and amounted to 11.26 inches, a difference of 8.44 inches in the storage period alone.

The yearly minimum precipitation of the Atlantic coast region for the period considered was in 1895 and amounted to 40.77 inches. The yearly minimum precipitation of the Central Lakes region was also in 1895 and amounted to 27.31 inches, a difference of 13.46 inches. The proposition that there was over 10 inches more runoff in the Atlantic coast region in 1895 than in the Central Lakes region is therefore abundantly established. In the same way a comparison of the balance of the regions will show in a general way the runoff that may be expected in any given year.

Taking into account in a broad way these several precipitation areas, we may say that in the minimum year the following quantities of water can be stored, the statement being made without reference to the economic conditions involved in considering the area of catchment, topography, cost, etc. The statement also involves conclusions based on consideration of all the circumstances, which are much too extensive to again give in detail but which are given in different parts of this report ·

1) On the western plateau, from 6 to 7 inches may be stored in the minimum year.

2) On the eastern plateau, 7 to 10 inches.

3) On the northern plateau, 10 to 12 inches.

4) In the Atlantic coast region, 13 to 15 inches.

5) In the Hudson valley, 10 to 11 inches.
6) In the Mohawk valley, 10 to 11 inches.
7) In the Champlain valley, 7 to 8 inches.
8) In the St Lawrence valley, 5 to 6 inches.
9) In the Great Lakes region, 5 to 6 inches.
10) In the Central Lakes region, 4 to 5 inches.
11) And finally, for particular localities, not more than 2 to 4 inches can be stored.

In the Atlantic coast region, by storage is meant the total quantity of water which may be practically utilized, either from surface flows or underflows.

Moreover, the foregoing statements are made for a single year and without reference to the water yield that may be supplied by considering a period of three years. Usually, taking into account a 3-year low-water period, more storage can be provided than when only a single year is considered, and the question as to just what the water stored is to be used for will largely determine which period to take. If for water power, where exceedingly large quantities of water are required, it is not generally desirable to take more than the single dry year, while for water supplies a period of three dry years may be taken.

Many persons consider that 11 inches of water collected in a dry year is a conservative assumption, but the preceding discussion will serve to show that anybody assuming such quantity in the State of New York would, in some parts, be wide of the mark.

STATE OWNERSHIP OF PUBLIC UTILITIES

When a country becomes thickly populated there are some things which can be better done by the State than by either an individual or by a single community. We will briefly discuss a case of this character here.

State water supply. New York State is specially suited for a State water supply because, due to fortuitous conditions, it is possible to deliver water by gravity without excessively long conduits, to nearly every city and town in the State. Such supplies would answer the requirements of purity and would settle the question of water supplies in this State for all time to come. The writer therefore considers that there should be a State commission specially authorized to define the limits of these reservations and that forestation should be carried on within the limits fixed by such a commission.

Examining the hypsometric map accompanying this report, we observe that there are six high points which may be denominated water centers, which are referred to on page 40.

The largest and most important of these is the elevated region known as the Adirondack mountains, or for present purposes, the Adirondack center, the highest peaks of which rise to an altitude of over 5000 feet, and there are about 4000 square miles at an elevation of 2000 feet and over. This region has a population of from 8 to 10 to the square mile. The population of the balance of the water centers is somewhat greater than this, but in none of them is it beyond the limit of a pure water supply, with proper precaution. The principal lakes lie at an elevation of from 1500 to 2000 feet.[1]

The second, or Catskill center, includes the Catskill mountains in the southeastern part of the State, where the highest points rise to an altitude of over 4000 feet and there is an area of about 1000 square miles at an elevation of 2000 feet and over.

The third, which may be called the Allegheny center, is the elevated region in the southwestern part of the State in Cattaraugus, Allegany and Steuben counties, where the highest points are at an elevation of over 2000 feet and there is an area of from 500 to 800 square miles at an elevation of over 1500 feet.

The fourth, or Rensselaer center, lies east of Troy, Albany and Poughkeepsie, and its highest altitudes are over 2000 feet, while there are from 1000 to 1200 square miles at an elevation of over 600 feet. Since the distance from the Hudson river is short, this elevation is enough to supply the cities and towns naturally tributary.

The fifth, or Chenango center, is west of the Catskill mountains, with an extreme elevation of over 1800 feet, and there are from 1200 to 2000 square miles at an elevation exceeding 1200 feet.

The sixth, or Lowville center, is to the north of Oneida lake, with an extreme elevation of from 1800 to 2000 feet, and there are from 400 to 600 square miles at an elevation of over 1200 feet. The issuing streams are lower than the foregoing, but still high enough to insure gravity supplies.

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[1] For elevation of lakes of Adirondack region, see pages 221 and 241.

The preceding statements of area above certain elevations are rather general—time has not been taken for detailed estimates. There are, however, from 8000 to 10,000 square miles available. From all these centers, uncontaminated streams of great natural purity issue. There are also several minor points throughout the State for which the same statement is true.

The Adirondack water center is separated from the Catskill by the valley of the Mohawk river, which receives drainage from both—the East and West Canada creeks and other tributaries of the Mohawk on the north side of the valley rising in the Adirondack center, while the Schoharie creek on the south side is an important tributary from the Catskill center.

In addition to the Mohawk river, other important streams of the State issuing from the Adirondack center are the Black, Oswegatchie, Grasse, Raquette, St Regis, Chateaugay, Great Chazy, Saranac, Ausable, Bouquet and Hudson rivers.

From Catskill center, in addition to Schoharie creek, we find issuing the headwaters of the Susquehanna, Delaware and Wallkill rivers and Esopus creek.

The Allegheny center supplies the headwaters of Cattaraugus creek, Genesee, Chemung, Canisteo, Tioga, west branch of the Susquehanna and Allegheny rivers.

From Rensselaer center issue Hoosic river, Kinderhook creek, Claverack creek, the Jansen kill and Croton river.

From Chenango center issue the Chenango and Tioughnioga rivers and Oriskany, Oneida and other small creeks, flowing north.

From Lowville center Salmon river issues, together with Sandy creek, Fish creek and other small streams.

Generally speaking the main river valleys of New York are at comparatively low elevations, as may be sufficiently appreciated by considering the elevation of a few of the principal streams. The main Black river valley is less than 800 feet above tide water; Oswego river, with its principal tributaries, the Oneida and Seneca, is less than 500 feet; main Mohawk river is less than 500 feet; Genesee river, between Rochester, Mount Morris and Dansville, is about 500 to 600 feet; main Hudson river, below Glens Falls, is less than 200 feet; main Susquehanna river is less than 1,000 feet, as is also the main Delaware; main Allegheny river in the State of New York is about 1,000 feet; Lake Erie is 573 feet;

Lake Ontario 247 feet; and the St Lawrence river, from 247 to about 100 feet above tide water. The cities and towns are mostly situated in these several valleys along the streams.

The quantity of pure upland water that can be furnished from the six water centers is sufficient for 45,000,000 to 50,000,000 people, as may be shown by considering that the available areas are more than 9000 square miles in extent. If we assume an average collection of only 400,000 gallons per day from 9000 square miles and an average daily use throughout the State of 100 gallons per capita, we have water enough for 36,000,000 people, and which could easily be increased by additional storage to a supply sufficient for 45,000,000 to 50,000,000 people.

On the accompanying map, the reserved elevated areas are considerably in excess of 9000 square miles, but this is merely to insure that no town or group of towns be required to go further than necessary for an upland water supply. These areas can be reduced when definite information is at hand as to just where the supply for each town or group of towns can be obtained.

In order to emphasize the proposition that the main river valleys of the State should be kept clear for manufacturing, they are generally excepted from the pure water reservations, shown on the accompanying map. This map is subject to modification in this particular on detailed study.

The Adirondack center is a rugged region, consisting of primeval crystalline rocks, covered locally with sand areas. Here appeared some of the first dry land on the western continent, and thus was laid, in early geologic time, the basis of those fine river systems which, issuing from this water center, have created water resources of vast value to the citizens of New York. From this center water may be supplied to Plattsburg, Malone, Canton, Potsdam, Ogdensburg, Utica, Herkimer, Johnstown, Saratoga Springs, Schenectady, Lake George, Albany, Troy and many other large towns of the region, all within practical distance of the purest water, flowing from granitic catchments. This region is also extensive enough to furnish abundant supplies to the cities of the Hudson valley, including the City of New York.

The geologic history of Catskill and Allegheny water centers is quite different from that of the Adirondack center. In both these regions the sedimentary sandstone rocks of the Chemung and Catskill groups have attained their greatest development. In the Catskill mountains these rocks are still practically horizontal, as originally deposited, and in places several thousand feet in thickness. Limestones and other hard rocks, underlaid by shales and soft formations, are found beneath the sandstones in a lower stratigraphic horizon.

From Catskill and Rensselaer water centers, water may be taken to Albany, Troy, Hudson, Catskill, Kingston, Schenectady, Newburg, Goshen, Monticello, Delhi, Cooperstown and other large towns of the surrounding region. The City of New York is now chiefly supplied from Croton river, which issues from the south end of the Rensselaer center.

From Chenango center, water may be taken to Norwich, Cortland, Binghamton, Oswego, Syracuse, Utica, Auburn, Waterloo, Geneva and other places nearby.

From Lowville center, Lowville, Watertown, Carthage and Oswego may be reached.

From Allegheny center, Buffalo, Lockport, Albion, Batavia, Warsaw, Rochester, Geneseo, Angelica, Bath, Corning, Elmira, Canandaigua and Lyons may be reached.

In view of the vast increase of population in New York State for the past one hundred years the writer considers that the time has arrived when the State should make provision for retaining a portion of the headwaters of the streams issuing from these several elevated regions as a future water supply for the inhabitants.

The population of New York in 1800 was 589,051. In 1900—one hundred years later—it was 7,268,894. In the year 2000—another one hundred years—it is perhaps difficult to predict what it will be, but if with the data from 1790 to 1900, inclusive, we plot a population curve, a reasonable estimate of the population in the year 2000 is found to be 20,000,000—it may be one or two million more than this, or one or two million less, but for a period nearly one hundred years in advance, 20,000,000 is a conservative estimate.

Of the present population of 7,268,894, in 1900 6,206,657 were on an area of approximately 23,440 square miles, or a trifle less than one-half the land area of the State, which is, according to the twelfth census, 47,620 square miles. However, this statement does not quite represent the conditions in New York State as regards the relation between population and area. If we consider that there are thirty-seven cities included in the preceding area of 23,440 square miles, in which there is a population of 4,302,000 on about 1000 square miles, or at the average rate of something like 4300 per square mile, we learn that on the 23,440 square miles the purely rural population may be taken in 1900 at 1,904,000, which rural population is again situated on about 22,400 square miles, or at the average rate of about 84 per square mile.

The foregoing review of the statistics of population in New York indicates the present tendency to concentrate in cities. Undoubtedly, such tendency will be considerably accentuated in the future. The clear tend of perhaps one-half of New York State to become a great manufacturing district will lead to this result.

In the year 2000 it is probable that a relatively larger proportion of the population will be located in the river valleys than at present. Time will not be taken to discuss the conditions in each valley, but the Mohawk valley will be briefly referred to as illustrating conditions in several of the more important river valleys.

The catchment area of Mohawk river is 3468 square miles and the population of nineteen principal towns situated therein was in 1900, 215,539. These towns are all large enough to have sewerage works at the present time. They are manufacturing towns and are growing rapidly. If they were to increase in the same proportion as the whole State, the population in the year 2000 would be something like 600,000, but undoubtedly they will increase much more rapidly than the whole State and we will not be far from right if we take the population in the year 2000 at 1,000,000. Moreover, this urban population will not be scattered over the whole 3468 square miles, but will be concentrated on perhaps 1200 square miles. The average population will, therefore, be, aside from the denser population of the cities, over 800 per square mile. Approximately the same average conditions will obtain on about 20,000 square miles of the State.

With an average population of over 800 per square mile on 20,000 square miles, the 20,000 square miles will have become urban and sub-urban area, with water supply and sewerage in every street, and a vastly important question is raised not only as to the source of the water supply, but as to the sewage disposal.

With an ample upland water supply for the entire State assured, we may consider a little further the most practicable form of sewage disposal to be applied in New York. The majority of the streams are already so far contaminated as to make their use for water supplies undesirable, the more especially as it is entirely practicable to obtain uncontaminated upland sources of water supply without prohibitive expense. In many cases, several towns will join together for the construction of a conduit and in order to harmonize the various interests, a State commission should take charge of the construction.

The writer fancies that in many cases purification of sewage by dilution will be sufficiently effective even when the population of the State shall have reached 20,000,000, and in other cases, some different form of purification may be used. For satisfactory results by dilution, there should be in the stream about 4 cubic feet per second for every 1000 of the population. For Mohawk river, when the population of the valley reaches 1,000,000, this would mean a flow in the stream of 4000 cubic feet per second.

The minimum flow at the present time is for short periods occasionally as low as 0.1 cubic foot per second per square mile, although such flows continue for only a few days and would hardly apply in discussing sewage disposal.[1] For present purposes, we may take the low water flow at from 0.25 to 0.3 cubic foot per second per square mile, or at about 1000 cubic feet per second for the flow of Mohawk river at its mouth. The balance of the 4000 cubic feet per second must be furnished by storage, which will again provide the water power for driving a considerable proportion of the manufacturing establishments of the valley. 3000 cubic feet per second furnished from storage is as much as can be practically developed. Hence, when the population of Mohawk valley reaches about 1,000,000 some other plan must be adopted, but up to that point, the writer considers that the preferable plan is to go to the neighboring highlands for uncontam-

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[1] For minimum flows of Mohawk river in detail, see tables on pages 406-10, together with statements on pages 508-9.

inated water supplies, discontinuing the use of Hudson and Mohawk rivers therefor, and reserving them instead for sewage disposal. This proposition is equally true as regards the other principal rivers of the State.

The foregoing indicates that pure water supply and sewage disposal must go together—that they are of equal importance and neither can be neglected. To accomplish these objects, a permanent State water supply and sewage disposal commission should be created at some time in the future. This commission would work substantially on the lines laid down by the several English commissions, who have considered questions of water supply and sewage disposal for the last 40 to 50 years.[1]

Before the work of such a commission can be effective, it is necessary that a new topographical map of the State be made at a scale not smaller than $\frac{1}{15,000}$. The work of the English commissions has been specially effective because of having the Ordinance Map of Great Britain at a considerably larger scale than $\frac{1}{15,000}$. The area included in the several water centers should be undertaken first and will occuy from 10 to 15 years. After this map is well advanced, such a commission could be properly appointed.

In reference to the present topographical map of the State, it is at too small a scale ($\frac{1}{62,500}$) to be of use other than as a general guide. The definition of the several water areas will require more precision than is possible on a map of the scale of the present topographical map.

The writer will indicate some of the duties which may be likely to fall upon such a commission as is here suggested, drawing somewhat upon an act proposed a few years ago in New Jersey, largely the work of the late Lebbeus B. Ward, of Jersey City.

In the first place, with the topographical map at a scale of $\frac{1}{15\,000}$ in hand, the commissioners would precisely define the area

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[1] Some of these commissions are. (1), Sewage of Towns Commission, 1858–65; (2) First Rivers' Pollution Commission, 1868; (3) Second Rivers' Pollution Commission, 1870–74; (4) Royal Sanitary Commission, 1871; (5) Royal Commission on Metropolitan Sewage Discharge, 1884–85; (6) Royal Commission on Metropolitan Water Supply, 1893; (7) Royal Commission on Metropolitan Water Supply within the limits of the Metropolitan Water Companies, 1898–99; (8) Royal Commission on Sewage Disposal, 1898–date.

from which a given water supply was to be drawn, such a definition to be made with due reference to the several interests, whatever they may be. Especially, in making their determinations, the interests of manufacturing by water ,power should be duly conserved.

After these preliminaries had been attended to, the commission should investigate the possible sources of the supply of water as they now exist, and should tabulate and report in detail upon each supply. There are a number of places where the water supply is not only ample, but of which the purity cannot be improved, but due consideration should be had as to the sufficiency of the present supply for future growth. The possibility of sewage in the future going into any present water supply should be taken into account.

These commissioners would be empowered to construct and maintain works to supply, from the specially reserved State catchments, any city or town in the State which would comply with certain conditions. It would be made the duty of such a commission to defend the rights of the State, as regarded the use of reserved waters, and as to the policing and other lawful control of the same. Where necessary, proper sewage disposal works would be included, although generally, with the rivers left free to take sewage, this would be unnecessary—at any rate, for the present.

Any town or group of towns wishing to receive a water supply from a State catchment would be authorized to make application to the State board therefor, and thereupon the commissioners should consider such application, make examination, and submit plans and estimates, together with recommendations as to the best source and method of furnishing a supply, either singly or jointly with other municipalities, as in the judgment of the board was most expedient. Preferably, such recommendations would be made with reference to the supply of each municipality being an integral part of a comprehensive system of State water supply.

The plan proposed could be submitted to a vote of the electors of the town or towns at such time and place as might be decided upon. If resulting favorably, the commission would proceed to construct the works and furnish the municipalities so accepting the plans and provisions of the act, with a permanent water supply from the State catchment. The amount to be paid per unit of water for such supply should be included in the report.

No street distribution mains, or other apparatus constituting or directly pertaining to the internal distribution system of any municipality should be constructed by the State, but main conduits only, terminating at the boundaries of towns. The main supply system would be under the control of the State water supply and sewage disposal board.

In case the electors of any municipality should decline to accept the plan proposed at the election, the municipality should be at liberty to renew its application at any time after a year, requesting the State board to present a different or modified plan, but it should be optional with the board whether to present such modified plan or present the one previously proposed.

The State board should be empowered to issue bonds which may be denominated water and sewage disposal revenue bonds. The body of the bond should contain a declaration that the security therefor was the annual payment collectable from the municipality, together with the stipulation that a sinking fund of one per cent per annum should be invested and held in trust for the final redemption of the bonds. The bonds could have fifty years to run and should not bear more than 3½ per cent interest. The annual payments of the several municipalities, to meet the interest on the bonds and provide the sinking fund, should be assessed by the State water supply and sewage disposal board each year in proportion to the quantity of water used by each municipality and the special expenditure incurred on account of such municipality. The moneys collected would be returned to the State Treasurer and by him deposited in the treasury as a pledge for the security of the bonds. Provision should also be included for the collection in case of a default by any municipality.

The act should provide for furnishing water to private companies which already hold franchises for supplying any city or town, but it should not be furnished to any such private company at a less price than to a public water supply. The tendency of such an act would be to uniformity in price of water to all municipalities accepting its provisions.

In order that such a board might properly transact its business, provision should be included for the Comptroller to make advances out of any money in the treasury not otherwise appropriated, the total amount of such advancement to be limited to a certain sum, which should be repaid to the State treasury when properly assessed and collected from the municipalities. In this way, and also by virtue of the preceding suggestion as to bonds, the State may temporarily loan its credit to any municipality requiring an upland water supply, but the cost of such must in the end be returned to the State.

Finally, it is suggested that a commission of three is amply large, two of whom could be appointed by the Governor, and the third—who should be an hydraulic engineer—be elected by the two. These commissioners should devote their whole time to the work.[1]

THE DEVELOPMENT OF WATER POWER IN NEW YORK

Power employed in manufacturing. The Twelfth Census Report gives the steam power employed in manufacturing in 1900 in the State of New York as 677,219 horsepower, while the water power employed in manufacturing was 368,456 horsepower; in 1890, the steam power aggregated 537,447 horsepower; and the water power 233,795 horsepower; in 1880, the steam power amounted to 234,795 horsepower and the water power to 219,348 horsepower; in 1870, steam power was 126,107 horsepower and water power, 208,256 horsepower. These statistics show that in 1880 the two kinds of power were substantially equal—steam power exceeded water power by only 15,447 horsepower; in 1870, water power exceeded steam power by 82,149 horsepower.

According to the statement[2] of Dr Chas. E. Emery, the yearly cost of steam power, with coal at $3 per ton, will, for 365 days of 20 hours each vary, depending upon the kind of engine used, from $76.54 to $48.79. At the present time, with everything

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[1] Partly abstracted from paper, State Water Supply in New York, in Proc. Ninth An. Convention of Am. Soc. of Municipal Improvements, held at Rochester, ctober 7–9, 1902.

[2] Cost of Steam Power, by Chas. E. Emery, Ph. D., in Trans. Am. Inst. Elec. Engrs., March, 1893.

somewhat more expensive than when this table was made, these figures may be taken at $85 and $53, although such costs imply small developments in units of not exceeding about 500 horsepower. In large units of from 3000 to 5000 horsepower, steam power may be developed considerably cheaper than this. Nevertheless it is still true that steam power will cost more than water power. We may profitably inquire then why, with so much undeveloped water power in the State, the more expensive steam power has developed to a greater extent relatively than water power.

Steam power. Let us consider the following tabulation of steam power in the census years from 1900-1870, inclusive, in the States of Connecticut, Massachusetts, Rhode Island and New York:

	1900 No. of H. P.	1890 No. of H. P.	1880 No. of H. P.	1870 No. of H. P.
Connecticut	178,708	98,038	57,027	25,979
Massachusetts	579,110	355,226	171,397	78,502
Rhode Island	115,876	85,327	41,335	23,546
New York	677,219	537,447	234,795	126,107

Water power. The following tabulation shows the development of water power in the census years 1900-1870, inclusive, in the four States:

	1900 No. of H. P.	1890 No. of H. P.	1880 No. of H. P.	1870 No. of H. P.
Connecticut	71,414	64,655	61,205	54,395
Massachusetts	187,848	159,787	138,362	105,854
Rhode Island	29,035	27,258	22,240	18,481
New York	368,456	233,795	219,348	208,256

Percentage increase of steam power. The following tabulation shows the percentage of increase of steam power in the four States for the same period:

	1890-1900 per cent	1880-1890 per cent	1870-1880 per cent
Connecticut	82.3	71.9	119.5
Massachusetts	63	107.3	118.3
Rhode Island	35.8	106.4	75.6
New York	26	128.9	86.1

Percentage increase of water power. The following tabulation shows the percentage of increase of water power:

	1890-1900 per cent	1880-1890 per cent	1870-1880 per cent
Connecticut	10.5	5.6	12.5
Massachusetts	17.6	15.5	30.7
Rhode Island	6.5	22.6	20.3
New York	57.6	6.6	5.3

The foregoing tabulations show that in all the States enumerated there has been great development of steam power in the last thirty years, but that in Connecticut, Massachusetts and Rhode Island there has been relatively less development of water power than of steam power. In New York State the development of water power in the last ten years is relatively double the development of steam power.

In considering statistics, it is important to draw the right conclusions—an error perpetuated, may falsify history and lead to the adoption of erroneous policies. Let us examine, therefore, as to the real significance of these statistics. In the first place, they indicate that twenty to thirty years ago, in Connecticut, Massachusetts and Rhode Island, the most of the available water power had been developed, but that manufacturing as a whole had not by any means reached a maximum. When we consider the history of these States we find that every stream has a reservoir upon it and that the water power has been developed to its full capacity. The developments in these States in the last ten to twenty years have mostly been those that were not developed earlier because of greater cost. Probably some developments were overlooked, but still the general proposition is true, that in any manufacturing community expensive developments will not be entered upon until after the cheaper ones are fully utilized.

Comparison of the development of water power in New York with the development in New England. It has been the custom to consider New York State as first in rank of population, manufactures, development of water power, etc. The writer, however, considers that Connecticut, Massachusetts and Rhode Island all outrank New York State in these particulars. It ought to be well understood that a comparison without regard to area is not legitimate—that the only way in which these states can be compared with New York is on equivalent areas. If, in comparing the States of Connecticut, Massachusetts and Rhode Island with New York on this basis, we find that the aggregate wealth per unit of area is greater, we may be very sure not only that there is a good reason for it, but, as will be shown further on, that the real reason is largely due to mistaken views in New York as to the State's attitude towards the developing of manufacturing. The main reasons why the development of water power versus steam power has been so different in the leading New England States from what it has been in New York are as follows:

Water power reservoirs in New England. In the New England States, as well as in most of the southern and in several western States, there are a series of statutory enactments which are designed to encourage the erection of mills. Under their provisions parties desiring to flow the lands of others for the purpose of creating water power to propel mills may do so under condemnation proceedings analogous to those for acquiring lands and property for canals, railways and other public purposes. This peculiar extension of the principle of eminent domain has grown out of the original conditions of interdependence of the early colonists to whom mills for grinding grain were among the necessities of life. The first mill acts originated in Massachusetts and Virginia, from whence they have been adopted into the statutes of many of the other States.

In order to show what may be accomplished in a comparatively small State by properly encouraging manufacturing, we will refer to conditions as existing in the State of Massachusetts. This State has always been mindful of the interest of manufacturing, and accordingly at the beginning of the eighteenth century a mill act was enacted, and while the original act was merely intended to encourage the erection of grain and flour mills, it has been gradually extended to include all kinds of manufacturing operated by water power on the ground that the Commonwealth was directly concerned in the development of all such. The writer has no intention of discussing the mill acts of Massachusetts in detail, and wishes merely to point out that such acts have also been enacted in Maine, Wisconsin, Rhode Island, New Hampshire, Connecticut, Vermont, Pennsylvania, Virginia, West Virginia, Kentucky, Mississippi, Alabama, Missouri, Indiana, Iowa, Illinois, Michigan, Nebraska, Minnesota, Kansas, North Carolina, Tennessee, Georgia, Delaware, Arkansas, Florida and Oregon, or in twenty-eight States in all. In New York State we have been so wedded to the single idea of canals that we have never enacted a mill act. That this failure has been to the material disadvantage of the State may be easily shown.

Special mill acts in New York. While no general mill act has ever been enacted in New York, nevertheless the legislature has in a number of cases, in effect, recognized the principle which they embody. As for instance in chapter 235, laws of 1854, an act for the improvement of the Saranac river and lakes; chapter 505, laws of 1865, an act for the improvement of the navigation of the Oswegatchie river, and of the hydraulic power thereon, and to check freshets therein; and in chapter 289, laws of 1868, an act to provide for the improvement of the hydraulic power of the Great Chazy river and to check freshets therein.[1]

None of these acts has ever been subjected to the tests of the courts. By their terms commissioners are appointed who may erect dams, and, if possible to agree on terms with the owners, purchase the necessary lands, taking a conveyance thereof to themselves, their heirs and assigns forever. If they can not agree on the terms of purchase, then title may be acquired under the general condemnation laws of the State. Under the provisions of the act applying to the Raquette river, a dam was constructed a couple of miles below Raquette pond about 1872. This dam stored water over Raquette pond, Tupper lake and a number of smaller ponds in that vicinity. It was destroyed by the people of the vicinity, as the writer recollects, about 1875. Under the provisions of the act applying to the Oswegatchie river, a dam

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[1] There are a considerable number of similar acts, of which, so far as known, the following is a complete list: Salmon river, chap. 268, laws of 1872; Raquette river, chap. 90, laws of 1869; Raquette river, chap. 432, laws of 1872; Raquette river, chap. 425, laws of 1873; Raquette river, chap. 269, laws of 1874; Raquette river, chap. 148, laws of 1877; Oswegatchie river, chap. 505, laws of 1865; Grasse river, chap. 83, laws of 1869; Saranac river, chap. 684, laws of 1871; Saranac river, chap. 685, laws of 1871; Moose river, chap. 94, laws of 1872; Great Chazy river, chap. 289, laws of 1868; and Chateaugay river, chap. 652, laws of 1874.

was also built on the outlet of Cranberry lake, which is still standing. This lake has a water area of 12.8 square miles.

While it is true that these acts recognize the principle of the mill acts, still, if called upon to defend them, their originators would probably hold the improvement of navigation and the checking of freshets as the real matter of public utility.

Although we have no general mill act in New York State, we nevertheless reap the benefit on the Hudson river of the mill act in the neighboring State of Massachusetts. Thanks to State lines. we receive this benefit without cost to anybody in the State of New York.[1]

The greatest development of these waterpower reservoirs is probably in Rhode Island and Connecticut, although they are common in Maine, New Hampshire and Massachusetts.

The absence of such legislation in this State is to be traced largely to the growth of the idea here that the navigation interests are paramount to those of manufacturing, whence it has resulted that the important streams of this State have been mostly reserved for the benefit of the internal navigation system, although the showing herein made, as to the value of the water of the Hudson river for waterpower in comparison with its value for the use of navigation, may well lead us to consider whether after all the manufacturing interests of this State are not quite as worthy of consideration as those of the neighboring New England States. We ought not to forget that, aside from carrying grain for producers outside of this State, the chief business of the canals must come from fostering manufacturing interests within the State itself.

State ownership of the Hudson river and its effect in restricting the development of waterpower. Titles to lands bordering on and lying under the beds of large rivers like the Hudson have been somewhat complicated in this State by the peculiar circumstances of its early settlement and history. Thus, all original titles in the lower and middle Hudson valley, as well as in the most of the Mohawk valley, are derived from the laws of Holland as they existed early in the seventeenth century. Under the Dutch law the riparian proprietors owned neither the beds nor banks

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[1] For account of reservoirs in Massachusetts see page 265.

of streams, but both remained the property of the State. When the colony of New Netherlands passed into the hands of the English government, the colonists were assured the peaceful enjoyment of all the rights they then possessed. The beds of large streams, never having been conveyed, became then vested in the English government as ungranted lands, to which as a consequence of the Revolution, the State of New York succeeded in due course.

Throughout the Colonial as well as the early State period this right seems never to have been questioned; it was only after the beginning of the era of internal improvement that questions arising under this head became leading ones in the jurisprudence of this State.

The English common law, which became in force in the colony of New York after the English occupancy, differs from the civil law of Holland in affirming the right of the riparian proprietors, not only to the banks of non-navigable large streams, but also to the beds thereof and hence to a right to the flow of the water paramount to that of the State, which could only acquire rights therein by the exercise of eminent domain and the granting of just compensation.

The principle of State ownership of the Hudson and Mohawk rivers was strongly asserted over one hundred years ago, in 1792, when on March 30 of that year an act passed the legislature incorporating the Western Inland Lock Navigation Company, having for its object the improvement of navigation of the Mohawk river from the navigable portion of the Hudson to Rome, and thence to Lake Ontario and Seneca lake, and the Northern Inland Lock Navigation Company, having for its object to open a like communication from the navigable part of the Hudson river to Lake Champlain. In an amendment to this act, passed December 22, 1792, it is provided that all the land under the Mohawk and Hudson rivers which may be occupied by those corporations is vested in them during the continuance of the franchise "as a free gift from the people of this State," saving and reserving to the people the right to all the lands under the water not so occupied as aforesaid, to be appropriated as the legislature might from time to time direct.

Again, later on, in 1823, the State acquired by purchase all the rights in the Hudson and Mohawk rivers which these two companies were possessed of, which purchase has been taken as reconfirming the State's absolute title to the beds and waters of these two streams.

The following are some of the more important cases bearing upon the ownership of the Hudson river which have been passed upon by the courts of last resort in this State.

The first important case is that of the Canal Appraisers vs. The People on the relation of George Tibbetts, determined in the Court of Errors in 1836. In this case it was held that if in the improvement of a navigable river the waters of a tributary stream are so much raised as to destroy a valuable mill site situate thereon, and if the tributary stream on which said mill site is situate be generally navigable, although not so at the particular locality of the mill site, the owner is not entitled to damages within the provisions of the canal laws, directing compensation to be made for private property taken for public use.

In this case Tibbetts claimed damage for the destruction of a waterpower situate in the middle sprout of the Mohawk river by the erection of the Troy dam. The case was first tried in the Supreme Court in 1826, when the relator obtained a rule that the Canal Appraisers should show cause why a mandamus should not be issued commanding them to assess the damage. The Canal Appraisers had refused to allow damages, assigning as a reason that Tibbetts had no legal claim to the land under the water of the middle sprout because it belonged to the people of the State. After various proceedings, which need not be specially referred to here, the Court of Errors held as in the foregoing, thereby confirming the position of the Canal Appraisers.[1]

In the case of The People vs. Tibbetts, decided by the Court of Appeals in 1859, it was held that the State in its sovereign character owns the beds of navigable streams to high-water mark, and that the right of a riparian owner is subservient to the power in the State to abridge or destroy it at pleasure, although the riparian owner may undoubtedly use the water passing his land so long as he does not impede the navigation, in the absence of

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[1] The Canal Appraisers vs. The People, 17 Wendell, 576.

any counterclaim by the State as absolute proprietor. The court said: "It is beyond dispute that the State is the absolute owner of the navigable rivers within its borders, and that as such owner it can dispose of them to the exclusion of the riparian owners."[1]

In the case of The People vs. The Canal Appraisers, decided in 1865, the following points are passed upon affirmatively:

1) The Mohawk river is a navigable stream and the title to the bed of the river is in the people of the State.

2) Riparian owners along the stream are not entitled to damages for any diversion or use of the waters of the Mohawk river by the State.

3) It seems the common law rules, determining what streams are navigable, are not applicable in this country.

This was a proceeding by mandamus, decided by the Supreme Court and carried to the Court of Appeals, to compel the Canal Appraisers to assess and appraise the damages which one A. Loomis had sustained by the diversion of the Mohawk river at Little Falls for the purposes of the Erie canal. After a learned discussion of the several questions involved, the court held as in the foregoing 1), 2) and 3); the judgment of the Supreme Court was affirmed and the mandamus denied.[2]

Without discussing the question more elaborately, we may conclude it is a well settled doctrine that the banks to high-water mark and the beds and waters of the Hudson and Mohawk rivers are the property of the State and may be disposed of as the legislature may see fit, and absolutely without reference to the rights of abutting proprietors. Acting on this view, the Erie and Champlain canals have taken water supplies from these two rivers and payments of damages have never been made to anybody. As regards the Hudson river, the principle, so far as can be learned, has never been questioned since the legislature first saliently affirmed it by the enactment of 1792. For one hundred and twelve years, the State's right to absolute control of the Hudson river has been a fixed fact, alike recognized by the courts, canal officials and the owners of abutting lands.

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[1] The People vs. Tibbetts, 19 N. Y. 523.

[2] The People vs. The Canal Appraisers, 33 N. Y. 461.

Although not specially germane to the subject, it may be remarked in passing that this condition of absolute State ownership only applies to the Hudson and Mohawk rivers. The titles to lands bordering on the balance of the large rivers of the State have mostly originated since the English occupancy and the common law rule governs. Lack of appreciation of this distinction on the part of the Canal Appraisers has led to a number of extensive litigations. One of these is Kempshall vs. The Commissioners of the Canal Fund, decided in 1842, wherein it is expressly held that the banks and bed of the Genesee river belong to the riparian owners, and that even though the stream had been legislatively declared a public highway, still such declaration only gave rights of navigation on the stream itself, and did not in any degree confer upon the State the right to divert its waters into another channel, as the Erie canal, without first obtaining such right by an exercise of eminent domain and the granting of just compensation under due process of law.[1]

If, then, the State's title to the water of the Hudson river is complete, there is still responsibility attached to such ownership. The conditions leading to this ownership were peculiar and exceptional and at variance with the rules governing not only in the balance of the State of New York, but in most of the other states as well. When the legislature first affirmed this principle one hundred and twelve years ago, manufacturing, as any considerable element of our State and National wealth, was an unknown quantity. Its phenomenal development since then has created conditions and needs so entirely different that if we attempt to decide the questions of today by the old standard we shall paralyze the industries of a locality.

As regards the paramount right of the State to the waters of these streams, it may be assumed that the only direction in which the State is likely to exercise this right is in the interests of navigation, and inasmuch as its exercise for this purpose on the tidal section can only be of benefit to the other interests on the stream, there is every reason why such an exercise of the right should be made.

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[1] Kempshall vs. Commissioners of the Canal Fund, 26 Wendell, 404.

In any case the day has passed when the State in its sovereign capacity can, without loss of dignity, simply say: This stream is State property, to be held and even disposed of absolutely without reference to the wants or wishes of the riparian proprietors.[1]

The Seneca river controversy. By way of further illustrating the relations of the State to many of the important water powers, we will refer to the conditions existing on Seneca river.[2]

In December, 1807, the State of New York by letters patent, conveyed to John McKinstry 640 acres of land situated in the township of Junius, Seneca county, and bounded on the south by Seneca river. The northerly portion of the village of Waterloo now stands on this lot. Subsequently, McKinstry conveyed this lot to Elisha Williams who, some time between 1808 and 1814, erected a mill and constructed a raceway leading from the Seneca river to the same from a point near where the present Waterloo dam stands.

Chapter 144 of the laws of 1813 incorporated the Seneca Lock & Navigation Company, giving to said company the authority to construct a canal between Cayuga and Seneca lakes. This act provided that any owner or occupant of any land adjoining Seneca river or outlet may use the water for mills or other hydraulic works, but such use shall at no time impede the passage of boats or other water craft. That it shall be lawful for the owner or occupant of lands adjoining the said outlet or canal to make from the canal all necessary cuts, at his own expense, to conduct the water to his mills or other hydraulic works so, however, as not to impede the navigation or prevent the company from the use of so much water as at all times shall be necessary for the purposes of navigation.

About 1813 hydraulic privileges on Seneca river became valuable. Elisha Williams, who owned the waterpower on the north side of the Seneca river at Waterloo, was also a stockholder in the Seneca Lock & Navigation Company, and drew the act incorporating the same.

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[1] The two preceding chapters are partly abstracted from the Report on Upper Hudson Storage Surveys, dated December 31, 1895.

[2] Report of Superintendent of Public Works, 1896.

Pursuant to chapter 271 of the laws of 1825, the State of New York purchased all the right, title and interest of the Seneca Lock & Navigation Company.

Elisha Williams died in 1833, at which time all the hydraulic privileges owned by him, estimated to be thirty rights, each equal to one run of stone, were sold.

On the south side of the river the conditions were somewhat different. In the year 1799 Samuel Bear settled on the south shore of Seneca river, on land which is now included in that part of the village of Waterloo which lies south of said river. In 1804 the State of New York conveyed to Bear one hundred acres of land lying along and south of the river, together with the water-power and privileges connected therewith. Bear then excavated a raceway and erected a mill on this land.

The present Cayuga and Seneca canal was completed by the State in 1829, by which year water power on the Seneca river had become very valuable.

The foregoing historical matter shows that the State only owns rights of navigation on Seneca river, and that the water power belongs to the riparian owners, as was fairly recognized in the original enactments. The Superintendent of Public Works states, however, that from 1829 to the present time the Seneca canal has been depleted of water for the use of the mills, frequently to such an extent that it has been extremely difficult to maintain navigation continuously during the whole season. The canal has indeed been looked upon and treated by the mill owners as an hydraulic canal to conduct water to their mills, rather than as a canal to be maintained for navigation. Following this line, the Superintendent of Public Works expresses the opinion that so long as the State holds out inducements to boatmen to expend their energy and capital in the business of carrying freight on the canals, and to merchants and traders to embark their goods thereon, the water supply provided for the purposes of navigation should be used therefor to the last drop, if necessary, before any other interest is subserved; hence, the Superintendent is of the opinion that a series of piers and tide bulkheads should be constructed, by which the water of Seneca river may be controlled for the purposes of navigation, and without reference to the rights of the riparian owners—although such rights have been guaranteed by legislative enactment—except as there may be surplus water over and above the necessities of the canal.

Referring to the tabulations of tonnage of the canals for the year 1896, as given in the same report of the Superintendent of Public Works, it appears that the total tonnage of Seneca canal for that year was 54,739 tons, of which 45,493 tons were anthracite and bituminous coal, carried for Pennsylvania coal producers, and only 8,295 tons of domestic produce carried for shippers living within and doing business in the State of New York. At the best, the cost of transportation on these 54,739 tons could not have been over $25,000 less than it would have been if transported by rail.

The manufacturing establishments on the Seneca river at the present time include the following firms:

The Gould Manufacturing Company
American Globe & School Supply Company
Seneca Falls Manufacturing Company
Shoemaker & Daniels
National Advertising Company
Seneca Woolen Mills
Seneca Electric Company
Gleason & Bailey
Gleason Knitting Mills
American Fire Engine Company
Yawger Milling Company
Harrison & Chamberlain
Davis & Stevens Manufacturing Company
Rumsey & Company, Limited
W. J. Littlejohn
H. C. Silsby
Roberts & Briggs

The amount of capital employed and the annual product of these firms is unknown, but as several of them are very strong firms, employing large amounts of capital and a great number of hands, the total capital employed may be safely placed at not less than $2,500,000, and the total number of employees at probably exceeding 1500. In effect therefore, the proposition of the Superintendent of Public Works amounts to this: That if necessary he would stop all these great manufacturing industries which are now owned and operated by citizens of the State of New York in order, chiefly, to transport 45,493 tons of coal for Pennsylvania mine owners.

In justification of this position of the Superintendent of Public Works it may be pointed out that as the Executive Officer of the Canal Department he is charged with the maintenance of the canals and the execution of the canal laws generally. Officially, he can therefore take no other position than the one herein discussed. The criticisms are therefore directed towards the policy and not towards the official who is doing his duty under existing law.

Compensation in kind on Black river. Chapter 157 of the laws of 1836 provided for the construction of the Black river canal. One of the provisions of this law was that the feeder and canal shall be so constructed as to pass as large a quantity of water to the Erie canal as can reasonably be spared from Black river, and from the northern portion of the Black river canal. The Black river canal proper extends from Rome to the Black river at Lyon Falls, from whence to Carthage navigation is maintained on that river by means of jetties, locks and dams. In 1848 a dam was built at Forestport, diverting the waters of Black river through a feeder ten miles in length, leading from Forestport to Boonville, where it enters the summit level of Black river canal; thence its waters flow both southerly to Erie canal at Rome, and northerly through Black river canal to where that canal enters the river at Lyon Falls, at which place such portion of the water as flows northerly is restored to Black river.

The feeder is estimated to carry 16,000 cubic feet per minute between Forestport and Boonville. Of this amount 5000 cubic feet per minute is returned to Black river at Lyon Falls, whence the diversion to Erie canal becomes, less the evaporation and percolation losses, 11,000 cubic feet per minute.

The Forestport feeder was opened regularly for use in July, 1849, and shortly thereafter claims were made by the owners of water power upon Black river for damages, but for several years the Canal Commissioners took the ground that the appropriation was only temporary, and allowed damages on that basis between Forestport and Lyon Falls. In 1854, however, the auditor refused to pay one of the drafts presented in payment of such a claim, maintaining that the appropriation was permanent and that the commissioners had no authority to settle on the basis of temporary diversion. After litigation the Court of Appeals sustained the auditor.

Following this decision, sixty-two claims for permanent damage, aggregating $600,000, were presented to the Canal Appraisers. Hearings on these claims continued from July to December, 1858. The evidence showed that a large number of persons had made claims who were not users of the water power in 1849, and on this basis the Canal Appraisers rejected forty of the claims, finally awarding on twenty-two of them the sum of $91,108.

The claimants, however, appealed from these awards on the ground that the Appraisers in making their award of damages had not taken into account the full amount and flow of water to be supplied to the Black river by the construction and maintenance of the reservoirs designed to limit the use of water of said river by the State, as contemplated by the act of 1836, and which reservoirs were in process of construction and would soon be completed so as to supply a quantity of water nearly adequate to the wants of the State, as now completed, and thus return to the claimants the water of which they would otherwise have been deprived.

In explanation of the foregoing statement of the Canal Commissioners, it may be remarked that in 1850 Daniel C. Jenne, at that time Resident Engineer of the Eastern Division, acting under instructions of the Canal Board, made a report on the Black river diversion, in which he said that unless an amount of water be returned to Black river equal to the quantity diverted heavy damages to water power would ensue, the amount of which would be almost incalculable. Based upon this report the legislature, by chapter 181 of the laws of 1851, provided for the construction of reservoirs on Black river of sufficient capacity to supply the Black river canal feeder with such quantity of water during the summer months as shall be necessary for the supply of the Black river and Erie canals, and shall give to Black river, as nearly as may be, as much water as ordinarily flows therein during the summer months. The act further provides that the waters from said reservoirs shall be discharged so that the waters so reserved shall be let into Black river during the summer months in such manner and in such quantity as to give, as far as practicable, to the inhabitants residing on said river the benefit of said reserve waters when the same shall be required for use, and such supply shall not be less than the quantity which ordinarily flows in said river during the summer, provided the supply from said reservoirs will furnish such quantity after supplying the Black river and Erie canals with water.

We have here a case, therefore, in which the legislature, by chapter 181 of the laws of 1851, provided for compensation in kind. So far as can be learned, this is the only case in New York where the principle of compensation in kind has been adopted on a large scale on account of hydraulic diversion. Usually when such questions have been litigated the courts have held that there must be money compensation.

The construction of the reservoirs began in 1852, and proceeded, as legislative appropriations were made, from year to year, although in 1858, when the appraisers were considering the Black river claims, only the North branch reservoir had been completed. Work had been begun on the South branch, Woodhull and Chub lake reservoirs, but stopped in 1857 for lack of funds.

As already stated, the Canal Commissioners appealed from the awards of the Appraisers on the ground that the said Appraisers had not taken into account the full amount and flow of water to be obtained from the reservoir system. The Canal Board rendered its decision on this appeal in February, 1860. The position of the Canal Commissioners was sustained and the Canal Appraisers' awards reduced pro rata 35 per cent—that is to say, the Canal Board took the ground that the construction of the reservoirs was to a considerable degree compensation for the diversion.

Since 1860 a number of reservoirs have been built until the actual storage capacity on the headwaters of the Black river is considerably in excess of the full amount diverted to the Erie canal during the dry season, but for various reasons the construction of these reservoirs has not supplied the water needed—or at any rate it is so claimed by the owners of mills on the Black river.

The chief reasons why the large storage capacity of the various reservoirs has not been sufficient to provide a proper dry-weather flow are stated as:

1) The inaccessibility of several of these reservoirs.

2) The constant surreptitious use of the water by lumbermen for the purpose of floating logs down the streams, from which it results that the storage is drawn off in the spring, thus leaving the reservoirs empty when actually needed later in the season.

The question may be very properly asked: Why, if the State had inaugurated by chapter 181 of the laws of 1851 a reservoir system on Black river, with a view of compensation for the diverted water in kind, there should have been any payment of damages at all? The answer to this question is as follows: While the reservoirs were actually authorized in 1851, still in 1858-59, when these claims were under consideration, only one reservoir—that on the North branch—had been completed, work having been stopped on the South branch, Woodhull and Chub lake reservoirs in 1857 for lack of funds. The mill owners had therefore waited ten years without having received either money compensation for the damage or compensation in kind. Commenting on this situation the Canal Appraisers in their discussion of difficulties in the way of estimating damages state in effect that owing to the uncertainties of legislative action no one can say when the reservoir system will actually be completed, but if the reservoirs were completed, and they had accomplished wholly or in any ascertained part the desired object of producing a larger summer flow in Black river, such fact would have an important bearing in reducing the amount of permanent injury to the water power. In view of the foregoing, the appraisers say:

> These claims can not receive as satisfactory decision as we should desire until the successful or unsuccessful working of the reservoirs, if completed, can be known, or the policy determined whether or not they are to be completed; and the appraisers have almost as little faith in the correctness of the conclusions which they may reach as in the belief that those conclusions will satisfy either the claimants or the State. For the nearly four years that the present Board of Appraisers have held office, they have kept these claims in abeyance in the hope that the time would come when they could dispose of the claims in a manner which would,

at least, be satisfactory to themselves; but the claimants have waited patiently nine years, trusting to the good faith of the State to make good their losses, and it is unreasonable to ask them to wait for an indefinite number of years more. The State has permanently appropriated this water and will use it, and has, by the act of appropriation, in the exercise of its sovereignty, the right to use and control it through all future time, and enough is known from the experience of the last nine years to show that considerable damage has already accrued, which no mere restoration of the water can atone for.

Under the head of leading principles that would be recognized and followed in deciding these cases, the Canal Appraisers remark that in order to save the necessity of presenting general views in each case they will state certain leading principles to be recognized and followed in passing upon all these claims:

1) The State will be held liable for the damage sustained by the riparian owners in consequence of the diversion, on the principle that fresh rivers to the middle of the stream belong to the owners of the adjacent banks; that they are entitled to the usufruct of the waters as pertinent to the fee, and for an interruption in the enjoyment of their privileges in that respect in consequence of public improvements made by the State, are entitled to compensation for damages sustained.

2) There can be allowance made only to those who owned in 1849, or to the assignees of their claims.

3) Nor can any allowance be made, even to the owners of 1849, for any special damages from year to year since, except by way of interest on the sum that shall be determined as the real loss when the injury occurred.

4) The State can not be held to pay for mills or other structures erected, or investments made, since that year, when everybody knew that the waters had been diverted; these erections or investments were at the risk of those who made them.

5) Nor can the appraisers take into consideration remote or contingent damages to property, separate and distinct from water power, and the property upon it alleged to have been depreciated in value by the diversion.

6) In estimating damages to a particular water power, additional expenses incurred in putting in new machinery, etc. adapted to the new order of things will be considered, but only as bearing upon the extent of the damages of 1849, which required such expenditures to restore the power.

7) While we can not wholly ignore the fact that the State has had in contemplation the erection of the reservoirs and may yet complete them and the water be restored, we can only take these things into account in a qualified and limited sense.

With the foregoing principles in view, the Board of Appraisers handed down their decisions on each individual claim, the aggregate being, as already stated, $91,108.

Later on the State made additional appropriations, finally carrying out an extensive reservoir system on Black river. The reservoirs constructed to date, with their available capacities, are as follows:

Name of reservoir	Mean area, acres	Mean depth, feet	Available capacity, cubic feet
White lake	296	5.0	64,000,000
Chub lake	200	4.0	35,000,000
Sand lake	306	15.0	200,000,000
Woodhull lake	1,118	18.0	438,000,000
Bisby lakes[1]	......	3.5	40,000,000
Canachagala lake	320	4.0	56,000,000
North lake	277	28.0	676,000,000
South lake	372	26.0	350,000,000
Twin lakes	175	8.0	60,000,000
Fulton chain lakes	......	....	800,000,000
Stillwater[2]	3,200	6.0	850,000,000
Forestport	700	7.0	213,000,000
Total			3,782,000,000

The foregoing total of 3,782,000,000 cubic feet storage is sufficient to furnish a mean flow from the storage alone of about 220 cubic feet per second for 200 days.

Notwithstanding the liberal reservoir capacity on Black river, the mill owners have complained from year to year that they suffer from shortage of water on account of the diversion for Black river and Erie canals, and an investigation in 1888 having shown that the mill owners' claim that the water was improperly used by lumbermen was well founded, the legislature, by chapter

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[1] This reservoir has been abandoned.

[2] This reservoir is rebuilding in 1902-3-4.

188 of the laws of 1894, authorized the Governor to appoint three citizens of Jefferson county and one of Lewis county, interested in the use of and owners of water power on Black river, Beaver river or Moose river in such counties, to be Commissioners of Water Power for Black river. These commissioners are authorized to appoint a gatekeeper for the State dam at Stillwater on the Beaver river, and also for the dams constructed by the State on the Fulton chain and on Moose river. The act also authorizes the commissioners to make rules and regulations for the management of the gates in said dams, subject to the approval of the Superintendent of Public Works, and the gatekeepers are directed to observe and obey all rules and regulations so made and approved, under penalty of removal, at any time, either by the commissioners or by the Superintendent of Public Works.

The commissioners are further authorized to regulate the discharge of water through such gates, at such times and in such quantities as they may deem proper, but not in such manner as to injuriously interfere with canal navigation or the navigation of that portion of the river used for canal purposes. This act was reenacted by chapter 795 of the laws of 1896, with the addition thereto of an increase of salary of the gatekeepers, the act of 1894 only permitting an expenditure of $500 a year for this purpose, while that of 1896 permits an expenditure of $1,100.[1]

The case of Skaneateles lake. Chapter 728 of the laws of 1889 provided that under certain conditions the city of Syracuse might draw a water supply to the extent of 15,000,000 gallons daily from Skaneateles lake, which had been permanently appropriated as a State reservoir for the supply of the Jordan level of the Erie canal in 1844. Since this case presents many interesting points in illustration of the peculiar relations between the State and the riparian owners in New York, it will be briefly discussed, beginning with the early history.

About 1824 the owner of land at the foot of Skaneateles lake constructed a dam across the outlet, whereby the waters of the lake were raised from 4 to 6 feet above their natural level, thus creating a reservoir and waterpower sufficient to propel mills

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[1] Report of the State Engineer and Surveyor for the year ended September 30, 1888.

and machinery at that point. The outlet of Skaneateles lake is a very rapid stream, descending in a distance of nine miles nearly 500 feet, and furnishing frequent waterfalls, many of which have been improved by the erection of large manufacturing establishments, dependent for their propelling power upon the water of the outlet.

The water of Skaneateles creek was appropriated to feed Erie canal in its first construction, and a dam across the creek and a raceway or feeder were constructed at or near the village of Jordan. It will be understood that the original State construction of a dam and feeder at the village of Jordan did not in any way interfere with the reservoir dam constructed as stated in 1824 at the foot of the lake itself. The canal authorities, however, claimed that the effect of the dam at the outlet, and other dams on the stream where power development had been made, was at times such as nearly to prevent the flow of any water into the canal; hence, it was found necessary during the dry period of nearly every year to resort to Skaneateles lake itself to procure a temporary supply of water for the canal. For the use of this water as taken from year to year the State for many years paid damages to the owners of the hydraulic privileges at the outlet of the lake. Thus payments were made in December 1833, December 1835, June 1837, and in 1840, this latter payment being on appraisement made pursuant to chapter 150 of the laws of 1839 for the use of water from 1824-30, inclusive. Payments were also made in 1840 and 1841, the whole amount paid for temporary use of water from the lake up to 1841 being $13,154.

In 1844 the Canal Commissioners, in a report submitted to the senate in response to a resolution asking for information as to how much had been awarded to the mill owners and others on Skaneateles creek for water drawn from that stream and lake for the use of the canal, etc. reported that in their opinion measures should be taken without delay to secure independent control of the waters of Skaneateles lake, thus severing the injurious connection between the interests of the State and those of private individuals. The commissioners also say in this report that the Canal Board had, in 1841, passed a resolution permanently appropriating the waters of Skaneateles lake as a reservoir and feeder to the canal, but that the resolution authorizing this appropriation also contained the provision that the State should draw all the water furnished by Nine Mile creek and Carpenter's brook for supplying the Erie canal during the dry portions of the navigation season.[1] This order, the commissioners state, was rescinded, because of containing conditions that might have rendered the reservoir unavailable at a time when most required.

In September, 1843, the Canal Board made another order, appropriating the waters of the lake as a reservoir and feeder, omitting what from the State officials' point of view were the objectionable features of the previous order—that is to say, the order of September 1843, appropriated the water of the Skaneateles lake and outlet, without reference to the rights of the riparian owners, any further than that they were to be paid for actual damages incurred.[2]

Following this order the Canal Appraisers awarded damages to the owners of water rights on Skaneateles outlet to the amount of $28,450. Later on the State reconstructed the dam at the foot of Skaneateles lake, at the same time cutting down the bottom of the outlet enough to permit of drawing 7 feet depth of water, measuring from the surface of highwater as indicated by a certain stone monument.

Previous to 1888 the water supply of the city of Syracuse was furnished by a private company. The water furnished was, however, of inferior quality and the distribution system inadequate to the wants of a growing city like Syracuse. Under these conditions the citizens of Syracuse procured the passage of an act, chapter 532 of the laws of 1888, constituting a board of special commissioners to inquire into and investigate the several sources of water supply which could be made available for the public, mechanical and domestic uses of said city. It was also provided that said investigation should take into account the abundance of the proposed supply of water, its quality and character.

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[1] Presumably what was meant was that all the water these streams could furnish should be drawn before any was taken from Skaneateles lake.

[2] For an extended abstract of early history of Skaneateles feeder, see the Supreme court case of the city of Syracuse against Richard M. Stacey and others, Syracuse, 1894.

The special commissioners employed as their engineer J. J. R. Croes to take charge of the investigation to be made by the board. Under Mr Croes's direction investigations were made as to possible municipal water supplies for Syracuse from eleven sources: Salmon river, Skaneateles lake, Lake Ontario, Seneca river, Onondaga creek, Gang wells, Cazenovia lake, Oneida lake, Otisco lake, Tully lakes and the supply of the Syracuse Water Company. After an exhaustive study of these possible sources of supply, Mr Croes submitted a report under date of January 26, 1889, in which he recommended that Skaneateles lake be adopted as the source of the municipal water supply, on the ground chiefly that the water of this lake was superior to any of the others from a sanitary point of view; that it could be supplied by gravity, and that the cost would be less than a proper supply from any other of the available sources.

In the report of the special commissioners it is pointed out that section 6 of article 7 of the Constitution of New York would render it impossible for the city of Syracuse to obtain Skaneateles lake as a source of water supply, because that lake constitutes part of Erie canal, and is therefore the property of the State and can not be disposed of by it. The constitution, however, does not define what the Erie canal consists of, but by article 1, title 9, chapter 9, part 1 of the revised statutes, the legislature has enacted that the navigable connections joining the waters of Lake Erie with those of Hudson river, and all the side cuts, feeders and other works belonging to the State, connected therewith, shall be known by the name of the Erie canal.

The special commissioners held that the constitution did not make Skaneateles lake a part of the Erie canal, but that what the constitution means is that Erie canal—the channel across the State and the waters necessary for its use—shall not be sold, and not that any feeders originally designated by the State as forming a part of it may not be disposed of and others substituted in their places. Further, inasmuch as the constitution has not defined what shall be considered as the Erie canal, but that such definition has been made by the legislature, it therefore follows that if the legislature were competent to enact that all feeders of the Erie canal should become and be a part thereof, it was equally competent to declare that certain feeders shall cease to be a part of the canal, especially when such feeders cease to be necessary or useful for this purpose.

The commissioners also pointed out that by the revised statutes the legislature has enacted that whenever any water may be spared from any canal or works connected therewith without injury to the navigation or safety of such canal, a sale of such surplus water may be made. The commissioners recognized, however, that this act provides that the State shall have the right wholly to resume the waters so conveyed and the privileges thereby granted whenever it shall become necessary for the use or safety of the canal, but on this point they suggested that if the State by an act of the legislature has the power to make a revocable grant of waters of a feeder of the canal, but not necessary for its use and safety, it also has the power to make an irrevocable grant of such waters. The plan proposed by Mr Croes included the construction by the city of Syracuse of a compensation reservoir on Carpenter's brook, whereby the water taken from Skaneateles lake for the public water supply of the city of Syracuse may be returned to the State in kind. Such an exchange, the commissioners said, could in no way impair the usefulness or safety of the Erie canal, nor in any manner injure the interests of the State. The commissioners also said that it did not seem to them that such forced or technical interpretation of the constitution should be resorted to as would preclude the possibility of a municipality of nearly 100,000 people securing a proper and suitable source of water supply. They believed indeed that the necessities of the city in this regard were so urgent, and its welfare and prosperity so largely dependent upon securing water from Skaneateles lake, that the authorities of the State should feel constrained to accede to the demand of the city for this water as the source of its municipal supply.

Following the special report of the commissioners, chapter 728 of the laws of 1889—An Act to establish and maintain a water department in and for the city of Syracuse—was enacted. This act was strongly opposed by those interested in the Erie canal, the opposition being chiefly on the ground that the taking of the waters of Skaneateles lake for the supply of the city of Syracuse would work great injury to the navigation interests. While this act was under consideration by the legislature, the Senate requested the State Engineer and Surveyor to furnish whatever information he might possess as to sources of water supply which could be made available for the Jordan level, together with his opinion as to the mode by which such water supply could be stored, and the probable cost of the work for such purpose. Pursuant to this resolution, the State Engineer and Surveyor reported, under date of March 12, 1889.[1] In this report the State Engineer stated that it did not seem practicable to make provision at Skaneateles lake for a greater amount of storage than that given by the existing dam, nor did there seem to be any point for additional storage reservoirs between the lake and Erie canal on the line of the Skaneateles creek. It was, however, pointed out that about two miles east of Jordan, Carpenter's brook enters Erie canal. On the line of this brook, about a mile southerly from the canal, the topography is such as to afford a location for a large reservoir and dam 55 feet in hight. At this place there could be created a reservoir flowing 650 acres and impounding 807,000,000 cubic feet of water. The catchment area of Carpenter's brook above the proposed dam is stated at 14.5 square miles, which, according to the estimate of the State Engineer and Surveyor, may furnish 429,500,000 cubic feet yearly. Carpenter's brook, however, now supplies to the Erie canal during the navigation season about 200 cubic feet per minute which, for the whole season, may be taken at 70,500,000 cubic feet. Therefore there would remain available for storage in the reservoir, beyond present demands, the annual quantity of 359,000,000 cubic feet.

It will be noticed that the stated capacity of Carpenter's brook reservoir of 807,000,000 cubic feet is in excess of the yield of the catchment area of 429,500,000 cubic feet. This excess capacity of the reservoir the State Engineer proposed to utilize by diverting water, either through a feeder, or by pipe lines leading to the Skaneateles outlet, whereby it would be made possible to direct, when necessary, the flood-flows of Skaneateles outlet into the Carpenter's brook reservoir.

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[1] Senate document No. 54 (1889).

After discussing these several questions, the State Engineer expressed the opinion that the creation of a storage reservoir, as outlined in the foregoing, would be the only safe method by which a portion of Skaneateles lake water could be used.

The act authorizing the city of Syracuse to take its water supply from Skaneateles lake, as finally passed by the legislature, provided as follows:

> The Syracuse Water Board, by and with the consent of the Canal Board, is hereby authorized and empowered to appropriate so much of the waters of Skaneateles lake as may be necessary to supply the city of Syracuse and its inhabitants with water, upon the express condition, however, that the city of Syracuse shall, when so required by the Canal Board, furnish from such other source or sources, and in such manner as the Canal Board may designate, as much water for the use of the Erie canal as shall be taken by the city from Skaneateles lake, and the power granted in this act shall be deemed to include authority and power to provide such compensating water supply for the Erie canal, and to do and perform all those acts and things which shall be needful to acquire for said city and its inhabitants the waters of Skaneateles lake.

This act was sharply contested on the ground that it did not properly provide for the rights of the riparian owners, the misconception of former days, that the State by an act of appropriation for purposes of navigation absolutely extinguished all rights of the riparian owners, again coming up. As regards water powers on Skaneateles outlet, this principle was finally decided in the case of Waller vs. The State of New York, in 1893,[1] in which the question as to the State's absolute control of the waters of Skaneateles outlet was decided adversely, the theory of the State being that the purchase of a piece of land through which Skaneateles outlet flowed, at or near the foot of Skaneateles lake, and the erection of a dam thereon, had given to the State the full right of control of the waters of the outlet. The decision was that State control was for the purpose of navigation and no further, and that any interference with the natural flow beyond that required for the benefit of the canal navigation, was a damage to the riparian owners, to be compensated for like any other

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[1] 144 N. Y., 579.

damage. The case presented, however, by the Syracuse water act was claimed by the opponents of the scheme to be very different in that it provided in effect—if the consent of the Canal Board be obtained—that the entire flow of the catchment area be held at the will of the city of Syracuse and without reference to the rights of the riparian owners. Without stopping to discuss this point at length, it may be pointed out in passing that the city of Syracuse has taken measures to become possessed of all the water rights on the stream, either by purchase or by condemnation, the condemnation cases being in process at the present time.

As a further technical objection, it was contended by the opponents that the Syracuse water act did not provide for money compensation, but for the construction of a storage reservoir to furnish compensation in kind. The proposition advanced under this head was that money, which is the only measure of damage or value known in the commerce of the civilized world, was the only proper compensation to make, the principle of water compensation, as extensively developed abroad, apparently being unknown to those opposing the Syracuse water act.

After exhaustive hearings before the Canal Board, in which arguments of the opposition were strongly presented, the Canal Board finally granted the permission authorized by the law passed in 1889.

Waterpower development discouraged in New York. We have, therefore, the following contradictory conditions, tending to discourage the development of waterpower existing in the State of New York. Special mill acts applying to the northern part of the State have been enacted, but there is no general mill act applying to the entire State. [Since writing the foregoing, Senate bill No. 679 of session of 1904, An Act to establish a permanent commission for the regulation of the flow of watercourses in this State in aid of public health and safety, to be known as the River Improvement Commission, has received Executive approval]. On Hudson and Mohawk rivers the State claims the right to the waters, while on the Genesee river and other streams of the western part of the State the English common law rule prevails. On Seneca river there has been a controversy as to the water rights extending from 1830 to the present time. Due to restrictive laws, the position of the canal department in this controversy has been that if necessary the department could stop industries in favor of navigation, although the money interest is much greater in favor of manufacturing than in favor of navigation. On Black river the principle of compensation in kind has been adopted in the most explicit manner, while in the case of Skaneateles lake it is assumed that the wants of a great municipality are superior to the demands of navigation.

There are many other cases throughout the State equally emphasizing the contradictory nature of the laws governing the ownership of water. It is inevitable that such laws should paralyze industry, with the result that only about 25 per cent of the total waterpower of the State is developed. Had these laws not existed, or had they been either removed, modified or made consistent forty or fifty years ago, it is believed that from 60 to 75 per cent of the total waterpower would now be developed and the population and wealth of the State would be far greater than it is under present conditions.[1]

These interesting problems are presented for consideration in the hope that the people in their wisdom will arrive at a solution which, while protecting whatever rights the State may justly retain, will still in no way interfere with the full development of manufacturing enterprise on any stream.

During the last ten to fifteen years the electrical transmission of power has rendered it possible to utilize power from large central stations distributed to relatively remote points. It is now possible to use mountain powers for the operation of single plants often many miles distant. Electrical transmissions of from forty to sixty miles are no longer very difficult, and such transmissions have been made in the west for from one hundred to two hundred miles. But it should not be overlooked that in the case of some of the lines there, used for mining, etc., it has been a question purely of electrical transmission or no power—the question of expense has not entered specially into the account. The more advantageous use of large streams, but under conditions which present many difficulties without the

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[1] See discussion of future power development in the Adirondack region on page 555.

agency of the electrical current, may also be mentioned as a reason for the increased use of waterpower recently in New York State. The development of electric power transmission at Niagara Falls has been the largest and most conspicuous work of its kind done anywhere.

The significant increase in the use of waterpower in New York State is also accounted for by the growth of the paper and pulp business. The increase here is directly traceable to the great expansion in the development of the manufacture of wood-pulp. This business depends entirely upon waterpower—so far as known, wood-pulp is not made by steam power anywhere. About 65 horsepower per ton per twenty-four hours is required, and if steampower were utilized, it would immediately make pulp cost at least double its present price. In New York State waterpower was used in paper and pulpmills in 1890 to the extent of 65,052 horsepower, while in 1900, 191,117 horsepower was utilized. This industry, therefore, accounts for 126,065 horsepower of the increase of 134,661 horsepower in New York from 1890 to 1900.

In Massachusetts the increase of 28,061 horsepower in the use of waterpower from 1890 to 1900 was due to the additional use of waterpower in the paper and cotton industries. In 1890 29,148 water horsepower was reported in papermills and 44,935 water horsepower in 1900, an increase of 15,787 water horsepower. In cotton mills in Massachusetts waterpower to the extent of 55,944 horsepower was in use in 1890, and 64,158 water horsepower was in use in 1900, an increase of 8214 water horsepower. These two industries account for 24,000 of the total increase of 28,061 water horsepower.

The census statistics are not complete as to the waterpower in either Connecticut, Massachusetts, Rhode Island or New York. The power furnished from electric motors is reported separately and it is impossible to determine what proportion of it is made by steam and what by water—for the whole United States it is 311,016 horsepower. Probably for the State of New York it is from 80,000 to 100,000 horsepower, making the total water horsepower in this State in 1904 in reality something like 450,000. In either Connecticut, Massachusetts or Rhode Island, on the contrary, electrical development has been relatively much smaller than in New York—probably for these three States it does not exceed 25,000 water horsepower in all.

Although once stated in a general way, it may be again repeated that nearly all the available waterpower was developed relatively earlier in the States of Connecticut, Massachusetts and Rhode Island than in New York.

It will be shown in detail further on that the Adirondack region, when fully utilized, is capable of developing at least 800,000 water horsepower, although the present use on the streams issuing from this region is not more than about one-quarter of this.

Future power development of the Adirondack region. A number of years ago the State entered into a policy of conserving this region for a State park, and a notion that the interests of people who go to the park is inimical to that of manufacturing has become prevalent. Here are located the best streams of the State of New York, with unparallelled opportunities for storage. Aside from a few developments, the region is as yet untouched. This extraordinary fact becomes specially pertinent when we consider that not only is the area of the Adirondack region larger than that of the State of Massachusetts, but that the quality of the soil and the climate is not very different therefrom. Massachusetts is a rugged region, largely underlaid with granitic rocks—the same thing is true of the Adirondack region. Had the State not entered into a mistaken commercial policy this region would have been developed somewhat the same as Massachusetts is, and the population instead of being from 90,000 to 100,000 would have been perhaps 1,500,000, its river valleys would be dotted with thriving manufacturing villages and its assessed valuation instead of being perhaps $100,000,000 would have been, in 1900, from $1,000,000,000 to $2,000,000,000.

The proviso is made that this region would have been developed *somewhat* the same as Massachusetts, because it is realized that Massachusetts possesses some advantages which the Adirondack region does not possess, as for instance, proximity to the ocean, etc. This region is, however, near to the main lines of transportation from the east to the west, and can therefore receive raw material at low cost. This fact, in conjunction with its abundant and cheap waterpower, must inevitably make it one of the ultimate chief manufacturing districts of New York.

The real value of the Adirondack region. In regard to the Adirondack region as a whole we may consider that the climate is mostly too severe for the ordinary agriculture of the lowlands of the State of New York. During several years, in which the writer was more or less in the northern forests, frosts occurred there each season, at an elevation of about 1800 feet, in both of the months of June and August, July being the only month entirely free from frost. Under these circumstances it is impossible to raise corn, wheat or barley. Oats, potatoes and meadow grass are the ordinary agricultural crops raised, and even these only with difficulty because of the vast areas of boulders with which the region is largely covered. As an economic proposition, therefore, the Adirondack region is useful for but three purposes; 1) for cultivating timber, which can be easily done under rational forestry administration without prejudice to the other interests; 2) for water storage, which, because of the numerous natural reservoir sites, may be more cheaply carried out here than in any other locality in the eastern states; and 3) for a great State park, which ultimately, by the construction of good wagon roads, may be made an easily accessible pleasure resort for the people of the State of New York.

Rather singularly the great mass of the people who go into the woods for pleasure regard forestry and water storage as inimical to their interests. They assume, indeed, that the Great Northern Forest should be preserved as a pleasure resort alone; and many with whom the writer has conversed are apparently unable to see that the State owes any duty to its manufacturing interests. This position of the woods-going pleasure seekers, fishermen, hunters, etc. while extremely unsatisfactory, has still a certain rational basis underlying it all. It is due very largely to the indifference of the lumbermen in former years, when many acts of vandalism were laid at their door, though to some extent unjustly. At the present time a number of the leading lumbermen of the State are members of the American Forestry Asso-


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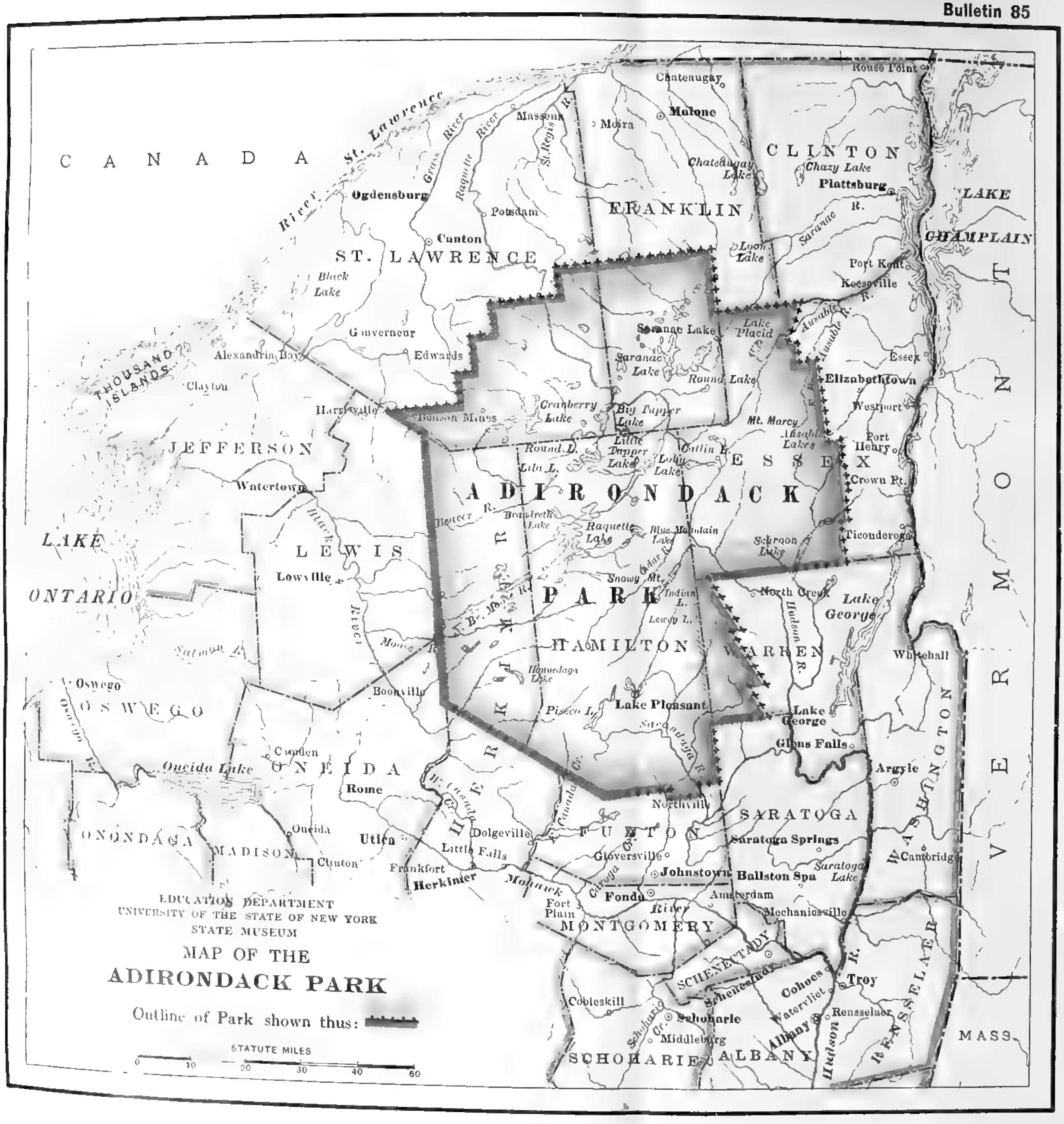

EDUCATION DEPARTMENT
UNIVERSITY OF THE STATE OF NEW YORK
STATE MUSEUM

MAP OF THE
ADIRONDACK PARK

Outline of Park shown thus:

STATUTE MILES
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ciation and of the Society for the Protection of the Adirondacks, and are actually interested in the work of these associations.

People owning cottages on the margins of natural lakes likely to be made into reservoirs object very strongly on the ground that the raising of the water will be prejudicial to health. On this point the writer can not but think that the popular opinion is based on misinformation, although it is freely admitted that the Adirondack region is now extremely healthful and the State ought not to either do anything itself, nor permit anything to be done which would deteriorate it. The popular view, however, that the construction of reservoirs must necessarily produce unhealthful conditions is thus far not sustained by any considerable amount of well-attested facts. The writer is disposed to look upon such view as largely a fad. Indeed, he has taken special pains to study the question both in this country and abroad, and has thus far to learn of a case where well-attested facts show that any considerable amount of ill health has been caused by properly constructed reservoirs.

In the Adirondack region, where at the heads of nearly all the lakes there are now extensive marsh areas, the conditions will be materially improved by cutting the timber and covering the marsh areas with water, the more especially when the new water surface is high enough to cover the entire marsh area, a condition which in the majority of cases may be easily attained. Moreover, the Adirondack lakes and ponds have at their sides mostly sand, gravel, boulder or natural rock beaches, on which the annual fluctuation can have absolutely no effect. The marsh areas are usually in the continuation of the valleys at the heads of the lakes. As just stated, as soon as we attain an elevation of about 1800 feet, July is practically the only month without frost; but the reservoirs will ordinarily be full or nearly full of water during July. It is mostly only in the cooler months of September and October that the conditions of runoff are such as to require their being greatly drawn down. There seems little reason to doubt, therefore, but that the effect of constructing the reservoirs will be, on the whole, to increase the healthfulness of the region by doing away with numerous marsh areas which are now, during the warm weather, possibly the source of malarial influences.

A striking illustration of how unreasonable public prejudice in the North Woods may be was afforded by the writer's experience at Indian lake in the fall of 1897. At that time investigations as to the foundation of the new Indian lake dam were in process, and in order to expedite the study it was proposed to draw the water out of the lake. This fact becoming known, violent protests were made by people living several miles away, who urged that if the lake were drawn down there was certain to be serious sickness, diphtheria among other diseases being mentioned as likely to occur. Time was an element of importance, and inasmuch as it would require at least ten days to draw the water to a level low enough to be of any special assistance in the study in hand, it was finally left undrawn, the water surface of the lake remaining during the whole summer and fall of 1897 at about the crest of the original timber dam, or at about twelve feet above extreme low water. In spite, however, of the water not being drawn there was a great deal of sickness in the vicinity of Indian lake in the fall of 1897, diphtheria especially attacking a large number of children. Certainly had the water actually been drawn, as originally proposed, no amount of argument would have availed to show that the drawing of the water was not responsible for the disease.

Power development at Glens Falls and vicinity. The truth of the general proposition may be sufficiently appreciated by considering the development on the upper Hudson river and in the immediate vicinity thereof.

At Glens Falls there are extensive sawmills turning out twenty million feet of sawed lumber annually; one of the largest papermills in the country, including a pulpmill, with other industries is located here. There are also lime-kilns, producing 500,000 barrels of lime annually. The Glens Falls Portland Cement Works produce 1000 barrels of cement a day. In addition, there are in the town, shirt and collar factories, employing about 2000 people.

At Sandy Hill there are large bag and paper establishments, wall-paper works, iron and brass works, friction-pulley works, works for the manufacture of machinery of many kinds, lumber mills and yards, producing 10,000,000 feet of sawed lumber annually. The sulphite mills of the Union Bag and Paper Company are also located here.

At Fort Edward there is a papermill larger than that at Glens Falls, with pulpmill, sulphite mill and chemical works.

At Fort Miller there are pulp and papermills, and at Schuylerville there are wallpaper, pulp and papermills, and also cottonmills.

At Mechanicville the great papermill of the Duncan Company is located. The Hudson River Power Transmission Company is also located two or three miles below this place.

At Waterford there is a large knitting industry, and at Cohoes there are six large cotton mills and about forty knitting mills, one of which is stated to be the largest of its kind anywhere. There are also large rolling mills, tube works, axe factories, foundries, machine shops and various other establishments.

Fifteen miles west, on the south bank of the Mohawk, is the city of Schenectady, with a population of about 40,000. Its manufacturing establishments include shawls, knit goods, locomotives and many other articles. The works of the General Electric Company are located here, covering an area of about 90 acres. This is the largest factory for electric works in the world. These works manufacture electric motors and machinery of every variety. There are about ten thousand people employed, with a weekly payroll of $175,000.

North of Schenectady there is Ballston Springs, where are located a large tannery, bag, pulp and paper works, axe and scythe factories, etc.

Five miles further north is Saratoga Springs, which, although nominally a watering place, still has considerable manufacturing.

One of the large papermills of the International Paper Company is located at Palmers Falls, while one of the George West papermills is at Hadley, a few miles above.

At Warrensburg there is a papermill, woolen factory and many other industries.

Troy, Watervliet, Lansingburg, Waterford, Cohoes and Schenectady constitute perhaps the largest manufacturing center in the

State of New York. In 1900 there were eight hundred and forty industrial establishments in Troy, with a capital of over $24,000,000. The chief industries of Troy are men's furnishing goods, iron and steel, foundry and machine products, liquors, hosiery and knit goods, paper and wood pulp, printing and publishing newspapers and periodicals, flouring and gristmill products, etc.

Statistical comparisons

Relation of population to capital invested in manufacturing. Let us see what is the relation, based on unit area, of population to capital invested in manufacturing in Connecticut, Massachusetts, Rhode Island and New York.

Percentage increase of population. The following tabulation shows land area as per the Twelfth Census; population in 1900 and 1890; percentage increase from 1890 to 1900, and population per square mile in 1900, for the aforesaid states:

Name of State	Land area in square miles	Population in 1900	Population in 1890	Percentage increase	Population per square mile in 1900
(1)	(2)	(3)	(4)	(5)	(6)
Connecticut	4,845	908,420	746,258	21.7%	188
Massachusetts	8,040	2,805,346	2,238,943	25.3%	349
Rhode Island	1,053	428,556	345,506	24.0%	407
New York	47,620	7,268,894	5,997,853	21.1%	153

The following tabulation as taken from the Twelfth Census shows the population in 1900, the capital invested in manufacturing, the value of the annual manufactured product, the assessed value of real estate, value of lands and buildings used in manufactures, the percentage which the value of the lands and buildings used in manufacture is of the total assessed value of real estate, the manufactured product per capita, and the real estate per capita, for the states of Connecticut, Massachusetts, Rhode Island and New York:

Name of State	Population	Capital invested in manufacturing	Value of annual manufactured product	Assessed value of real estate	Value of lands and buildings used in manufacturing	Per cent of assessed value $=\frac{\text{column (6)}}{\text{column (5)}}$	Manufactured product per capita $=\frac{\text{column (4)}}{\text{column (2)}}$	Real estate per capita $=\frac{\text{column (5)}}{\text{column (2)}}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Connecticut	908, 420	$314, 696, 736	$352, 824, 106	$486, 787, 973	$66, 872, 050	13.7%	$388	$536
Massachusetts	2, 805, 346	823, 264, 287	1, 035, 198, 989	2, 247, 094, 547	173, 694, 674	7.7%	370	801
Rhode Island	428, 556	183, 784, 587	184, 074, 378	320, 318, 384	44, 180, 729	13.8%	430	747
New York	7, 268, 894	1, 651, 210, 220	2, 175, 726, 900	5, 093, 025, 771	392, 174, 641	7.7%	299	701

The following tabulation gives the same data for the year 1890, as taken from the Eleventh Census Report.

Name of State	Population	Capital invested in manufacturing	Value of annual manufactured product	Assessed value of real estate	Value of lands and buildings used in manufacturing	Per cent of assessed value $=\frac{\text{column (6)}}{\text{column (5)}}$	Manufactured product per capita $=\frac{\text{column (4)}}{\text{column (2)}}$	Real estate per capita $=\frac{\text{column (5)}}{\text{column (2)}}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Connecticut	746, 258	$227, 004, 496	$248, 336, 364	$261, 451, 666	$49, 277, 118	18.8%	$332	$351
Massachusetts	2, 238, 943	630, 032, 341	888, 160, 403	1, 600, 137, 807	124, 833, 215	7.8%	398	710
Rhode Island	345, 506	126, 483, 401	142, 500, 625	243, 081, 296	28, 274, 887	11.6%	412	704
New York	5, 997, 853	1, 130, 161, 195	1, 711, 577, 671	3, 403, 751, 246	262, 403, 520	7.7%	285	567

The preceding tabulations show that in New York the total capital invested in manufacturing in 1900 was $1,651,210,220, and the value of the annual manufactured product was $2,175,726,900.

In Connecticut the total capital invested in manufacturing in 1900 was $314,696,736, and the value of the annual manufactured product was $352,824,106. If Connecticut had the same area as New York, with proportionate manufacturing, the value of the annual manufactured product in Connecticut would be over $3,500,000,000, or about one and one half times as great as that of New York.

In Massachusetts the total capital invested in manufacturing in 1900 was $823,264,287, and the value of the annual manufactured product was $1,035,198,989. If Massachusetts had the same area as New York, with proportionate manufacturing, the value of the annual manufactured product in Massachusetts would be over $6,000,000,000, or roundly, three times as great as that of New York.

In Rhode Island the total capital invested in manufacturing in 1900 was $183,784,587, and the value of the annual manufactured product was $184,074,378. If Rhode Island had the same area as New York, with proportionate manufacturing, the value of the annual manufactured product would be $7,362,975,120, or about three and one half times as great as that of New York.

As to why this is so, as regards the State of Massachusetts the census report furnishes a decisive answer in the following language:

> The principal advantage which the State of Massachusetts possesses is its water power. * * * The power of the Connecticut river at Holyoke and at Turners Falls, in the town of Montague, utilized by means of immense dams of the most permanent construction, and by a system of canals, affords in each place a succession of mill sites along the entire water frontage. The Deerfield, Millers, Chicopee and Westfield rivers, tributaries of the Connecticut, are all noteworthy power-producing streams. At Lowell and Lawrence, upon the Merrimac, the possession of similar advantages led to the selection of these places for the installation of the factory system in the manufacture of textiles. At Fall River the power furnished from Watuppa pond has been

an essential element in the development of that cotton manufacturing center; while upon the Blackstone river, and many lesser streams throughout the State, the existence of sites naturally adapted to the erection of mills was influential in the expansion of the woolen and cotton industries in the early part of the century, thus laying the foundation of numerous thriving communities.

In Massachusetts, Connecticut and Rhode Island a liberal policy towards manufacturing has always been exercised. There is a system of reservoirs practically utilizing the water power of every stream, and even comparatively small brooks are in many cases fully developed and are the source of wealth to the citizens.

There is another significant fact to be mentioned in regard to the foregoing tabulations. In Connecticut, Massachusetts and Rhode Island not only was the annual manufactured product per capita greater than it was in New York in both 1900 and 1890, but the real estate per capita was also greater, although the difference was less in 1900 than in 1890.

Relation of area to population. A further test of such statistics is as to the effect upon population. If we find population proportionately increased in Connecticut, Massachusetts and Rhode Island, we may assume that a chief incentive has been the rational encouragement of manufacturing through the operation of well-devised mill acts.

According to the tabulations the population of New York in 1900 was 7,268,894; of Connecticut, 908,420; of Massachusetts, 2,805,346, and of Rhode Island, 428,556. Assuming that Connecticut had the same area as New York, with a population proportionate to its present population, we would find a total population for Connecticut of 9,084,200; in Massachusetts, the actual population in 1900 was 2,805,346, but with the area of New York, the proportionate population would be 16,856,000; the population of Rhode Island is for an area of a little over 1053 square miles, 428,556; with an area forty-five times as great—the equivalent of the area of New York—the population of Rhode Island would be 19,285,000. We reach, therefore, the conclusion that in Connecticut, Massachusetts and Rhode Island, on an actual area of a little less than 14,000 square miles, with a present population of about 3,150,000, if we take the area proportionate to that of New York, with the population proportionate to that of the States themselves, there would have been in these States in 1900 over 40,000,000 persons. Undoubtedly these figures would be modified on as large an area as New York, but we should nevertheless expect a considerably larger population in New York than actually exists.

Relation of values of agricultural products to waterpower values. We may now consider the relation of values of agricultural products to waterpower values. The following tabulation from the Twelfth Census may be taken to show that in Massachusetts and Rhode Island the value of farms has increased in some proportion to the development of waterpower. The reason for this may be found in considering that in a manufacturing community the demand is for the products of gardens rather than for grain, hay, etc.

Name of State (1)	Total number of farms (2)	Total acreage figured on area of State (3)	Total acreage of farms as per Census Report (4)	Total acreage of improved farms (5)	Total value of farm property (6)	Total value of farm products (7)	Average value of farm property per farm $= \frac{\text{column (6)}}{\text{column (2)}}$ (8)
Connecticut	26,948	3,100,800	2,301,083	1,064,525	$113,305,580	$28,276,948	$4,205
Massachusetts	37,715	5,145,600	3,147,064	1,292,132	182,646,704	42,298,274	4,843
Rhode Island	5,498	673,920	455,602	187,354	26,989,189	6,333,864	4,909
New York	226,720	30,476,800	22,648,109	15,599,986	1,069,723,895	245,270,600	4,718

We also note that the average value of farms in Massachusetts is $4843 and in Rhode Island, $4909, while in New York it is $4718.

Again, the total acreage of the State of Connecticut is 3,100,800, while the acreage of improved farms in that State is 1,064,525. The improved farms are therefore about 34 per cent of the total area of the State.

In Massachusetts the total acreage is 5,145,600, while the acreage of improved farms is 1,292,132, or the acreage of improved farms is only about 25 per cent of the total area of the State.

In Rhode Island the total acreage of the State is 673,920, while the acreage of improved farms is 187,354, or the acreage of improved farms is about 28 per cent of the total area of the State.

In New York the total acreage based on area of the State is 30,476,800, while the acreage of improved farms is 15,599,986, or the acreage of improved farms is about 51 per cent of the total area of the State. These statistics show that in Connecticut, Massachusetts and Rhode Island there is very much more waste land than there is in New York. They also show that the average farm in Massachusetts and Rhode Island is more valuable than it is in New York.

There is another interesting fact brought out by the foregoing tabulation. The total value of farm products in Massachusetts in the census year of 1900 was $42,298,274, and in New York $245,270,600. Since the area of New York is about six times as great as that of Massachusetts, it follows that on 25 per cent of the total area of Massachusetts relatively as much agricultural value is produced as on 50 per cent of the area of New York. If, therefore, about 50 per cent of the area of Massachusetts was improved farms, the value of the agricultural products, computed on actual area, would be twice as much as in New York.

The total value of farm products in New York in 1900 was $245,270,600, of which we may assume 7 per cent as profit; whence the total annual profit becomes $17,160,000.

In the report on a water supply from the Adirondacks, made to the Merchants' Association of New York city, in 1900, it is shown that on Hudson river the net annual profit on each net horsepower is $16.20. There is a possibility of a total of 1,500,000 gross horsepower being developed in this State, on which the net annual profit per gross horsepower would be, roundly, $12. The establishments on the Hudson river are mostly papermills, and without doubt in miscellaneous manufacturing the profit would be from three to five times as great as this, but we will assume it all over the State, for the purpose of the argument, at $12 per horsepower. At this rate 1,500,000 horsepower would pay an annual profit of $18,000,000, and represent at 4 per cent a capitalized investment of $450,000,000. Waterpower therefore may be easily made equal to agriculture, the net annual profits of these two industries being very nearly the same.

The proper remedy. There are a number of remedies which may be applied, but first of all we need a comprehensive act in this State which shall permit of developing water storage to its full capacity without any further grant of powers from the legislature than those granted in the general act. As to the form of such an act the writer is not specially insistent, although he may point out that the mill act of Massachusetts, by reason of long and successful application, is an excellent model. A copy of this act may be found in Angell on Watercourses. It is possible, however, that a mill act on the Massachusetts lines may not be in accord with the trend of legislation in this State.

There should be a permanent State commission specially charged with the control of the rivers. To this commission should be submitted everything relating to the rivers of the State. It should be given broad powers as regards the carrying out of projects for improvement, for preventing floods or for other purposes. Water-storage projects should be submitted to it for decision. The commission should have funds enough at its command to enable all necessary investigations to be made.

The act authorizing this commission may be considered as applying to large water-storage projects where the interests of extended communities are to be unified. For smaller manufacturing projects there should also be a mill act permitting lands to be flowed after due process of law and just compensation without any further appeal to the legislature. The encouragement of manufacturing would then become the commercial policy of the State instead of as at present, by restrictive and contradictory laws tending to discourage it.

As to the drainage of swamps and lowlands where an improvement in the public health may be reasonably expected, the State should pay a portion of the cost. On rivers like the Hudson and Mohawk, where the State assumes to absolutely control the waters without regard to the rights or wishes of the riparian proprietors, the State should in consideration of such control make all necessary improvements at its own expense. On the rivers of the balance of the State, where a different rule prevails, the State may in consideration of the abatement of floods and improvement of the public health pay a portion of the cost.

Constitutional amendment. One difficulty in New York is such defects in the constitution as prevent thorough development of the natural resources of the State by means of works serving to control water. This fact is the more extraordinary because a number of western States have embodied in their constitutions articles empowering the legislatures to apply a taking by right of eminent domain upon payment of just compensation for the necessary purposes of retaining, excluding or conveying water. The contradictory laws of New York may be sufficiently illustrated by stating that it was discovered a few years ago that under the amended charter of New York city the city had no right to secure an adequate water supply. The result of this was to throw the furnishing of water into the hands of a private company.

Constitutional precedents for an act of the kind here proposed have been enacted in Missouri, Colorado, Illinois, California, Idaho, Montana, Washington and Wyoming. In Wyoming the provision reads as follows:

> Private property shall not be taken for private use unless by consent of the owner, except for private ways of necessity, and for reservoirs, drains, flumes or ditches on or across the lands of another for agricultural, mining, milling, domestic or sanitary purposes, nor in any case without due compensation.

In New York the law on the subject of mill and flowage acts is, as already shown, in an unsettled state, and a constitutional amendment enabling proper legislation to be enacted is needed in order to develop hydraulic works as well as other natural resources of the State.

It has been said that it is no more justifiable to take property for mills on the ground that their business is beneficial to the public than to take it for groceries or hotels, but the *capacity to have* groceries or hotels in many communities would have to be dependent on the exercise of the power of condemnation to make the cases parallel.[1]

In 1894 Clemens Herschel proposed the following amendment to the constitution of the State of New York. With the amendment made, section 7 would read as follows:

> *Compensation for property taken.* When private property shall be taken for any public use, the compensation to be made therefor, when such compensation is not made by the State, shall be ascertained by a jury, or by not less than three commissioners appointed by a court of record, as shall be prescribed by law. *The necessary use of lands for the construction and operation of works serving to retain, exclude or convey water for agricultural, mining, milling, domestic or sanitary purposes is hereby declared to be a public use.* Private roads may be opened in a manner to be prescribed by law; but in every case the necessity of the road, and the amount of all damage to be sustained by the opening thereof, shall be first determined by a jury of freeholders, and such amount, together with the expenses of the proceedings, shall be paid by the person to be benefited.

Unfortunately, owing to the prevalence of a too conservative spirit, as well as a lack of appreciation of the benefits to follow, this amendment did not pass, although the eight States previously cited have similar provisions, as well as most of the countries on the continent of Europe.

The same year the writer was a member of a committee of the Rochester Chamber of Commerce appointed to consider some of the phases of this amendment as introduced by Nathaniel Foote, delegate to the Constitutional Convention from Rochester. The writer set forth the value of such an amendment, but the committee considered that the Rochester Chamber of Commerce ought not to advocate the amendment because it was at that time endeavoring to secure the passage of an act whereby Genesee river storage would be constructed by the State. To this it was said that there was no probability of the State ever building Genesee river storage, but a too conservative spirit prevailed, and the sense of the committee was that such amendment ought not to pass.

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[1] From circular letter addressed by Clemens Herschel to the delegates to the Constitutional Convention of 1894.

Waterpower by industries in 1900. The following tabulation, from the Twelfth Census, shows the number of water wheels and the power developed in New York in 1900:

	Number of wheels	Net horsepower
Agricultural implements	34	1,691
Boots and shoes	8	590
Boxes	33	920
Brick and tile	1	50
Carriages and wagons	31	1,002
Cheese, etc	35	709
Chemicals	24	114
Cotton goods	45	8,524
Dyeing, etc	6	440
Electrical apparatus	2	48
Flouring mills, etc	2,131	58,384
Foundry	136	6,273
Furniture	56	1,834
Hosiery	95	7,069
Ice	1	25
Iron and steel	8	1,150
Leather	42	1,258
Lime and cement	38	827
Malt liquors	3	95
Lumber	1,201	44,324
Planing mills, etc	86	2,803
Marble and stone	2	75
Paper and pulp	1,021	191,117
Printing	61	406
Silk	15	852
Woolen	71	4,101
Worsteds	14	3,310
	5,200	337,991
Other uses		30,465
		368,456
Estimated electric motors from water power		81,544
Total in State		450,000

In the preceding statement we see that there is 337,991 horsepower developed on 5200 wheels, whence the average power per wheel is 65 horsepower. There are also other uses to the amount of 30,465 horsepower which, however, are not specifically enumerated. The total quantity for the State, including electrical power, of which water power is the primary source, is taken at 450,000 horsepower. The census figures, however, only show a total of 368,456 horsepower, and the electrical power actually in use in 1900 is estimated at 81,544 horsepower. The statements of the several companies furnishing electrical horsepower would aggregate more than this, but probably 81,544 horsepower is a conservative estimate. Statements as to the subdivision of this power among the various industries can not be made.

WATER STORAGE PROJECTS.

In the last ten years a number of large projects for storing water for power and other purposes have been proposed in the State of New York. There are several of these of special importance with which the writer has been concerned, as on Genesee river, Salmon river, Black river, Hudson river, Schroon river, etc. There are also a number of projects of considerable importance which have been developed by others, and of which a brief description will be given here.

On Genesee river an extensive development of water power has led to a demand for storage reservoirs on that stream. The State surveys indicated that a reservoir of 15,000,000,000 cubic feet capacity could have been constructed in 1896 at a cost of $2,600,000, or at the rate of about $173 per million cubic feet of water stored. In 1904, due to change in labor conditions and the considerable advance in prices generally, this reservoir would cost about 25 per cent more, or $3,250,000.

Chapter 605 of the laws of 1898 authorized a private company to construct this reservoir. The project has not thus far been carried out.

The developed waterpower on the Genesee river has increased from a little over 6000 net horsepower in 1882 to about 20,000 net horsepower in 1904.

In 1898 and 1899 there was worked up for the Board of Engineers on Deep Waterways a reservoir project on Salmon river, where it is feasible to develop a reservoir with capacity of 7,000,000,000 cubic feet. The object of this reservoir was to provide storage within reasonable distance of the main deep waterway, so that in case of temporary stoppage of the main feeder to the north, water could still be supplied to the canal. The hight of the main dam on Salmon river was about 56 feet. In addition to this there were three dykes, cutting off lateral valleys at different points of the reservoir.

On Black river also a reservoir was surveyed for the Board of Engineers on Deep Waterways for a main water supply for the proposed canal. When constructed this reservoir will be the largest in the State. The water surface at Carthage will be raised 48.5 feet and an area flooded at extreme high water of nearly 78 square miles, or roundly 50,000 acres. The cubic content of the reservoir at high water will be nearly 70,000,000,000 cubic feet, and at spillway crest over 57,000,000,000 cubic feet. The area flooded at spillway crest will be 73.2 square miles and 13.6 inches stored on the tributary catchment of 1812 square miles.

Extended studies were also made in 1895-96 of the possibility of water storage on the Hudson river, where the waterpower has increased from less than 13,000 horsepower in 1882 to something like 50,000 horsepower at the beginning of 1898 and to about 80,000 horsepower in 1904. The Legislature failed to make an appropriation in 1897 and these studies have never been completed, although considerable addition to the information has been made since that time. The studies so far as carried show that it is possible to create on the Hudson river a continuous permanent power of about 175,000 horsepower, and undoubtedly when the studies are completed it will appear that considerably more than this can be developed at a cost which will be commercially feasible. Probably at least 210,000 horsepower can be commercially developed.

In 1900, in a report to the Merchants' Association of New York, a large reservoir on Schroon river, with capacity of 21,662,000,000 cubic feet, was proposed. This reservoir had been formerly proposed as the Tumblehead reservoir of the Hudson system, but the original proposition was to make it of a storage capacity of 16,246,000,000 cubic feet.

A large reservoir on the Wallkill river was also proposed in 1900 for the water supply of New York city. The detail of this reservoir may be found in the Report to the Merchants' Association on the Water Supply of the City of New York, by Jas. H. Fuertes. The Wallkill reservoir is also described in a report by John R. Freeman, made in 1900. The available capacity of the Wallkill reservoir was about 22,000,000,000 cubic feet.

The considerable storage projects in the Croton valley for the water supply of New York city will also be briefly considered.

Reservoirs have also been proposed on Esopus, Schoharie, Catskill, Fishkill, Wappingers creek, Roeliff Jansen kill, etc. for the water supply of the City of New York, which will be discussed somewhat in detail, not only because of their great size, but because they embody interesting features in reservoir construction.

The power developments on Niagara river at Niagara Falls, on St Lawrence river at Massena, on West Canada creek at Trenton Falls, on Raquette river at Hannawa Falls, and at several other places in New York are among the most significant industrial movements now taking place in the United States. The future power of these several streams may be placed at nearly 1,000,000 horsepower.

There are a number of other interesting developments throughout the State, but the foregoing are the more important.

Storage Reservoir on Genesee River

The following statements in regard to the Genesee river storage reservoir are partially condensed from the detailed reports in the Annual Report of the State Engineer and Surveyor. The portions not taken therefrom are from original manuscript thus far unpublished.

A general description of this river has been given on page 210; its discharge measurements have been discussed on page 331; its flood-flows on page 441; and reference has been made on page 494 to the low-water flow, indicating that during the summer the available supply is small. Notwithstanding this, development of water power has proceeded rapidly. As shown by the reports on Water Power of the United States in the Tenth Census (1880), the total water power on Genesee river from Rochester to Portage in 1882 was 6882 net horsepower. An examination of the amount in use on the same reach of river in 1896 showed that the total based on manufacturers' rating of wheels, was 19,178 net horsepower, or based on the manufacturers' statements of the quantity of water required to operate the wheels, and allowing 75 per cent efficiency of the water, the total power developed by the wheels in place in 1896 is found to have been 17,248 net horsepower, or about three times that in 1882. In 1904 this has increased to about 20,000 net horsepower, and at the same time the steam power in use at Rochester has increased several thousand horsepower. In comparison with these statements it should be noted that for several months during the summer and fall of 1895 the total power did not exceed 4000 to 5000 horsepower. The same condition has existed during the dry period of a number of years previous, but not so seriously as in the fall of 1895. In 1899 the river was lower than in 1895.[1]

Preliminary investigations. The increased demand for power, as well as the serious summer droughts, led to the formulation of a project for constructing a storage reservoir at some point on the headwaters of Genesee river for assisting the summer flow. The first project included the development of the basin of Honeoye lake to its full capacity, surveys having been made for that purpose in 1887 and 1888. It appeared, however, that the yield of this catchment area, which is only about 43.5 square miles, was hardly adequate for the results desired, the estimate showing that even when developed to its full capacity it could not be depended on to furnish, in a dry year, more than 75 cubic feet per second, while the exigencies of the case demanded at least several hundred cubic feet per second. This project of building a large storage reservoir on the upper Genesee river was then formulated by the Rochester Chamber of Commerce.

In the meantime a number of breaks on the long level of the Erie canal, which extends from the foot of the locks at Lockport to the eastern part of the city of Rochester, a distance of about 62.5 miles, had emphasized the importance of the State's providing additional water for feeding the canal east of Rochester. For this purpose the construction of a large storage reservoir was

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[1] The statements of low waterpower are however kept on the original statement of 6727 gross horsepower. With 75 per cent efficiency, this is 5046 net horsepower.

advocated by the Rochester Chamber of Commerce as a State work, with the result that under a resolution of the Senate dated March 21, 1889, the State Engineer and Surveyor was directed to make a general investigation in regard to the possibility of storing water on the upper Genesee. The report made under the authority of this resolution appears in the Annual Report of the State Engineer and Surveyor for the year 1890. In 1892, under authority of a concurrent resolution dated March 15 of that year, Governor Flower appointed a commission consisting of Evan Thomas, Judge Charles McLouth, and John Bogart to investigate and report on the whole question of storage on the upper Genesee. This commission examined the site of the proposed reservoir and reported that it was entirely feasible to construct a large reservoir on the upper Genesee river, the site especially considered by the commission being in the Genesee canyon or gorge, a short distance above Mount Morris.

As the result of the recommendations of this commission, the sum of $10,000 was appropriated at the legislative session of 1893 for the purpose of studying in detail the several proposed sites for dams in the canyon of Genesee river, above Mount Morris. At that time the work was placed in charge of the writer.[1]

At the legislative session of 1894 a bill to construct a dam in the canyon a short distance above Mount Morris passed the Senate, but failed in the Assembly. At the session of 1895 a similar bill passed the Senate and Assembly, but was vetoed by Governor Morton, largely on the ground that the bill as passed made no provision for the owners of the water power and other interested parties bearing any portion of the expense. In his veto Governor Morton expressed the belief that if the State should determine to build a dam on Genesee river some provision should be made by which the city of Rochester—and possibly other localities interested in the work—might contribute to the expense of construction. Governor Morton also pointed out that if the proposed canal enlargement be approved by the people public sentiment might justify the construction of a storage dam on Genesee river for canal purposes. On the other hand, if the proposition to deepen the canal should not be approved the question would

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[1] The result of the studies in 1893 may be found in the Annual Reports of the State Engineer and Surveyor for the fiscal years ending September 30, 1893 and 1894.

still remain whether such a dam might not be desirable for the purpose of regulating the river and increasing the water power thereon.

In order to complete the preliminary investigations relative to the proposed Genesee storage, Governor Morton, in 1896, approved an additional appropriation, which was expended during the summer of that year in completing further surveys. To the present time the State has expended on preliminary investigation of the Genesee storage project the following amounts: In 1890, $3000; in 1892, $7000; in 1893, $10,000; in 1896, $10,000; in all, $30,000. As a result of this expenditure complete plans and specifications have been prepared as shown in the Annual Report of the State Engineer and Surveyor for 1896.[1]

Interests to be served. The following are the interests to be served by the construction of these extensive storage works on Genesee river:

1) The flow of the river would be regulated, thus effectually preventing in the future the devastating floods which occurred in 1815, 1835, 1857, 1865, 1889, 1893, 1894, 1896 and 1902. The floods

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[1] By way of presenting a full list of the work on the Genesee storage, reference may be made to the special report of John Bogart, State Engineer and Surveyor in Appendix F of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1890. The reports of Messrs Bailey and Kibbie, assistant engineers to Mr Bogart, are covered by the same reference. The report of Martin Schenck, State Engineer and Surveyor, may be found at page 44 of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The report of E. Sweet, ex-State Engineer and Surveyor, as consulting engineer, may be found in Appendix H of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The report of the commissioners appointed in 1892 by Governor Flower may be found in Senate Doc. No. 23, 1893. The first report of the writer may be found in Appendix G of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The second report may be found in Appendix E of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1894. The work done in 1896 is described at length in the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1896. See also a paper by the writer, Genesee River Storage and its Relations to the Erie Canal and the Manufacturing Interests of Western New York, prepared for the Rochester Chamber of Commerce. This paper contains a large amount of historical information not given in the official reports. Governor Morton's veto may be found in the Governor's State Papers for 1895.

in the years just enumerated were specially severe, but floods not so severe, yet doing considerable damage, have occurred in several of the intervening years.

2) Water would be supplied for the enlarged Erie canal. According to Mr Bogart's report of 1890, there should have been provided a storage on Genesee river of 1,500,000,000 cubic feet for the purpose of supplying Erie canal as it existed at that date.

3) The agricultural production of the broad level area included in the Genesee valley between Rochester, Mount Morris and Dansville, estimated at from 60 to 80 square miles, might be greatly increased by moderate irrigation if the flood contingency was removed and the proper irrigation channels were constructed.

4) Considerable sanitary benefit would result from the increased flow during the low-water period through the proposed regulation. The entire sewage at Rochester, a city of 175,000 inhabitants, now passes into Genesee river. The channel of this stream, beween the foot of the lower falls at Rochester and Lake Ontario, is so broad and deep that during the time of extreme low water in the summer and fall the current is scarcely perceptible. The sewage of the city therefore lodges in this section, producing a serious nuisance. The regulation of the river, by preventing floods, would also improve the sanitary condition of the broad upper valley, where the annual overflow has been shown to cause more or less sickness.

5) The waterpower would be increased. Wheels are now set on the Genesee river capable of producing, at the manufacturers' rating, about 20,000 net horsepower, while the low-water flow of the stream does not exceed about 5000 net horsepower.

In summation of the preceding points it may be urged, in general, that in constructing the proposed Genesee storage dam, in addition to the private interests to be conserved, public service of an extended character would be performed.

Mount Morris site. Referring to Mr Bogart's report of 1890, it is learned that the investigations of that year were general in their character. The work was carried on more particularly with reference to a location in the Genesee river gorge, between Mount Morris and the foot of the Portage falls. No detailed surveys were made further than necessary to make a general estimate of the cost of a dam 58 feet in hight, which would store 1,500,000,000 cubic feet, the amount considered necessary for canal purposes alone. Such a dam, Mr Bogart estimates, could be erected for about $1,000,000.

The work performed under the direction of the writer in 1893 was of an entirely different character. The report of 1890 having indicated the Mount Morris canyon as a desirable location, with a number of sites pointed out, of which general investigations had been made, it became desirable to investigate those sites in detail and to prepare close estimates of the cost of constructing dams at each. Detailed investigations were accordingly made of the three sites favorably reported upon in 1890, the results of which may be found in the Annual Reports of the State Engineer and Surveyor for 1893 and 1894, where estimates of the cost of the several dams are also given in detail. Referring to the estimates, it appears that at site No. 1, in Mount Morris canyon, a dam raising the water surface 130 feet would cost, if built of concrete alone, $2,450,000, but if built with sandstone faces throughout, except for the spillway, where granite is provided, the estimated cost would become $2,590,000. A dam of the same hight at site No. 2, if built throughout of concrete, would cost $2,600,000, but with sandstone faces and independent spillway the cost would be $2,720,500.

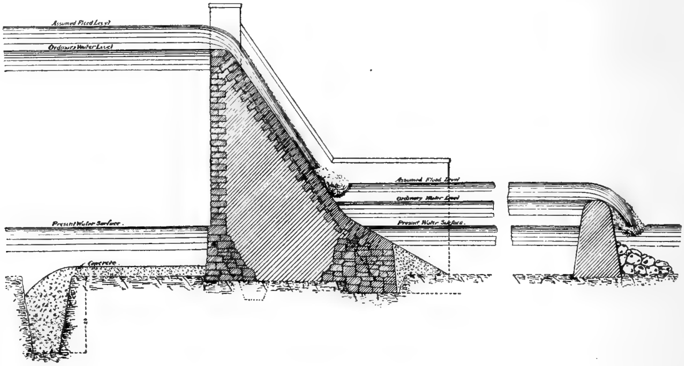

Fig. 39 Dam, 58 feet high, proposed for Genesee river near Mount Morris.

In regard to the total storage to be obtained in Mount Morris canyon the following are the figures at sites Nos. 1 and 2, the two sites chiefly considered: At site No. 1 a dam of 130 feet in hight will store 7,700,000,000 cubic feet, and at site No. 2 a dam of the same hight will store 7,040,000,000 cubic feet. Since no conclusion has been reached as to which of these sites to adopt, for the purposes of comparison a mean of 7,370,000,000 cubic feet has been taken as the approximate available storage, and the mean of $2,785,000 as the approximate total cost. On this basis the estimated cost of the storage becomes $377.88 per million cubic feet of water stored. These figures should be increased by 25 per cent in order to conform to conditions in 1904.

Portage site. Investigations of the Genesee river storage project were finally completed in 1896. In that year detailed surveys were made of a new site known as Portage site, the proposed dam to be located at Portageville, about 1400 feet above the Erie railway bridge, at a point where the gorge presents extremely favorable conditions for the erection of a high dam. At this place solid rock exists immediately in the bed of the river, with only a couple of feet of water flowing over it, and also extends high up on the bluffs at either side, whereas at all of the sites in the gorge near Mount Morris the rock was only found at from 15 to 20 feet below the water surface and of such an open texture as to require cut-off trenches about 30 feet deep, or to a total depth of nearly 50 feet below the water. The proposed Portage dam is also 500 feet vertically above the previously mentioned sites, thus rendering that additional number of feet available for power purposes—a fact which places a materially different aspect on the commercial side of the Genesee river storage project.

A short distance above the proposed Portage site the upper Genesee valley broadens out to a width in places of from one to two miles, although the general width of the valley does not exceed, for several miles in extent longitudinally, about one mile. It narrows in two or three places to a less width than this. The valley is now a good agricultural region, in a fair state of cultivation, and presents, on the whole, as favorable conditions for farming as any similar valley in the State. The Pennsylvania railway passes through the middle of the valley on the line of the abandoned Genesee Valley canal. Along the line of this railway the villages of Portageville, Rossburg, Wiscoy and Fillmore are situated. The reservoir project includes the relaying of the railway above the flow line on the west side of the valley, as well as the removal of the villages named. The total area below the flow line is 12.4 square miles, and the entire area proposed to be taken for reservoir purposes, including a strip 10 feet vertically above the flow line, is 13.7 square miles. The project also includes the removal of several cemeteries, the building of highway bridges across the reservoir, and the construction of a roadway entirely around the same.

Without having made a detailed canvass, it is estimated that the present population of the proposed Portage reservoir site, in the villages and on the farms, is about 1200. In reference to dispossessing this number of people of their homes for the purpose of creating a large storage reservoir, it may be said that such a proceeding is not only not uncommon in this State, but that the population to be removed in the case of the new Croton reservoir is far greater than at the Portage reservoir. According to maps furnished by the Croton Water Department, it appears that the new Croton reservoir includes the taking of either the whole or parts of something like three large villages and nine or ten hamlets. The total population to be removed from the submerged area of the new Croton reservoir is not given, but actual inspection of maps of the proposed sites indicates that it must be several times larger than the number to be dispossessed at Portage. The villages of Katonah, Purdy Station, and Croton Falls are much larger than any of the villages in the Portage reservoir site. The main line of the New York and Northern railroad passes for several miles through the valley and requires relocating above the flow line, the same as is proposed for the Pennsylvania railway along the Portage reservoir. It appears, therefore, that the City of New York has recently done under State laws everything in the way of so-called radical change which it is proposed to do at Portage. In both cases the sufficient reason for these changes may be found in the better meeting of public necessities.

The original estimated cost of the proposed Portage reservoir, including land damages, dam, reconstruction of railway, removal of cemeteries, the cutting of all timber within the catchment areas, the construction of highway bridges, etc. is $2,600,000, the storage to be provided by this expenditure amounting to 15,000,-

000,000 cubic feet; at this rate the cost per million cubic feet stored would be $173.33, but with 25 per cent added to the estimate to conform to conditions in 1904, the cost per million cubic feet stored is $216.67.

The main characteristics of the proposed reservoir are shown by table No. 83, condensed from pages 708-9 of the Report of the State Engineer and Surveyor for 1896:

TABLE No. 83—CAPACITY OF PROPOSED PORTAGE RESERVOIR

Elevation of water surface above sea level, feet	Area of water surface, square miles	Total volume of water in reservoir, cubic feet	Inches on catchment
1,100.0	0.2320	101,400,000	0.044
1,105.0	0.5330	217,623,000	0.094
1,110.0	0.8340	333,900,000	0.143
1,115.0	1.1350	450,100,000	0.194
1,120.0	1.4357	566,300,000	0.244
1,125.0	2.0659	942,100,000	0.406
1,130.0	2.6692	1,318,000,000	0.567
1,135.0	3.3264	1,694,000,000	0.729
1,140.0	3.9566	2,070,000,000	0.891
1,145.0	4.5255	2,780,000,000	1.196
1,150.0	5.0944	3,490,000,000	1.502
1,155.0	5.6633	4,200,000,000	1.808
1,160.0	6.2322	4,910,000,000	2.113
1,165.0	6.8293	5,945,000,000	2.559
1,170.0	7.4264	6,980,000,000	3.004
1,172.0	7.6652	7,395,000,000	3.182
1,173.0	7.7846	7,602,000,000	3.271
1,175.0	8.0235	8,016,000,000	3.451
1,180.0	8.6206	9,051,000,000	3.896
1,185.0	9.4362	10,366,000,000	4.462
1,190.0	10.2518	11,681,500,000	5.016
1,195.0	11.3007	13,257,000,000	5.710
1,200.0	12.3495	15,000,000,000	6.458

Comparing the foregoing statements of cost with those made on the preceding page with reference to the cost of the proposed reservoir in Mount Morris canyon, it appears that at Portage a storage of 15,000,000,000 cubic feet can be made for somewhat less than the cost of 7,300,000,000 cubic feet at Mount Morris; or, as a general statement, we may say that a given expenditure at Portage produces double the storage that it will produce at Mount Morris. The Portage reservoir develops the full capacity of the catchment area for such a dry year as 1895. It is considered that this full development is necessary in order to obtain the most satisfactory results in river regulation.

As reasons in detail for preferring the Portage site to that at Mount Morris, the following may be mentioned:

1) The Portage site affords more water for a given expenditure.

2) The Portage site is considered safer than the Mount Morris site. As shown in the Genesee Storage Reports of 1893-94, the shales at Mount Morris are open; and while it is, without doubt, possible to make a safe dam there, it would be at much greater cost than at Portage.

3) The material for the dam is nearly all on the ground at Portage, while at Mount Morris it needs to be brought from a distance.

4) The Portage site affords greater waterpower development. With the Genesee storage dam located at Mount Morris the total head on which the storage can be applied is 282 feet, while with a dam at Portage the total head on which the stored water may be applied is 782 feet.

5) On account of the great depth of the foundation at Mount Morris, it would be necessary to expend over $1,000,000 before the dam could be brought to the level of the present water surface.

The proposed regulation of Genesee river at Portage has been computed on the basis of a minimum discharge of 300 cubic feet per second, in the case of a reservoir storing 7,500,000,000 cubic feet, and on a basis of a minimum of 457 cubic feet per second in the case of a reservoir storing 15,000,000,000 cubic feet. As to the reason for fixing upon these minimums, in river regulation the outflow from the storage reservoir should be so arranged as to make the benefit to all parts of the stream equal. Especially is this proposition true when, as in the present case, there is waterpower distributed throughout the whole extent of the stream below the storage point. Obviously the way to do this is to plan for an outflow proportional to the catchment area. In the present case we have a catchment area at Rochester of 2365 square miles, and one of 1000 square miles above Portage, or the area above Rochester is about 2⅓ times the area above Portage. The minimum regulated flow at Rochester may be made 2.365 times the assumed minimum flow at Portage.

In the foregoing, the statement is made that the outflow should be proportional to the catchment area. This is the theoretical view purely, and provided reservoirs can be constructed at equally low cost in all parts of a catchment, it is the preferable principle to follow. But this can seldom be done because reservoirs will vary greatly in cost in different parts of a catchment—they may run all the way from $15 to $20 per million cubic feet stored to from $600 to $1000 per million cubic feet. This practical consideration will modify the theoretical conclusion.

Assuming 680 cubic feet per second as the flow below which the stream will never be allowed to fall at Rochester, we have for a reservoir storing 7,500,000,000 cubic feet a corresponding minimum outflow from the reservoir of 300 cubic feet per second, or for a storage of 15,000,000,000 cubic feet an outflow of 457 cubic feet per second, the latter figure being arrived at by assuming the maintenance of a minimum flow at Rochester of at least 1000 cubic feet per second. The computations of tables Nos. 84 and 85 are carried out on this basis. The regulated flows for the month of May are greater than for the other months. They are also greatest during the months of canal navigation, the addition being made in order to provide for the quantity of water to be taken for the enlarged Erie canal, which quantity has been fixed at 80 cubic feet per second for every month of the navigation season except May, and at 177 cubic feet per second for that month, the excess quantity for the month of May being required in order to provide for filling the canal at the beginning of the month.

Table No. 84 shows the effect on the flow of Genesee river from June, 1894, to November, 1896, inclusive, as influenced by the storage at Portage of 15,000,000,000 cubic feet of water, provided at least 457 cubic feet per second is allowed to flow continually at Portage and at least 1000 cubic feet per second is always flowing at Rochester in addition to the amount required for canal purposes. The figures given in column (2) show the proposed minimum flow at Rochester, this being the 1000 cubic feet per second noted above, together with 80 cubic feet per second for the canal for the months from June to November, inclusive, and 177 cubic feet per second for the month of May. Columns (3) and (4) give the discharges at Rochester and Portage under natural conditions. Column (5) gives the difference between these, or the quantity of water entering the river below Portage. Column (6) gives the amount which goes to the canal while column (7) gives the ratio of amount to canal to actual flow. Column (8) gives the minimum amount to be added at Portage in order to maintain the proposed minimum flow at Rochester of 1000 cubic feet per second, not including the amount taken by the canal. The quantity available at Rochester for power purposes is shown in column (9). The actual outflow from the Portage reservoir is given in column (10) in cubic feet per second, while column (12) gives the same thing in inches on the catchment area. Column (11) gives the surplus flowing over the spillway at the Portage reservoir.

Table No. 85 exhibits the condition of the reservoir from month to month under the above conditions. The figures are given not in cubic content but in equivalent depth in inches on the total tributary catchment of 1000 square miles. The reservoir is assumed to be full at the beginning of June 1894, the total storage of the reservoir being equivalent to 6.46 inches in depth on the catchment area. The total waste from June 1, 1894, to December 1, 1896, equals, under the conditions of this table, 2.11 inches on the catchment.

Similar tables have been computed showing the regulation of the river as affected by the storage at Portage of 7,500,000,000 cubic feet of water for the same period, with at least 300 cubic feet per second always flowing at Portage, and at least 600 cubic feet per second at Rochester, in addition to the amount required for the canal. The chief difference between these two tables is in the amount of water utilized. In the case of a reservoir of 15,000,000,000 cubic feet capacity, during only three months of

TABLE No. 84—REGULATION OF GENESEE RIVER BY STORAGE AT PORTAGE

[With storage of 15,000,000,000 cubic feet at Portage and flow of at least 1000 cubic feet per second at Rochester]

MONTH	Proposed minimum flow to be maintained at Rochester — cubic feet per second	Natural flow at Rochester — cubic feet per second	Natural flow at Portage — cubic feet per second	Flow at Rochester less flow at Portage — cubic feet per second	Amount to canal — cubic feet per second	Ratio of amount to canal to actual flow $=\frac{(6)}{(5)}$	Minimum amount to be added at Portage in order to maintain 1,000 cubic feet per second at Rochester — cubic feet per second	Quantity available at Rochester for power purposes — cubic feet per second = (5) + (10) + (11) − (6)	Actual outflow from Portage reservoir — cubic feet per second	Surplus flowing over spillway at Portage reservoir — cubic feet per second	Column (10) in inches on the catchment
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1894											
June	1,080	2,321	981	1,340	80	0.035	....	1,717	457	521	0.51
July	1,080	292	123	169	80	0.274	911	1,000	911	....	1.05
August	1,080	442	187	255	80	0.181	825	1,000	825	....	0.95
September	1,080	1,963	830	1,133	80	0.041	....	1,500	457	....	0.51
October	1,080	899	380	519	80	0.089	561	1,000	561	....	0.65
November	1,080	1,729	731	998	80	0.046	82	1,375	457	....	0.51
December	1,000	1,256	531	725	......	....	275	1,181	457	....	0.53
1895											
January	1,000	1,335	565	770	......	....	230	1,227	457	....	0.53
February	1,000	495	209	286	......	....	714	1,000	714	....	0.74
March	1,000	3,985	1,684	2,301	......	....	....	2,758	457	....	0.53
April	1,000	4,257	1,800	2,457	......	....	....	3,972	457	1,058	0.51
May	1,177	385	163	222	177	0.460	955	1,000	955	....	1.10
June	1,080	283	120	163	80	0.283	917	1,000	917	....	1.02
July	1,080	232	98	134	80	0.345	946	1,000	946	....	1.09
August	1,080	254	108	146	80	0.315	934	1,000	934	....	1.08
September	1,080	221	93	128	80	0.362	952	1,000	952	....	1.04
October	1,080	230	97	133	80	0.348	947	1,000	947	....	1.09
November	1,080	993	420	573	80	0.081	507	1,000	507	....	0.56
December	1,000	2,710	1,146	1,564	......	....	....	2,021	457	....	0.53
1896											
January	1,000	964	408	556	......	....	444	1,013	457	....	0.53
February	1,000	2,005	848	1,157	......	....	....	1,614	457	....	0.49
March	1,000	6,158	2,604	3,554	......	....	....	4,011	457	....	0.53
April	1,000	7,172	3,033	4,139	......	....	....	4,946	457	350	0.51
May	1,177	347	147	200	177	0.513	977	1,000	977	....	1.13
June	1,080	654	277	377	80	0.122	703	1,000	703	....	0.78
July	1,080	501	211	290	80	0.159	790	1,000	790	....	0.92
August	1,080	416	176	240	80	0.192	840	1,000	840	....	0.97
September	1,080	327	138	189	80	0.245	891	1,000	891	....	0.99
October	1,080	3,667	1,556	2,111	80	0.021	....	2,488	457	....	0.53
November	1,080	1,728	731	997	80	0.046	83	1,454	457	....	0.51

TABLE NO. 85—FLOW INTO AND FROM PORTAGE RESERVOIR UNDER THE CONDITIONS ASSUMED

(In inches on the catchment)

MONTH	Runoff—inflow to reservoir	OUTGO FROM RESERVOIR			Excess	Deficiency	Amount in reservoir at end of month	Wasted	Remarks
		Evaporation	Amount to stream	Total outgo sum of (3) and (4)					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1894									
June	1.10	0.05	0.51	0.56	0.54	....	6.46	0.54	Reservoir full at beginning and end of June (6.46 inches = total storage, reservoir full)
July	0.14	0.06	1.05	1.11	......	0.97	5.49	......	
August	0.22	0.07	0.95	1.02	......	0.80	4.69	......	
September	0.93	0.04	0.51	0.55	0.38	....	5.07	......	
October	0.44	0.03	0.65	0.68	......	0.24	4.83	......	
November	0.82	0.02	0.51	0.53	0.29	....	5.12	......	
December	0.61	0.01	0.53	0.54	0.07	....	5.19	......	
1895									
January	0.66	0.01	0.53	0.54	0.12	....	5.31	......	
February	0.22	0.01	0.74	0.75	......	0.53	4.78	......	
March	1.94	0.02	0.53	0.55	1.39	....	6.17	......	
April	2.01	0.03	0.51	0.54	1.47	....	6.46	1.18	
May	0.19	0.06	1.10	1.16	......	0.97	5.49	......	
June	0.13	0.06	1.02	1.08	......	0.95	4.54	......	
July	0.11	0.05	1.09	1.14	......	1.03	3.51	......	
August	0.12	0.04	1.08	1.12	......	1.00	2.51	......	
September	0.10	0.03	1.04	1.07	......	0.97	1.54	......	
October	0.11	0.02	1.09	1.11	......	1.00	0.54	......	
November	0.47	0.01	0.56	0.57	......	0.10	0.44	......	
December	1.32	0.01	0.53	0.54	0.78	....	1.22	......	
1896									
January	0.47	0.01	0.53	0.54	......	0.07	1.15	......	
February	0.91	0.01	0.49	0.50	0.41	....	1.56	......	
March	3.00	0.02	0.53	0.55	2.45	....	4.01	......	
April	3.38	0.03	0.51	0.54	2.84	....	6.46	0.39	
May	0.17	0.05	1.13	1.18	......	1.01	5.45	......	
June	0.39	0.05	0.78	0.83	......	0.44	5.01	......	
July	0.24	0.06	0.92	0.98	......	0.74	4.27	......	
August	0.20	0.05	0.97	1.02	......	0.82	3 45	......	
September	0.16	0.03	0.99	1.02	......	0.86	2.59	......	Total waste from June 1, 1894, to December 1, 1896, equals 2.11 inches
October	1.74	0.02	0.53	0.55	1.19	....	3.78	......	
November	0.82	0.02	0.51	0.53	0.29	....	4.07	......	

the period from June, 1894, to November, 1896, inclusive, would there be any water wasted from the reservoir, the total for this period being 2.11 inches. In June, 1894, 521 cubic feet per second; in April, 1895, 1058 cubic feet per second, and in April, 1896, 350 cubic feet per second. In no case would there be at Rochester less than 1000 cubic feet per second.

In the case of a reservoir of 7,500,000,000 cubic feet capacity, there would have been wasted a total of 9.36 inches on the catchment during the same period. In June, 1894, 645 cubic feet per second; in November, 1894, 287 cubic feet per second; in December, 1894, 216 cubic feet per second; in January, 1895, 260 cubic feet per second; in March, 1895, 1266 cubic feet per second; in April, 1895, 1440 cubic feet per second; in March, 1896, 1145 cubic feet per second; in April, 1896, 2716 cubic feet per second, and in November, 1896, 269 cubic feet per second. The amount flowing at Rochester would not have been less than 600 cubic feet per second.

Moreover had the enlarged canal been in operation in July, 1894, and taking the estimated quantity of 80 cubic feet of water per second from Genesee river, the amount of water going to the canal would have been 27.4 per cent of the total flow of the river for that month; in August, 18.1 per cent; in May, 1895, 46 per cent; in June, 28.3 per cent; in July, 34.5 per cent; in August, 31.5 per cent; in September, 36.2 per cent, and in October, 34.8 per cent. In May, 1896, the canal would have taken 51.3 per cent of the total flow of the river for that month; in June, 12.2 per cent; in July, 15.9 per cent; in August, 19.2 per cent, and in September, 24.5 per cent. It appears, therefore, that the taking of 80 cubic feet per second from the Genesee river for canal purposes is a very serious matter to the waterpower of the stream and is unjustifiable, unless it be clearly shown that the addition to the wealth of the State is greater than if the water were used for supplying power. The actual damage resulting from taking at times 50 per cent of the unregulated flow of the stream is about as follows: As shown on a previous page, the minimum flow of the river is capable of producing 6727 gross horsepower, or, what is the same thing, assuming 75 per cent efficiency, 5046 net horsepower. One half of the low-water power may therefore be taken at 2523 net horsepower.

So long as the possibility exists of a draft upon the river equal to one-half of its minimum flow, this 2523 net horsepower is practically rendered useless to its owners by reason of the uncertainty as to the exact time of the draft, or if not rendered useless, is far less valuable than if it were absolutely permanent power. In enforcing this view it may be pointed out that Rochester is a manufacturing town, made up chiefly of establishments using comparatively small quantities of power at each place, but that the power must still be continuous every day; that is to say, it must be permanent power. So long, therefore, as one-half the total minimum power of the stream is subject to stoppage during any month, the manufacturers will preferably use steam power, on account of its permanency, even at considerably greater expense. Bearing on this view it may be pointed out that the use of soft coal in Rochester for steam purposes is fully 500,000 tons a year, which, at an average price of $2.40 per ton, amounts to the sum of $1,200,000 annually. It may be considered settled, therefore, that waterpower is valuable at Rochester, and that anything which tends to reduce the permanent power 50 per cent is a serious matter to the manufacturers of the city.[1]

Comparison of Mount Morris and Portage sites. As a further point in the discussion of Genesee river storage, comparison will be made between the Mount Morris project, storing 7,370,000,000 cubic feet at a cost in 1904 of about $3,500,000, and the Portage project storing 15,000,000,000 cubic feet, at an estimated cost in 1904, of $3,250,000, for the purpose of determining the relative commercial advantages.

With the reservoir at Mount Morris storing 7,370,000,000 cubic feet there is 282 feet fall, on which 7,370,000,000 cubic feet, less the quantity required for the canal, may be applied for power purposes. As already explained, the constant outflow from the reservoir would never be less than 300 cubic feet a second. Continuous power development under this plan would, therefore, be based on 300 cubic feet a second at Mount Morris, something more than this at Geneseo and York, and on 600 cubic feet a second at Rochester. On this basis of computation it appears that the total

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[1] The new project for a barge canal does not contemplate taking water from the Genesee river. This part of the argument is however allowed to stand as an illustration of conditions existing in the State of New York.

permanent, continuous power to be realized from a reservoir storing 7,370,000,000 cubic feet and located in the Mount Morris gorge would be 18,327 gross horsepower.

In regard to the increase in waterpower, the effective value of the storage will be the amount of permanent power above the low-water power of the stream. As already stated, the total permanent power for the unregulated stream is 6727 gross horsepower. The gain due to the storage is, therefore, 11,600 gross horsepower. Assuming a price of $10 per gross horsepower, we reach an annual return from the increased power of $116,000; but the Mount Morris reservoir is estimated in 1904 to cost $3,500,000, although ten years ago it was estimated at $2,785,000. Using the figure of the estimate of ten years ago, and assuming the project carried out by a private company with money at 5 per cent, the annual interest on the investment is $139,250—a sum $23,250 in excess of the probable annual income when all the power created shall have been brought into use; but there should be a sinking,

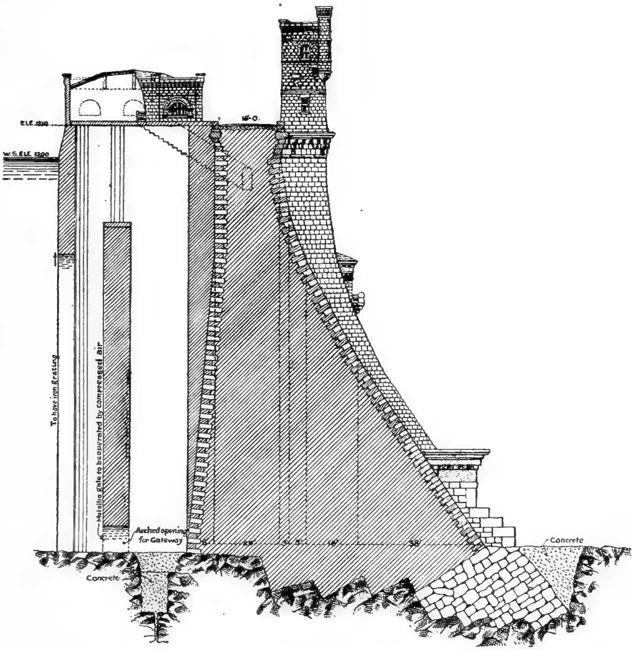


Fig. 40 Section of dam and gate-house as proposed for Genesee river at Portage.

maintenance and repair fund of at least $25,000 a year in order to repay the principal investment, which if taken into account increases the probable deficiency to $48,250 a year. It must be concluded, therefore, that with the present understanding as to the minimum runoff of the Genesee river the project of a storage reservoir in Mount Morris canyon, storing approximately 7,370,000,000 cubic feet of water at a cost of $2,785,000, is commercially impracticable, while at the estimated cost in 1904 of $3,500,000 it is even more impracticable.

If we consider the Portage project in its financial aspects, where it is proposed to construct a reservoir storing 15,000,000,000 cubic feet of water at a cost in 1904 of $3,250,000, we reach the following results:

The total fall from just above the upper fall at Portage to the mean level of Lake Ontario is 833 feet, of which the greater portion is available for the development of waterpower. Without going into detail, we may place the permanent, continuous gross horsepower of the river, with a storage of 15,000,000,000 cubic feet at Portage, at the following figures:

	Gross horsepower
Portage to Mount Morris	25,924
Mount Morris	835
Geneseo and York	624
Rochester	29,840
Total	57,223

Deducting from 57,223 gross horsepower the present permanent power of 6727 gross horsepower, we have 50,496 gross horsepower as the net increase in the permanent waterpower of the stream due to the construction of the Portage reservoir. At $10 per gross horsepower, as before, the annual income when the power is utilized amounts to $504,960. The estimated cost of producing this vast increase in power is $3,250,000 in 1904. Assuming an interest rate of five per cent, the annual interest is $172,500; adding to that amount $25,000 for sinking fund, maintenance and repairs, the total annual expense becomes $197,500. The difference of $307,460 is the net annual income.

As already shown, when interest is taken into account, the Mount Morris project becomes commercially impracticable. The Portage project, on the other hand, shows an annual income, above interest account, sinking fund, maintenance and repairs, of $307,460, which, capitalized at 5 per cent, represents $6,149,200. If we assume 4 per cent, the capitalization of the annual income may be expected ultimately to represent $7,686,500.

Summary of Genesee river storage. The following summation of the Genesee river storage projects is presented as embodying the main points involved.

1) Of the several available sites for reservoirs on Genesee river that at Portage is preferable to others, because it affords the largest storage at the smallest cost per unit volume.

2) Serious floods have occurred a number of times in the Genesee river at Rochester, the most serious being that of March 1865. The floods in April 1896 and March 1902 were nearly as severe as the flood of March 1865, although, as the river channel was clear, very little damage ensued.

3) As the result of three years' measurements of Genesee river, it is determined that the minimum flow of the stream may for the entire year be as low as 6.67 inches on the catchment area. Since 1896 the record of the flow of the stream has been extended without altering the conclusions of this paragraph.

4) A study of existing conditions shows that the Genesee river catchment area has been nearly denuded of forests, and hence that severe spring floods are likely to be frequent. For the same reason the summer flow of the stream is less than formerly.

5) As a tentative conclusion, based on the data at hand, it may be said that the deforestation of a catchment area may tend not only to increase floods somewhat, but to decrease materially the amount of the annual runoff.

6) A comparison of the conditions existing on the catchment area of the Genesee river with those of the upper Hudson, which is still largely in forest, shows less runoff under given conditions from the Genesee than from the Hudson, thus indicating the probable effect of the forest in increasing the runoff. The comparative diagram shown in fig. 11 is pertinent as illustrating this point.

7) As regards the upper Genesee catchment area, the forest has been removed by landowners who have commercially profited by such removal; the effect, however, has been to injure permanently every riparian owner on the stream; hence it is proper that the State should spend money either in partially reforesting the area or in constructing river regulation works. The latter is preferable, because the benefits can be realized in a few years. If the State does not desire to construct such works, there should be no obstacles interposed to their construction by a private company.

8) The proposed Portage reservoir will impound 15,000,000,000 cubic feet of water at an estimated cost in 1904 of $3,250,000, or at a cost of $216.67 per million cubic feet stored. It will afford a permanent, continuous power above the present low-water flow of the stream of 50,496 gross horsepower, while the reservoir at Mount Morris will afford only 11,600 horsepower above the present low-water power of the stream.

9) Based on manufacturers' ratings, the present total developed water power of Genesee river from Portage to Rochester, inclusive, is 19,178 net horsepower; or, basing the amount of water power on the manufacturers' ratings of water required, and assuming 75 per cent efficiency on the wheels, the total power is 17,248 net horsepower, of which about 16,650 net horsepower is within the limits of the city of Rochester. These figures apply to conditions as existing in 1897.

Early History

Erie canal in its relations to Genesee river. In order to show why the State was originally asked to build a storage reservoir on Genesee river for the benefit of private parties, the following from the early history of the Erie canal in its relations to the Genesee river is given:

The first mention of the Genesee river as a source of water supply for Erie canal is in the report of James Geddes, who was employed by Simeon DeWitt, the then Surveyor General of this State, to make the first examinations for the Erie canal. His report, which was submitted on January 20, 1809, may be found in the official history of the New York State canals (1825) page 13 and following.

Plate 12.

Upper and middle falls of the Genesee river at Portage.

Further mention of the Genesee river as a possible source of water supply of the Erie canal is given in a letter written by Mr Geddes to William Darby, under date of February 22, 1822, which may also be found in the official history of the State canals. Without giving these interesting historical documents in detail, it may be stated that Mr Geddes considered the Genesee river as an exceedingly important feeder of the Erie canal. We shall see, however, as we proceed how very materially this view was modified as more information was gained as to the dry weather flow, not only in the Genesee river, but in the other streams in western New York, until finally it became the settled policy of the canal authorities to derive water supplies from the lakes rather than from rivers. The effect of this settled policy upon the present project for storage of the water of the Genesee river will also appear as we proceed.

In order to exhibit the history of the Genesee feeder clearly, it will be necessary also to consider to some extent the general history of the New York State canals, and accordingly certain facts which are not set forth on a later page are given here.

In 1810 a concurrent resolution was adopted, appointing Gouverneur Morris, Stephen Van Rensselaer, DeWitt Clinton, Simeon DeWitt, William North, Thomas Eddy and Peter B. Porter commissioners for exploring the whole route of the Erie canal, etc. Chapter 193, section 43, laws of 1810, appropriated $3000 for the use of this commission. The commissioners reported under date of March 2, 1811.

They discussed questions relating to the Erie canal broadly and specially at considerable length the future water supply. The following extract from their report will show the conclusions to which their studies had brought them, and indicates they did not favor placing any special dependence upon a permanent supply to the canal from the rivers.

We shall see as we proceed that the principles announced in their report of 1811 were so far as possible followed in designing the permanent water supply of the Erie canal.

The following is from the commissioners' report:

In the construction of canals, when recourse is had (as must generally be the case) to rivers for a supply of water, it is found necessary to guard with scrupulous care, and, not unfrequently, at enormous expense, against those floods, which, pouring a torrent into a canal, and tearing down its banks, might at once destroy the navigation and inundate the country.

Moreover, it is found that canals depending on rivers, frequently, like the rivers themselves, want water in the season when it is necessary. Indeed, to suppose the water in a river, when turned into a canal, will remain the same, would lead to serious disappointment.

Much must be allowed for evaporation, and, notwithstanding the utmost care, more will filter through the sides and bottom of a canal than those of a river, which are generally saturated.

Thus, then, two prominent evils present themselves in feeding from rivers, viz., in spring, they pour in too much water, and can afford none in autumn, when it is most needed. There is still another evil, which though not so imminent, becomes eventually of serious moment.

When the country shall be cultivated, streams swollen by showers will bring down mixed with their waters a proportion of mud, and that, in the stillness of a level canal, will subside, and choke it up. It is also to be noted by those who shall construct canals in this country, that the true character of a river cannot now be known. Large tracts (for instance, west of the Genesee), which appear as swamps, and through which causeways of logs are laid for roads, will become dry fields, when no longer shaded (as at present) by forests impervious to the sun.

In the progress of industry, swamps (the present reservoirs of permanent springs that burst out on a lower surface) will be drained, whereby many of those springs will be dried. Of such as remain, a part will be used to irrigate inclined planes.

Moreover in every place tolerably convenient ponds will be collected for mills and other machinery, from whose surface, as well as from that of the soil, the sun will exhale an ample tribute of vapor.

Thus the summer supply of rivers will be in part destroyed, and in part consumed, whereby their present autumnal penury must be further enhanced. But in the spring, the careful husbandman and miller will open every ditch and sluice to get rid of that water, which though at other times a kind friend and faithful servant, is then a dangerous enemy and imperious master.

Of course, much of what is now withheld for many days, will then be suddenly poured out. The torrents must therefore rage with greater fury hereafter than they do in the present day.

Considerations like these, while they cast a shade over many contemplated enterprises, give by contrast a glowing hue to that which we now have to consider. The canal, from Lake Erie to the Hudson, may be fed by pure water from lakes, provided mounds and aqueducts be made over intervening valleys, or the canal be carried around them. In every case the attending circumstances must decide.

In June 1812, an act was passed authorizing the Canal Commissioners to borrow five million dollars in order to provide for the improvement of the internal navigation of the State.

The war of 1812 led to the suspension of the work, but in 1816 the project was revived; the act of 1812 was repealed and a new act passed appropriating twenty thousand dollars for additional surveys.

In the report of the Commissioners, 1817, under the last act referred to, in speaking of the proposed route across the Genesee river, they say:

> Pursuing this route the canal never rises above the Lake Erie level. It would, therefore, derive its waters, till it descends to the Genesee level, and as much farther as may be necessary, from that never failing reservoir (Lake Erie).

Finally, on April 15, 1817, an act was passed which actually led to the construction of the canal and which provides in detail the method of procedure.

In 1819, the canal having been partially constructed in the eastern part of the State, active operations were begun in the western part. During that year the Genesee river feeder was surveyed by Thomas Hutchinson, an engineer in the employ of the State. In 1820, in a communication from the Canal Commissioners to the Canal Committee of the Assembly, it is stated that:

> Whenever in its progress from Seneca river west, the canal reaches the Genesee river, that stream will afford an additional navigation connected with it, for a distance of nearly forty miles; that is, by making sixty-three miles of canal at about half the expense per mile at which the eastern section is estimated, the State will have the benefit of one hundred miles of interior navigation through a country, at least as populous and productive as any other of equal extent in the State. The surplus productions of Ontario county alone have been reckoned as high in some seasons as six hundred thousand dollars.

The preceding quotation is exceedingly important as indicating why the Genesee feeder was maintained after the canal had been completed to Lake Erie, and a permanent supply of water obtained from that source.

During the year 1820 contracts for the construction of the canal immediately east and west of Rochester were let.

In their report to the Legislature, under date of March 12, 1821, the Canal Commissioners discussed the practicability of two proposed routes for the canal from Rochester west, the northern of which would be below the level of Lake Erie, while the southern would rise above that level. The conclusion arrived at was that if the southern location were adopted there would probably be at times a serious shortage of water, in view of which, and other considerations, the Commissioners decided to adopt the present route from Lake Erie east, which does not at any point rise above the level of that lake, and which therefore admits of feeding the entire canal from that source. The Commissioners say:

> Having adopted that route for the canal, which, at every departure from the level of Lake Erie, in its progress eastward, will descend, till it reaches the Seneca river, we entertain no doubt of an abundant and permanent supply of water for every part of the canal. But, in order to provide against any possibility of danger on this subject, it is intended to construct the canal through the dry region between the locks at the mountain ridge and the Genesee river, with a descent towards the east of one or two inches in every mile; the necessary effect of which will be to save the expense of at least one lock, and to induce a current of so much water from Lake Erie towards the east as will leave but little to be required from the Genesee river; and this little may be still reduced, and if it shall ever become expedient, by a feeder from the Irondequoit creek, a copious and equable stream, which it was formerly supposed could not be drawn upon for the canal, but which, by the enterprising zeal of David S. Bates, Esq., one of our resident engineers, has been found capable of being taken into it at Pittsford, near the west end of the level, about thirteen miles in length. From this level eastward, there might be obtained a sufficient supply of water from the Canandaigua lake, Mud creek and several other sources, for all the demands of the canal if the Genesee river were annihilated.

From the Commissioners' report, submitted February 27, 1822, it is learned that contracts were signed for opening a feeder from the Genesee river into Erie canal, June 6, 1821. The Commissioners complete their report by stating that after this feeder is completed, which will probably be in May, 1822, it is expected that with a little additional expense, a good navigation forty miles up the river will be available, in connection with the Erie canal.

The canal was opened to Rochester in July, 1822, and the problem then was to obtain a sufficient supply of water from the Genesee river west until Lake Erie could be reached and its waters drawn upon.

On the 26th day of October, 1825, water having been turned into the canal from the harbor at Black Rock the first boat ascended the locks at Lockport and passed through the deep cut at the mountain ridge and on to Lake Erie. In their report, submitted to the Legislature, on March 25, 1826, the Canal Commissioners say:

> The first admission of a full head of water upon the dam and pier at Black Rock, and into the canal from Buffalo to Lockport, put to the test of actual experiment the strength and solidity of the works, the accuracy of the levels, and the practicability of carrying through the mountain ridge a supply of water, which would be adequate to the wants of the canal, during the dry season. The result of this experiment was entirely satisfactory.
>
> On the removal of the temporary dam which had been thrown across the narrowest part of the Black Rock basin, the water rose within a few inches of the level of the lake, and flowing into the canal below, gave a depth throughout its whole extent to Lockport, of from five and a half to six feet above the bottom line of the canal as originally located by David Thomas.
>
> This volume of water drawn eastward by the declivity in the canal, of one inch in a mile, will be sufficient to supply the Rochester level, and probably the canal as far eastward as the Cayuga marshes, without any aid from the Genesee river.

The event marked the completion of the original Erie canal, and further marked, in the opinion of the Canal Commissioners, the end of the use of the Genesee river as a source of water supply for the canal.

We are now able to discern the real reasons for constructing the Genesee river feeder. As the result of long and exhaustive examinations the Canal Commissioners adopted the settled policy of not depending upon the waters of the intersecting streams in the western part of the State, but on the contrary considered (and the judgment of the present day justifies them in their conclusions) that it was far safer to depend upon the unfailing supply which could be derived from Lake Erie without, as stated in their reports, " any injury to anybody."

It is clear, that the Genesee river was an important temporary source of supply during the period from 1822 to 1825, before Lake Erie was reached. Although it is evident, when one examines the documentary evidence in detail, that even during those years the canal could have been fully supplied without resort to the Genesee river. The question arises then, why, if the Canal Commissioners considered the use of the river as a feeder at an end in 1825, they did not close the channel which had been constructed from the canal to the Genesee river in order to take its waters. A decided answer to this question is found in the documents already cited, from which it appears that the one main object of constructing a canal feeder at Rochester was to open up a communication between the river and the canal, thereby extending, as we have seen the benefits of the State's system of internal navigation to a large and fertile region. The reasons, therefore, why the Genesee feeder was originally constructed were

1) In order to furnish a temporary supply to the canal during the years 1823–24 and 1825, while the canal was being constructed from Rochester west to Lake Erie; and

2) In order to connect the canal system with navigation on the upper Genesee river.

On an examination of the legislative journals for the years 1823 to 1828 we find a number of petitions from citizens of the Genesee valley praying the legislature to improve the navigation of the Genesee river to the south of Rochester.

It has been generally assumed that the Genesee river was declared a public highway in order that the State might more thoroughly control its waters for canal purposes. The real object was merely to make the Genesee river a part of the internal navigation system of the State. Such declaration did not in any degree give to the State the right to divert the water of the stream into an independent channel like the Erie canal.

In the foregoing discussion it has been shown why the Genesee feeder was originally constructed and why after the completion of the canal it was still maintained as a part of the canal system for the purpose of assisting internal navigation purely. We will now proceed to show how this state of fact has been in later years made the basis of what amounts to a claim of the right to take the entire flow of the Genesee river for canal purposes without compensation to the riparian owners as well as without due process of law.

In the years 1824-26 it appears from the records in the Canal Appraisers' office that a large number of awards were made to different parties at the then village of Rochester and vicinity for damages sustained in consequence of the construction and opening of the Erie canal.

The memorial of Jonathan Childs, George Ketchum and Richard Gorsline, which was presented to the Appraisers with their bills for damages, sets forth that their claim is specifically for damages during the years 1823, 1824 and 1825.

They say:

> If we thought the evil of which we complain would be perpetual we should ask to be amply remunerated for the cost or value of our whole sawmill establishments, but we hope for a better state of things in relation to the extensive hydraulic works upon the Genesee river at Rochester, and we therefore, at present, only ask that these certain, specific and reasonable profits of our business of which we have been deprived by the act of the State, and which are set forth in our accounts, be paid to us.

The accounts rendered to the Board of Appraisers by these gentlemen give in detail the damages which they sustained during the years indicated. Richard Gorsline, in his bill states that he has been damaged in 1824, by reason of no business done for want of water, 42 days; in 1825, 92 days.

Childs & Ketchum also furnish a statement in detail, of the damage to their mill by reason of standing still for lack of water at the same time.

From a study of the documents in detail it appears clear that Richard Gorsline and Childs & Ketchum had good reason to believe that the diversion of the waters of the Genesee river for the use of the Erie canal was at an end in 1825. In consequence of that belief they only made out a bill for specific temporary damages sustained during the years while the Genesee river water was used as the sole or nearly sole source of supply, which was during 1822 to 1825 before Lake Erie was reached.

On bills rendered as stated in the foregoing, and on the understanding that the awards were for temporary diversion only, the Canal Appraisers, in 1826, awarded damages to the owners of water rights at Rochester, as follows:

Childs & Ketchum	$140 00
Richard Gorsline	247 90
Hervey Ely	700 00
Hervey Ely	1584 79
William Atkinson	1000 00
William Atkinson	1241 65
E. Peck	382 00
A. & S. Carpenter	717 84
H. N. & A. B. Curtis	1318 62
Williams & Whitney	275 00
E. S. Beach	1332 16
E. Johnson and heirs of O. Seymour	300 00
E. Johnson	500 00
Thos. H. Rochester Co	1106 08
Buck & Lockwood	309 45
E. Gilbert	140 00
Amount	$12,049 66

So far as can be learned from the available records the foregoing sum of $12,049.66 includes all that has ever been paid to the owners of the hydraulic privileges at Rochester on account of diversion of the waters of the Genesee river for the use of the Erie canal.

The foregoing list includes a list of the original proprietors of the Rochester water power and in use at the time of the original construction.

The matter of payment for temporary damage at Rochester was a source of controversy from 1826 to 1852, in which year Jacob Graves and others, occupants of water power on the Genesee river at Rochester, filed a memorial with the Legislature setting forth their grievance. March 23, 1852, a select committee of the Assembly reported in favor of a relief act, and accordingly chapter 644 of the laws of 1853 authorized the Canal Appraisers to examine and report upon the claims of Jacob Graves and others on account of diversion of water from Genesee river. In February, 1854, the Canal Appraisers presented to the Legislature their report upon the claims of Jacob Graves and others, as authorized by chapter 644 of the laws of 1853. A majority report was presented by Messrs. D. A. Ogden and A. H. Calhoun and a minority report by William J. Cornwell, these gentlemen constituting the Board of Canal Appraisers of that day. The majority report denies the petition for the following reasons:

1) The State in 1822 took possession of and acquired the right and title to so much of the waters of Genesee river as was then and will in all time to come be necessary to keep the Erie canal in navigable condition, reference being always had to the supply from Lake Erie and other permanent sources, and by no subsequent act has the State abandoned or parted with the title thus acquired.

2) The owners and occupants of water rights having failed to prosecute their claims for permanent injury under the act of 1817, or other acts subsequently passed, have no remedy but through the Legislature.

3) There are equable considerations which commend most of the claimants to your favorable consideration.

Mr Cornwell differed in his minority report from some of the conclusions of his associates.

The Genesee River Company

The Legislature authorized the construction of a reservoir at Portageville in 1898. The following facts are given in regard to the company authorized, which was to be known as the Genesee River Company. It was organized to develop the water power of Genesee river to its fullest extent.

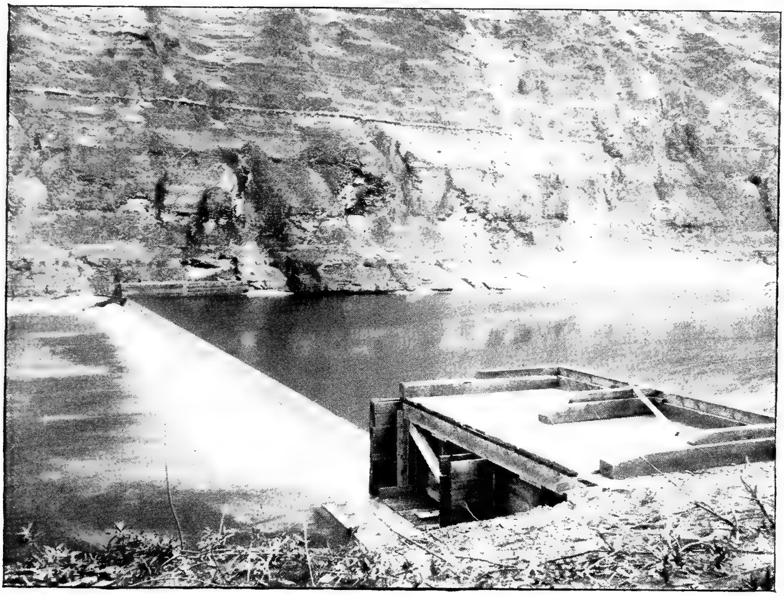
For the purpose of developing the water power, it was proposed to construct a large storage reservoir at Portageville, fifty-seven miles south of Rochester, with a capacity of 15,000,000,000 cubic feet. Such a reservoir will make a lake fifteen miles long, from half a mile to one mile wide and with an average depth of sixty feet. As shown by tables Nos. 84 and 85, it would control the entire flow of the river above Portageville, where the catchment area is 1000 square miles. Detailed statements as to the rainfall and water yield of Genesee river catchment may be found in the writer's report on Genesee river storage in the Report of the State Engineer and Surveyor for 1896, as well as in the preceding pages.

Genesee river waterpower. The waterpower of Genesee river is nearly all concentrated in six heavy falls. Three of these are within the limits of the city of Rochester and three are at Portage. The total descent from the head of the falls at Portage to the level of Lake Ontario is 833 feet, of which 262 feet are at Rochester and 290 feet at Portage. At Mount Morris the fall is 18 feet; between Mount Morris and the foot of the lower falls at Portage, 210 feet; the balance is in a reach of meandering river between Rochester and Mount Morris where, aside from small powers at Geneseo and York, there are no opportunities for developing power.

The present developed power on the stream is at Rochester, Geneseo, York and Mount Morris; the Genesee canyon and Portage falls are virgin territory, with no power now developed on this reach of the stream. With this storage project carried out, nearly 26,000 gross horsepower may be developed here.

The figures on page 590 show a total of 57,223 gross horsepower on Genesee river from Portage to Rochester. It is believed, however, that the computations for storage have been so conservatively made that it will yield fully 60,000 gross horsepower in the year of lowest flow. The tabulation on page 590 also shows a total at Rochester of 29,840 gross horsepower to be derived from 1000 cubic feet per second flow. This total is based on a utilization of the entire fall of 262 feet. Probably this is impracticable and 28,620 gross horsepower may be taken as the safe figure for a flow of 1000 cubic feet per second. However, the computations of tables Nos. 84 and 85 have been made on the basis of 80 cubic feet per second to the Erie canal, but under the new conditions existing in 1904, with the barge canal authorized and the entire water supply to be taken from Lake Erie, we may consider the

Plate 13.



A. Measuring weir constructed on Genesee river above Mount Morris in 1896.

B. Former timber dam on Genesee river at Mount Morris.

additional 80 cubic feet per second as available for producing power at Rochester. With this understanding there will be produced at Rochester somewhat over 31,000 gross horsepower in the year of minimum flow. For ordinary years there will be produced several thousand horsepower more than this.

Rochester is a manufacturing city of 175,000 inhabitants. The demands for power are large, and notwithstanding full development of the stream in its present state, the use of the stream is increasing from year to year.

Chapter 605 of the laws of 1898 incorporated the Genesee River Company and conferred the necessary powers for carrying out the project in detail.

Plan for acquiring water rights. During the several years of general discussion of this project at Rochester various plans for acquiring the water rights have been formulated. The water rights, as they now stand, are attached to real estate, but it is proposed that the owners deed to the company all interest in water rights, each owner retaining his real estate. The deeds would transfer to the company all power dams and head races which the company on its part would undertake to maintain, delivering water to the several properties at the race-wall, payment for water so delivered to be made to the company at the rate of $10 per year per gross horsepower. It is also proposed to limit the sale of water to present owners at a price of $10 per year per gross horsepower to present necessities—that is to say, to about 18,000 to 20,000 gross horsepower. This will leave about 10,000 to 12,000 gross horsepower to be developed at power stations.

Things to be done in order to place the project on its feet. The first thing to be done is to make a test case as to condemnation of flowage grounds. The act authorizing the Genesee River Company begins with a preamble, wherein it is stated:

> Whereas, It is necessary for the improvement and preservation of the public health, for the checking of floods, for the furnishing of water for the enlarged Erie canal, and for the supplying of pure and wholesome water for municipal purposes, that the land and real property comprised within the flowage limits hereinafter described of the main dam or reservoir to be erected on the Genesee river near the village of Portageville, as hereinafter in this act set forth and provided for, should be taken for

the public uses aforesaid, just compensation being ascertained and made for all private and public property so taken as in this act authorized.

It is also stated that in the judgment of the Legislature, the compensation for lands condemned should not be paid by the State, but should be paid by and through the corporation created by the act.

There is some doubt about the constitutionality of this provision, and the first thing to be done, therefore, is to test its constitutionality. For this purpose a friendly test case should be brought and carried to the court of last resort.

The next thing is to take options on the water rights from Lake Ontario to above the upper falls at Portage. There are about one hundred owners in all, of which about forty are at Rochester. The largest owners are the Rochester Gas & Electric Company at Rochester and William P. Letchworth at Portage.

The act of incorporation provides for condemnation of flowage ground of reservoir, if satisfactory arrangements can not be made with the owners. Before such proceedings can be instituted it will be necessary to have a map of the flowage ground, showing what area is to be taken from each owner. Such a map should be made at once, because many of the owners—probably from one-half to two-thirds of them—can be settled with without litigation. In order to accomplish this the flow line needs to be determined and the area of that portion of all farms extending up the side of the valley above the flow line and which is to be taken into the reservoir carefully computed. This survey will be the basis of the maps required by law to be filed with the county clerk.

The Pennsylvania railway now passes through the middle of the proposed reservoir for a distance of 15 miles. The storage plans include a relocation of this railway, on the west side hill well above the flow line. The increase in manufacturing and growth of population at Rochester and other points in the Genesee valley, which are certain to follow the construction of the Genesee river storage, will naturally incline the railway officials to be favorable to the project, but nevertheless since the negotiation with them is likely to consume considerable time, it should be gotten underway as soon as possible. Indeed, it is necessary that not only should the railway negotiation be closed and the new line placed under construction, but all rights in the flowage ground should be secured before beginning construction of the dam. This is because the plan of construction proposed involves the possible flooding of work while the dam is in process. It is obvious that should such flooding occur before the company had secured the area to be flooded, very heavy damages might accrue. The valley to be flooded is broad and deep, and there might even be loss of life. There is no other way, therefore, than to fully acquire the flowage ground and construct a new line of railway before beginning work on the dam.

With the foregoing several steps taken, the next thing will be to finance the project. Possibly this can be accomplished before acquiring flowage ground of reservoir and right to remove railway, although it is considered that with these several things fully accomplished the financing of the project will take care of itself.

Assuming that the necessary rights have been acquired and the finances arranged, the next step will be to construct the dam and the power stations at Rochester, together with any other special constructions that may be decided on.

Provided the matter be taken up actively and driven along in a businesslike manner, the work can be completed and the company ready to deliver power in from four to six years.

The foregoing statement of things necessary to be done before the Genesee River Company can be placed on its feet indicates that a considerable amount of money must be invested without being absolutely certain that the project will finally be carried out, and on presenting this phase of the matter to capitalists no one has thus far been willing to invest perhaps $300,000 to $400,000 on the chance, although the project is safe enough if one has a full realization of all the benefits to be derived.

Description of the Rochester Water Power

The following gives a brief description of the Rochester water power as it existed in 1900.

The power is developed at four dams. The first, or upper, one of these is known as the Johnson and Seymour dam. It is located in the heart of the city, just above Court street bridge.

There are two head raceways leading therefrom—one on each side of the river—which are entitled to equally draw one-half of the entire flow of the stream. Equal division of the water is accomplished by providing openings of the same size on both sides, with sills set at same elevation. The east raceway is known as the Johnson and Seymour, and that on the west side as the Rochester, Carroll and Fitzhugh raceway. The fall at these two raceways is usually stated at 19 feet, although in extreme low water the fall from water surface in headrace to tail-water in river is about 19.8 feet.

At the brink of the upper falls there is a second dam, which diverts water into Brown's race, on the west side, and into the raceway of the Rochester Power Company (now owned by Rochester Gas & Electric Company) on the east side. Brown's race is entitled to $\frac{79}{85}$ of the entire flow of the river and the Rochester Power Company's race to $\frac{6}{85}$. The fall is 90 to 92 feet.

The third dam is at the middle falls, where the head is 28 feet. The Genesee Paper Company own $\frac{17}{20}$ of the entire flow of the river, and the estate of Charles J. Hayden $\frac{3}{20}$. The Genesee Paper Company's holdings cover one-half of the entire flow to be applied on the east side of the river, and $\frac{7}{20}$ to be applied on west side, or $\frac{17}{20}$ in all, as just stated. The $\frac{3}{20}$ owned by the estate of Charles J. Hayden is to be applied on the west side.

The fourth dam is at the lower falls, where the total head is 96 feet. The Brush Electric Light Company (Rochester Gas & Electric Company) owns the entire flow of the river at this point.

There is also a fifth waterpower between the upper and middle falls, which, however, has never been developed, but which should be acquired as a guarantee against future development by parties other than the Genesee River Company. A power of a few feet head could also be developed below what is known as the feeder dam in the south part of the city.

As developed in 1900 the waterpower of Rochester was divided as follows:

	Feet	Per cent
Fall No. 1—Johnson and Seymour dam..	19.8	8.39
Fall No. 2—Upper fall of Genesee river..	92.2	39.07

	Feet	Per cent
Fall No. 3—Middle fall of Genesee river.	28.0	11.86
Fall No. 4—Lower fall of Genesee river..	96.0	40.68
Total	236.0	100.00

The foregoing total of 236.0 feet head does not include the undeveloped power referred to above.

The Rochester waterpower is subdivided among the raceways as follows:

	Per cent
Johnson and Seymour, ½ flow or river	4.195
Rochester, Carroll and Fitzhugh, ½ flow of river	4.195
Brown's race, 79/85 flow of river	36.312
Rochester Power Company, 6/85 flow of river	2.758
Genesee Paper Company, 17/20 flow of river	10.081
Estate of C. J. Hayden, 3/20 flow of river	1.779
Brush Electric Light Company, entire flow of river	40.680
Total	100.000

Owing to litigations and unsettled rights, there is a slight uncertainty as to exact proportion of flow some of the raceways are entitled to. This, however, is not material so far as present conditions are concerned. Obviously, if the property should all come into the possession of one owner, all questions as to quantity of water due to any particular raceway are eliminated. The Genesee River Company will naturally arrange its business on such a basis as best to supply its clients with water and power.

The selling price of the water rights at the various raceways in 1900 was as follows:

Johnson and Seymour raceway. As stated in the foregoing, the Johnson and Seymour raceway is entitled to ½ the flow of the river. The water rights are divided into 19 first rights and 32½ second, third and fourth rights.

First rights are based upon a flow of 9500 cubic feet per minute in the raceway. All share equally until the flow is reduced to this figure, when the 19 first rights take it, all sharing equally.

The value of the water rights on this raceway have been fixed in effect by a court decree, whereby first rights are valued at

$3000, second rights at $1800, third rights at $1100 and fourth rights at $1000. The total value of the water rights on this raceway becomes, therefore, $103,350.

Rochester, Carroll and Fitzhugh raceway. This raceway is also entitled to $\frac{1}{2}$ of the entire flow of the river. The water rights are divided into 76 first rights, which have been valued at about $1000. The last sale was in 1876, when the city of Rochester paid $1500 apiece for two rights which it owns on this raceway. Assuming the same average value for this raceway as the decreed value on the Johnson and Seymour raceway and the price per water right becomes $1360, or $103,360 for the whole.

Brown's raceway. This raceway is on the west side of the Genesee river, receiving its water supply from the dam just above the upper falls. Under the terms of certain partition deeds and court decisions Brown's race is entitled to receive $\frac{79}{85}$ of the entire flow of the river. The water rights are divided into 79 first rights. A water right on this raceway is therefore $\frac{1}{85}$ of the flow of the river. There have been a number of transfers of water rights on this raceway, the selling price ranging from $3000 to $4000 per right. In 1873 the city of Rochester paid $16,500 for three water rights and a mill lot on this raceway. The lot is 50 feet front, and may be valued at that time at $4500, leaving $4000 as the value per water right. Since 1873 one or two water rights on this raceway are stated to have been sold at from $3000 to $3500, but at the present time, so far as known, they are all held at $4000 per right, or more. Even at this price they are proportionately much cheaper than water rights on the Johnson and Seymour or Rochester, Carroll and Fitzhugh raceways. To prove this we will consider that 1081 gross horsepower on Johnson and Seymour raceway is valued, according to a court decision, at $103,350, or at $95.60 per gross horsepower. (This price assumes 1000 cubic feet per second in the river.) On Brown's race, where a water right may be taken at $\frac{1}{85}$ of 1000 cubic feet per second on 92 feet fall, the power of a water right amounts to 121.6 gross horsepower. At the price of $4000 per water right, the price per gross horsepower—on the basis of 1000 cubic feet per second in the river—becomes therefore $32.89.[1] If we compute the price per gross horsepower on

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[1] $\frac{1}{85}$ of 1,000 cubic feet per second equals 11.765 cubic feet per second, which is the amount of water each right is entitled to when there are 1,000 cubic feet per second in the river.

the basis of $3000 per water right, and further assume that the extreme low-water flow is 200 cubic feet per second, the value for permanent power becomes $120.35, while at $4000 per water right it becomes $164.45 per gross horsepower.

At the present time water rights on Brown's race are about as valuable for business purposes as those on the Johnson and Seymour and Rochester, Carroll and Fitzhugh raceways. Hence, at $4000 per water right, Brown's race is cheap waterpower even under present adverse conditions of low summer flow of at times only about 200 cubic feet per second or even less.

Rochester Power Company's raceway. This raceway is on east side of Genesee river, at upper falls. It is entitled to $\frac{6}{85}$ of the entire flow of the river, being the balance of the flow not taken into Brown's race. This power is now owned by the Rochester Gas & Electric Company, having been purchased by that company a few years ago. The purchase price is not known. On the same basis as on Brown's race, the waterpower would be worth $18,000. As a matter of fact, however, it is probably now valued much higher than this.

The Genesee Paper Company and estate of Chas. J. Hayden. This waterpower comprises the entire flow of the Genesee river at the middle falls, where the head is 28 feet. The Genesee Paper Company owns $\frac{17}{20}$ of the entire flow of river and the estate of Charles J. Hayden, $\frac{3}{20}$. With 1000 cubic feet per second flow, the gross horsepower at the middle falls is 3180. Of this, 2703 gross horsepower pertain to the Genesee Paper Company's power and 477 to the Hayden estate. The Genesee Paper Company offers its water rights at $125,000, or $200,000 for the whole property, which includes a number of not very valuable buildings and several acres of land. At $125,000 for the Genesee Paper Company's water rights, the price per gross horsepower, on a basis of 1000 cubic feet per second flow, becomes $46.24. At this price the total value of the water rights at the middle falls is $147,043. It is considered that the balance of property of the Genesee Paper Company is worth the price asked, namely, $75,000.

The property of the Genesee Paper Company was sold to the Rochester Gas & Electric Company in February, 1900.

Brush Electric Light Company's power at lower falls. This company, which was absorbed a few years ago by the Rochester

Gas & Electric Company, owns the entire flow of the Genesee river at the lower falls, where the head is 96 feet. With 1000 cubic feet per second flow there may be developed at this place 10,903 gross horsepower. At the same rate as computed above for the Genesee Paper Company's water rights—on the basis of that company's actual offer of $125,000—the total value of the Brush Electric Light Company's water rights is found to be $504,155.

Undeveloped power between upper and middle falls. So far as known, no price has ever been placed upon the undeveloped waterpower between the upper and middle falls. A low waterpower with 10 feet head can be developed here capable of furnishing, with 1000 cubic feet per second flow, about 1136 gross horsepower. There is also a possibility of developing seven feet head between the feeder dam, in the south part of the City of Rochester, and Johnson and Seymour dam, of which the power may be taken at 795 gross horsepower.

The foregoing values, it must be remembered, are based upon water rights merely—they do not include lands and buildings. The proposition is to purchase water rights and lease back—as one main consideration for selling—water in the raceways.

Estimated cost of water rights at Rochester. We will now make an estimate embodying the preceding information as to the value of the Rochester water rights.

Johnson and Seymour raceway	$103,350 00
Rochester, Carroll and Fitzhugh raceway	103,360 00
Brown's race	316,000 00
Rochester Power Company's race	24,000 00
Middle falls (Genesee Paper Co., etc.)	147,043 00
Lower falls (Brush Electric Light Co.)	504,155 00
Undeveloped power	20,000 00
Sum	$1,217,908 00
Add for contingencies	282,092 00
Total	$1,500,000 00

The foregoing is the basis of the statement that a fair value for the Rochester water rights is $1,500,000.

The following are the approximate quantities of permanent power in gross horsepower which may be realized at Rochester from a flow of 1000 cubic feet per second:

	Gross horsepower
Johnson and Seymour raceway	1,081
Rochester, Carroll and Fitzhugh raceway	1,081
Upper falls	10,448
Middle falls	3,180
Lower falls	10,903
Undeveloped	1,931
Total	28,624

The total theoretical power is, as stated on a previous page, 28,840 gross horsepower, which under the conditions of 1904, may be taken at over 31,000 gross horsepower.

Why the gross horsepower has been adopted as the unit of power. The unit of power adopted is the gross horsepower—that is, the theoretical power produced by a given quantity of water falling through a given space. The reasons for adopting this unit are as follows: Water is easy to measure, while the actual power produced by water wheels—that is, the net power—is difficult to measure. Again, the efficiency of water wheels varies greatly, the best modern wheels yielding from about 70 per cent to 75 per cent of the theoretical power of the water. On the other hand, many of the cheaper wheels do not yield more than 40 per cent to 50 per cent. With the gross horsepower adopted as the unit, the onus of getting the largest possible net power out of the given quantity of water is thrown where it belongs, namely, on the user. On any other basis there would be an uncertainty as to the quantity of water contracted for, with its attendant disputes.

Quantity of water per gross horsepower. The following are the quantities of water per gross horsepower on the several developed powers at Rochester:

Name of dam	Head in feet	Quantity of water in cubic feet per second per gross horsepower
Johnson and Seymour	19	0.4630
Upper falls	92	0.0957
Middle falls	28	0.3140
Lower falls	96	0.0917

Storage Reservoir on Salmon River West

In 1898 the Board of Engineers on Deep Waterways extensively considered a reservoir on Salmon river, just above High Falls, as one of the feeders of the proposed deep waterway. The object of the reservoir was to provide storage within reasonable distance of the main deep waterway so that in case of temporary stoppage of the main feeder to the north, water could still be supplied to the canal. The feeder crosses Salmon river a short distance below the proposed reservoir. The ordinary elevation of the water surface of Salmon river just above the proposed dam near High Falls is approximately 897 feet, the flats at the side being a little above 900 feet. The water surface elevation, as proposed for the reservoir, was 953 feet. The total rise of water surface at or near the dam was therefore, roundly, 56 feet. In addition to the main barrage there were three dikes, the first, cutting off a narrow, lateral valley near the lower end of the reservoir, while the second and third, to the south of the village of Redfield, were in a broad, nearly level, somewhat swampy plain, where a comparatively small rise would throw Salmon river water over into the catchment of Mad river, a tributary to the west branch of Fish creek.

The volume and area, as determined by the surveys, are as follows:

Elevation	Area, in square miles	Volume, in cubic feet
910	1.619	0
930	4.481	1,700,582,400
950	7.356	5,000,688,000
960	8.458	7,205,447,400

Elevation 910 was taken as the base of the sections, the volume below that level being neglected except that, in order to obtain a rounded quantity of 7,500,000,000 cubic feet for the volume at elevation 960, we may take the volume below 910 as 294,523,000 cubic feet, a quantity well within the volume shown by the surveys and maps. On this basis we have the following tabulation:

Elevation, in feet	Area, in square miles	Volume, in cubic feet
900	0.486	0
910	1.619	294,523,000
930	4.481	1,995,105,000
950	7.356	5,295,211,000
960	8.458	7,500,000,000

The small hamlet of Redfield is the only village within the area to be flooded. The lands to be taken include a considerable proportion of swamp and timber area, from which the valuable timber has been mostly cut. The balance of the area is not valuable, and this reservoir, as a whole, is considered to present favorable conditions for taking such an area. There is one cemetery to be removed at Redfield.

In the Report of the State Engineer and Surveyor for 1895 it is shown in the report of the upper Hudson storage surveys that reservoirs for storing water in the Adirondack region may be developed up to a storage of 13.5 inches on the tributary catchment area for a runoff like that of Hudson river. Since meteorological conditions on the Salmon river are substantially the same as on the Hudson, there is no reason why the argument made in the Hudson storage report may not apply here. Taking, then, the Hudson report as a part of this discussion, so far as necessary to cover the argument for reservoirs developing a storage of 13.5 inches on a catchment area subject to a runoff like that of the northern plateau of New York, we may state the general problem in this way: Having a reservoir of a given area and volume, with a tributary catchment area of 190.5 square miles, it is required to find how much water can be reasonably expected to be collected from the catchment, stored in the reservoir, and drawn from it during a dry year, or during a series of such years.

The water collected and stored in the Salmon river reservoir during the entire year may be drawn from it in three ways, as follows:

1) By evaporation from the surface of the reservoir.

2) By supplying a certain fixed quantity to Salmon river below the dam during the entire year.

3) By feeding the canal during the months of May, June, July, August, September, October and November.

There will also be a slight outgo by percolation, leakage, etc. which may be neglected here.

The catchment areas of the Salmon river and the upper Hudson being of the same general character as regards proportion of forests and annual rainfall, it is reasonable to estimate that the runoffs from the two streams will be substantially equal; hence, the

Hudson river data are, in the absence of extended gagings of Salmon river, taken as applying to this stream.

In the following tabulation we have the evaporation for the months of a water year as computed in inches on the Salmon river catchment area for the actual reservoir area:

December	0.043
January	0.020
February	0.021
March	0.053
April	0.104
May	0.182
June	0.221
July	0.192
August	0.212
September	0.160
October	0.115
November	0.057

In designing a storage reservoir the stream is entitled to some water at all seasons of the year, and computations of effective storage should be made with reference to allowing a definite quantity of water to go constantly to the stream. From this point of view it is necessary to decide on some mean flow below which the stream shall never be allowed to fall. This is done in the interests of water-power plants already located on the stream, fisheries, etc. In the Hudson report the quantity fixed upon for storage in the upper Hudson catchment area is 0.5 inch per month. In cubic feet this amounts to 0.45 cubic foot per second per square mile for a month of thirty days. This quantity may be used in the case of the Salmon river reservoir. With 0.45 cubic foot per second per square mile always flowing away from the regulated catchment area, we would have in the stream just below the Salmon river dam about 87 to 88 cubic feet per second, which was approximately the observed low-water flow in the summer of 1898.[1]

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[1] Also see a statement on a following page in regard to uniform supply allowed to flow from the Hudson reservoirs.

The following tabulation shows the state of the reservoir at the beginning and end of each navigation season, from December 1, 1891, to November 30, 1898, inclusive:

Date	Inches in reservoir
December 1, 1891	Empty
May 1, 1892	*13.50
December 1, 1892	11.07
May 1, 1893	*13.50
December 1, 1893	5.62
May 1, 1894	*13.50
December 1, 1894	6.61
May 1, 1895	*13.50
December 1, 1895	5.19
May 1, 1896	*13.50
December 1, 1896	8.12
May 1, 1897	*13.50
December 1, 1897	11.94
May 1, 1898	*13.50
December 1, 1898	10.86

The quantity wasted from the Salmon river reservoir in the water years 1892–1898, inclusive, is as follows: In 1892, 9.93 inches; in 1893, 9.36 inches; in 1894, 2.93 inches; in 1895, 0.30 inches; in 1896, 4.30 inches; in 1897, 11.51 inches; in 1898, 13.64 inches.

Tables are given in the Report of the Board of Engineers on Deep Waterways similar to those for the Genesee storage, showing the quantity of water which may be furnished from this reservoir during a series of years. In the absence of definite information derived from gagings, the inflow to this reservoir is taken the same as the runoff of the Hudson river, although there is some reason for believing that the runoff of the Salmon river is somewhat larger than that of the Hudson river. On the headwaters of Salmon river and Fish creek, there is a body stated at about 150,000 acres (234 square miles) of unbroken forest, and while aside from some irregular gagings, nothing is known as to the flow of these streams, the indications are that it is

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*Full.

large. Gagings were begun on Salmon river in November, 1898. The record shows that in April, 1899, 12.8 inches ran off, and that the total runoff of the storage period, December, 1898, to May, 1899, inclusive, was 25.2 inches. The writer had some doubt about this record at the time it was taken, although later observations seem to indicate that it may have been correct.

The runoff of the east branch of Fish creek at Point Rock begun in September, 1898, and continued until May, 1899, is also very large. The record shows that in April, 1899, 8.0 inches ran off. The writer's recollection is that the flow was larger than appears in the record both on Fish creek and Salmon river, but was cut down somewhat because of the unwillingness to assume that these large runoffs were right. Further consideration seems to indicate that they may perhaps have been true, and it is unfortunate that gagings have not been kept up continuously from that time to the present in order to settle this question of large runoff. The catchment of the east branch of Fish creek joins that of Salmon river on the east.

The figures given in the Deep Waterways report show that the proposed Salmon river reservoir will have a flood area of water surface of 8.46 square miles, storing with this water surface about 7,500,000,000 cubic feet, or storing temporarily on the catchment area 16.95 inches. The tables also show that 300 cubic feet per second may be delivered to the canal during the navigation season and still leave some surplus in the reservoir. These computations are on the basis of the Hudson river gagings; in case it turns out later on that the flows of the Salmon river are larger than those of the Hudson, more than 300 cubic feet per second can be furnished.

In designing the reservoirs for the supply of the proposed deep waterways it was deemed desirable that there be considerable contingency; thus, in the Salmon river reservoir, the quantity still in the reservoir at the end of 1895 is 5.19 inches on the catchment area, or about 2,250,000,000 cubic feet.

An estimate of the cost of this reservoir and of the other works on the deep waterways was made in detail. The total cost of the Salmon river reservoir was estimated in 1899 at $1,350,000. Probably, in 1904, it would cost about 25 per cent more, or perhaps $1,678,500. At the latter rate, the cost per 1,000,000 cubic feet of storage becomes $233.

Storage Reservoir on Black River

This project has been mentioned in the general statements on page 572. It includes the construction of a main barrage across Black river at the village of Carthage. From this point, for nearly thirty miles south, Black river meanders through a broad, nearly level valley, in one place about five miles in width, but gradually narrowing to a width of about one-half mile in the upper portion.

In the estimates the total quantity of land is taken at 50,000 acres, of which 49,200 acres are agricultural, timber and wild lands, and 800 acres are villages. The area flooded at elevation of spillway crest is 73.2 square miles and at 10 feet above it is nearly 78 square miles.

The catchment area of Black river at Carthage is 1812 square miles. In addition to the main barrage across the channel of Black river there are seven dykes to be constructed in the vicinity of Carthage across lateral valleys. The project also includes the relocation of nearly twenty miles of the New York Central & Hudson river railway (Rome, Watertown & Ogdensburg division), together with the raising of several miles of the same without change of the present location; the construction of three highways across the reservoir to take the place of existing highways; the reconstruction of highways along the margins; the partial or complete removal of the villages of Beaver Falls, Bushee's Landing, Carthage, Castorland, Dadville, Deer River, East Martinsburg, Glenfield, Lowville, Naumburg, New Bremen and Watsons. At Carthage and Lowville the submerged areas are relatively unimportant parts of the town. Several of the smaller villages are entirely submerged, while others are only partially submerged.

There are eight cemeteries within the limits of the flow line, including 26.2 acres area. Three of these are small family burying places, while the others are used by the communities living in the vicinity.

There are 807 dwellings, 14 common schoolhouses and 9 churches within the flow line. The work also includes 17.2 miles of new common roads in addition to the three highway crossings over the reservoir previously mentioned.

At present there are five bridges over Black river between Carthage and Lyon Falls, namely: Castorland, 1; Lowville, 2; Glenfield, 1, and Greig, 1. These three new crossings will fairly accommodate the traffic of the region.

According to the Black river canal levels, the crest of the State dam at Carthage is at an elevation of 723.53 feet above tidewater, while the water surface at Lyon Falls, 42.5 miles distant by the meander of the river, is 735.65. At present the slack-water navigation from Lyon Falls to Carthage is made by two dams with locks, one at Otter creek with a lift of about 4 feet and one at Bushee's Landing with a lift of about 4.5 feet. From Lyon Falls the Black river canal rises to the Boonville summit, where the elevation of the summit level is 1126.96 feet above tide in a distance of ten miles. From Boonville, Black river canal drops down to Erie canal level at Rome, a distance of 25 miles.

That portion of Black river valley within the flow line of the proposed reservoir presents a considerable diversity of soil. In the lower portion the soils to the east of the river are, in a large degree, sandy and of very little value for agriculture, while on the west side there are considerable areas of valuable bottom meadows. To the east and southeast of Carthage there are also extensive areas almost entirely covered with rock and of very nominal value. The following notes are cited as showing the value of these lands. All these statements are as per the assessors' books for 1899.

In the town of Denmark the assessors state that hill farms are valued at $20 per acre, flats at from $60 to $70. These the assessors consider to be nearly full values.

In the town of Croghan the assessors value the best farms in the flats at $37 per acre, and other lands at from $6 to $25 per acre; the rock and sand areas at from $2 to $5 per acre.

In the town of New Bremen the equalized assessed value per acre for the whole township is $8.25. The assessors state that this is about 60 per cent of value. On this basis the average value of lands in that township becomes $13.75 per acre.

In Greig township the assessors state that good river flats are assessed at $25 per acre; sandy flats at from $6 to $7 per acre; the best stony land at $12 per acre; poor stony land at $7 per acre, and swamps at $.50 per acre.

In Martinsburg township the best flat lands are assessed at from $30 to $35 per acre; swamps at $1 per acre. The equalized value per acre in this township, as per supervisors' equalization table for 1898, is $22.65.

In Lowville township river flats and all lands between the New York Central & Hudson river railway and the river are assessed at $50 per acre. The equalized value in this township is $66.50.

In the town of Turin flats are assessed at $40 per acre, and lands on the first bench above the flats at $30 per acre.

Referring to the supervisors' equalization table in the Proceedings of the Board of Supervisors of Lewis county it is learned that the total assessed area in Lewis county is 754,488 acres, on which the assessors place a total value of $8,834,204. At this rate the average price per acre for the whole county becomes $11.71.

The total value of the 50,000 acres of land to be taken for the Black river reservoir is estimated at $1,876,000. By way of showing that this is an ample estimate we may consider that while 50,000 acres is only about one-fifteenth of the total area of Lewis county, the estimated value of $1,876,000 is about one-fifth of the total valuation of the county; that is to say, the estimated value of the lands to be taken is nearly three times the average value of the lands of the whole county. The lands to be taken include, however, some of the best in the county, as well as a large proportion of the poorest lands.

Probably as serious a consequence as any to result from the construction of the Black river reservoir is the considerable interference with the waterpower at Beaver Falls, Lyon Falls, New Bremen, Lowville, Fenton's Mill and Deer River village. At Beaver Falls on Beaver river there are now four establishments ordinarily using 3071 horsepower and with a total valuation of $425,000, the total value of the annual product being $448,600. There are forty-two hands employed.

At Lyon Falls there is a custom feedmill as well as a small electric plant for lighting the village of Lyon Falls. These establishments are situated on the Black river canal, just above where said canal enters Black river, and will be entirely submerged. The value, however, is small, not exceeding $5000. The principal establishment at Lyon Falls is the newspaper mill of the Gould

Paper Company, where the water wheels ordinarily work under from 67 to 68 feet head, yielding a power of something like 7731 horsepower. The crest of the power dam above the falls is at an elevation of 801 feet above tidewater, while the crest of the barrage at Carthage will be placed at 772 feet above tidewater. There will remain, then, when the reservoir is just full, 29 feet head instead of about 68 feet, as at present. During such floodflows as occur, with the water surface of the reservoir above crest of barrage at Carthage, the head will be less, although this condition will only rarely occur. Usually, with the reservoir drawn somewhat down, the head at Lyon Falls will be, on an average, from 30 to 35 feet. In any case the mill will largely require reconstructing in order to conform to the new conditions, and from this point of view the damages have been liberally estimated. The Gould Paper Company was expending about $200,000 on improvements to their mill during the summer of 1899.

At Deer River village the backwater of the reservoir just about reaches the crest of the lower dam, practically eliminating waterpower at that dam.

At Lowville there is an old mill, the waterpower of which will be destroyed.

At New Bremen there are three small establishments entirely submerged.

At Fenton's Mill, on the east side of the reservoir, a small feedmill will be submerged.

The chief damage will occur at Beaver Falls and Lyon Falls, the mills at the other places being relatively unimportant.

Tabulations are given in the Report of the Board of Engineers on Deep Waterways similar to those given in discussing the Genesee river storage project, from which it is learned that a reservoir of the size and capacity indicated would furnish 2200 cubic feet per second to Black river every day in the year and at the same time be adequate to meet all possible contingencies of water supply for the proposed deep waterways. The total capacity of the reservoir would be about 2600 cubic feet per second.

The estimated cost of this reservoir was, in 1899, $5,712,200. In 1904 the cost may be expected to be approximately 25 per cent greater, or $7,140,000. The relations of cost to the water power to be developed may be obtained by considering the detailed tables of developed power on Black river as given in the Deep Waterways report. The storage of Black river reservoir at level of crest of dam is 57,260,000,000 cubic feet. Hence the cost per million cubic feet of storage becomes, on the basis of the estimate of 1904, about $125.

Storage Reservoirs on Hudson River

Hudson river is divided at the Troy dam into the upper or water-power section and the lower or tidal portion. The proposed reservoirs are in the upper section above Troy.

Early surveys. The project for constructing storage reservoirs on the upper Hudson has been agitated for many years, the first surveys for this purpose having been made in 1874. In that year Prof. F. N. Benedict conducted surveys, and in his report proposed an extensive system of reservoirs. The chief interest attaching to this report is the proposition on the part of Mr Benedict to build storage reservoirs at Blue Mountain, Raquette, Forked, Beach and Long lakes, and divert the water stored on these several lakes from their natural drainage into Raquette river, to the south, thus making them artificially tributary to the Hudson river. In proposing this diversion, Mr Benedict apparently assumed that the State, in its sovereign capacity, could divert waters from one catchment area to another without regard to the rights or wishes of the riparian owners.

In addition to the lakes already enumerated, which are naturally tributary to Raquette river, Mr Benedict proposed to make reservoirs of the following lakes and ponds in the upper Hudson catchment area: Round pond, Catlin lake, Rich lake, Harris lake, Lake Henderson, Newcomb lake, Lower works reservoir, Chain lakes, Goodenow pond, Goodenow river reservoir, South pond, Clear pond, Slim pond, Ackerman pond, Perch pond, Trout pond, Lake Harkness, Shedd lake, First Sergeant pond, Third Sergeant pond, Plumley pond, Moose pond, and Cary pond. The total storage to be furnished by the entire system of reservoirs is placed at 18,419,781,600 cubic feet. The total cost of the proposed reservoirs was placed by Mr Benedict at about $265,000, or, including the diversion canal and improvements at Long lake, at a total of about $460,000. The dams proposed were to be constructed of timber, very much after the plan of the timber dams still constructed by the lumbermen in this region.[1]

In 1874, when Mr Benedict prepared his report, the demands for water upon the Hudson river were far less extensive than at present, and even in 1882 the total waterpower of the stream was, according to the statistics of the Report on the Water Power of the United States, Tenth Census, only 12,894 horsepower, while in 1895 the total horsepower was 43,481. Taking into account additional wheels set in the last few years, as well as the extensive development of the Hudson River Power Transmission Company, 3 miles below Mechanicville, it is probable that in 1898 there were wheels set on the Hudson river capable of furnishing, at full capacity, not far from 55,000 horsepower. This great development has led to a very strong demand in the last few years for increased flow during the low-water period. The extensive plant of the Hudson River Water Power Company at Spier Falls is now approaching completion. In 1904 there are wheels set capable of producing about 80,000 horsepower.

Recent investigations. In 1895 a survey of the upper Hudson valley was authorized with the view of determining what lakes and streams may be improved, and the water stored and diverted, in order to provide for the enlargement of Champlain canal; for restoring to the water of Hudson river at or below Glens Falls the water diverted therefrom for canal purposes; and for improving the navigation of the lower Hudson river. The proposed reservoirs are all in the upper section, above Troy.

When one considers the scope of the investigation it may be readily seen that the studies must necessarily be of rather wide range. Special consideration should be given the following topics:

1) The area of the several subdivisions of the catchment area, together with the locations and extent of the reservoir sites, and the total area from which the runoff can be controlled.

2) The rainfall and mean temperature of the tributary region, as well as its physical characteristics, the relative amounts of timber and cleared area, etc.

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[1] For further particulars of Mr Benedict's reservoir system, see Report on a Survey of the Waters of the Upper Hudson and Raquette Rivers in the Summer of 1874, with Reference to Increasing the Supply of Water for the Champlain Canal and Improving the Navigation of the Hudson River, by F. N. Benedict, Ass. Doc. (1875), Vol. I, No. 6, p. 85.

Plate 14.

Beaver meadow, near Indian lake; a typical reservoir site in the Adirondacks.

3) The actual runoff of the stream from the known area for a series of years, and a deduction therefrom by comparison with the rainfall and temperature records of the amount which may be stored in the year of minimum rainfall; also the relation which the runoff in the year of minimum precipitation bears to what may be expected in the average year, and a deduction therefrom of the proper hight of flow lines for full-capacity development.

4) The areas of the reservoirs and the losses therefrom by evaporation which may be reasonably expected, with the amount of effective storage which may be gained by the reservoir system when developed to full capacity.

5) The amount of water now diverted for the use of Champlain canal, and the amount to be diverted for such use when the enlargement is completed; also the proper method of managing the system of reservoirs in order to secure the best results to the canal, the navigable section, and the waterpower.

6) The amount of waterpower now in use on the stream and the effect of the present and future diversion.

7) The regimen of the tidal section, and the effect of the unregulated fresh-water flow and of the construction of the system of impounding reservoirs.

8) The cost of the reservoirs and the relation which the actual cost bears to the amount of storage gained. This latter element determines the commercial feasibility of the project.

Reservoir sites. The surveys, so far as carried, indicate that economical reservoirs controlling the entire catchment area to full capacity in the year of minimum rainfall may be constructed in the Sacandaga, main Hudson and Schroon valleys, as shown by the following paragraphs:

The Sacandaga river has a total catchment area above its mouth of 1040 square miles. The catchment areas of reservoir sites on the Sacandaga river, in square miles, are as follows:

	Square miles
Lakes Pleasant and Sacandaga	45
Piseco lake	55
Arietta flow	40
Miscellaneous	50
Total	190

The main Hudson or North river has a total catchment area above Hadley, not including Schroon river, of 1092 square miles. Of this area the portions shown below may be developed to full capacity in the year of minimum rainfall:

	Square miles
Thirteenth pond	14
Chain lakes	58
Catlin lake	25
Lakes Rich, Harris, and Newcomb, and the Goodenow flow	83
Lake Henderson	18
Lake Sanford and the Tahawus flow	67
Boreas river and Boreas pond	45
Cedar river	58
Indian lake	146
Total	514

Schroon river has a total catchment area above its mouth of 570 square miles. The topography of the Schroon area is such as to admit of two distinct lines of treatment—either to construct one large dam at Tumblehead falls, about a mile below South Horicon, or to construct a series of 16 to 18 small dams at various points in the area. In either case it is possible to control substantially the full flow above Tumblehead falls, and the decision of which is better will turn chiefly on the question of relative cost, the estimate taking into account the fact that it will cost much more to operate a large number of reservoirs than to operate one. The following are the catchment areas of the system of small reservoirs as proposed for Schroon river:

	Square miles
Minerva brook at Olmsteadville	43.4
Hewett pond	2.5
Loon lake	11.6
Friend lake	4.9
Elk lake	15.9
Clear pond	2.3
New pond	1.7

	Square miles
Deadwater pond	18.9
Hammond pond	11.4
Dudley pond	3.9
Overshot pond	4.9
Paradox lake	31.6
Paragon lake	5.6
Crane pond	7.2
Pharoah lake	8.3
Brant lake	38.7
Valentine pond	6.7
Schroon lake at Starbuckville	259.2
Total	478.7

The area between Starbuckville and Tumblehead falls not available with the system of small reservoirs is 23.3 square miles.

The total controllable area of the upper Hudson, with the system of small reservoirs in the Schroon valley, is as follows:

	Square miles
Sacandaga valley	190
Hudson above Hadley	514
Schroon valley	479
Total	1,183

With one large reservoir in Schroon valley, the total catchment area is increased to 1206 square miles.

The system of small reservoirs outlined in the foregoing is estimated to store 15,330,000,000 cubic feet, at a cost of $1,172,500; hence, the cost per million cubic feet stored becomes $76.48. These figures, however, do not take into account the actual cost of maintenance and operation, which may be placed at $30,000 per year and capitalized at 5 per cent, is equivalent to a permanent investment of $600,000. Adding $600,000 to $1,172,500 gives a total permanent investment of $1,772,500.

The foregoing estimates were made early in 1896 and due to change in conditions, they would be considerably increased in 1904.

A general estimate of the cost of the single large reservoir in Schroon valley shows that with a dam at Tumblehead falls 59 feet in hight there would be impounded 15,925,000,000 cubic feet. The preliminary estimate indicates a total cost of $840,000, and a later survey indicates about $1,000,000. The final revision of the estimate on completion of the investigation may show a somewhat larger figure than this. Even if the cost were to be $1,100,000, it would still be exceedingly cheap storage, the cost for 15,925,000,000 cubic feet being on this basis only $69.14 per million cubic feet stored.

In order to appreciate fully the low cost of these reservoirs, it may be mentioned that reservoirs for municipal water supplies frequently cost from $5000 to $10,000 per million cubic feet stored. In specially unfavorable cases the cost is even higher than this—it may be as high as $12,000 to $15,000 per million cubic feet stored. Small reservoirs sometimes cost from $6000 to $8000 per 1,000,000 gallons stored.

The dam at Tumblehead falls would be located just below the outlet of Brant lake, the elevation of the water surface of which is 801 feet. The flow line of the proposed reservoir has been placed at an elevation of 840 feet, thus giving a depth of 39 feet over the surface of Brant lake, a depth of 33 feet over the surface of Schroon lake, and a depth of 20 feet over Paradox lake. With the reservoir full or nearly full, there would be continuous navigation from the head of Brant lake to the head of Paradox lake of about 35 miles. The villages of South Horicon, Bartonville, Starbuckville, and parts of Pottersville and Chester are within the flow line of this reservoir.

Indian lake is another large reservoir on the headwaters of Hudson river, that has been described on a preceding page.

Piseco lake is another large reservoir which may be constructed on the upper Hudson at low cost. It is estimated that a storage of 1,725,000,000 cubic feet may be made at an expenditure of $70,000, or at an average cost per million cubic feet stored of $40.

Without going further into detail, the following may be given as the approximate storage of the upper Hudson system, worked out to 1904.[1]

	Cubic feet
Storage of Sacandaga and main Hudson river catchment areas, not including Boreas river reservoir, Boreas pond, Indian lake, and Piseco lake	14,364,000,000
Boreas river reservoir and Boreas pond	1,111,000,000
Indian lake[2]	4,468,000,000
Piseco lake	1,725,000,000
Schroon valley	15,925,000,000
Hadley	4,000,000,000
Conklinville	10,000,000,000
Total	51,593,000,000

This storage is considered sufficient, in conjunction with the natural flow of the unregulated portion of the river, to maintain at Mechanicville a flow of at least 4,500 cubic feet per second during the entire year.

The general investigations indicate that there is an opportunity to make a large reservoir on Sacandaga river by the erection of a dam at Conklinville. The available storage of such a reservoir is from 8,000,000,000 to 10,000,000,000 cubic feet. It is taken in the preceding tabulation at 10,000,000,000 cubic feet.

There is also an opportunity to construct on the main Hudson at Hadley, just above the mouth of the Sacandaga, another reservoir of about 4,000,000,000 cubic feet capacity at a point where the natural conditions for constructing such a reservoir are good. At the site of the proposed dam the river shows a granitic rock bottom, with precipitous banks nearly forty feet in hight and about one hundred feet apart. The material for a

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[1] For full details, the reader is referred to the original Reports on the Upper Hudson Storage Surveys, in Annual Reports of State Engineer and Surveyor for the Years 1895 and 1896. Also, refer to Report to Merchants' Ass. of New York, 1900.

[2] The storage of this reservoir with the flashboards in place is taken at 5,000,000,000 cubic feet.

permanent stone dam exists in the vicinity, with an opportunity to construct a wasteway over natural rock at one side.

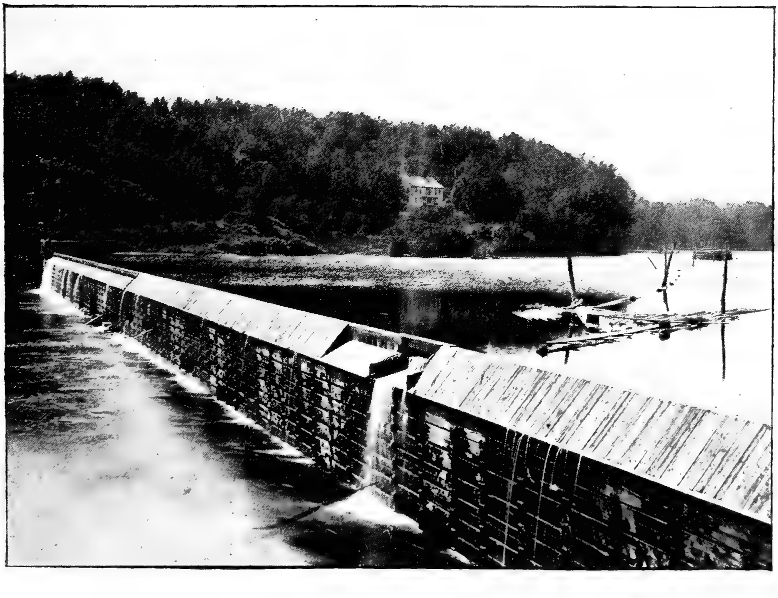
Inasmuch as all the storage except that of the Sacandaga area would pass through the Hadley reservoir, its construction would simplify the management of the system very greatly. In the summer season, as long as there is any storage above to be drawn upon, this reservoir could be kept nearly full and just the right quantity drawn out from day to day to keep the river at the assumed flow of 4500 cubic feet a second at Mechanicville.

The Water Storage Commission made surveys for several reservoirs on the Hudson river, but as there is nothing of interest about any of these, no special mention is made of them here.

Effect of proposed storage on river flow. The foregoing quantities of storage have been fixed upon on the basis that the water yield of the year of minimum stream flow will furnish a storage of at least 12 inches, the flow line of the reservoirs themselves being located with reference to holding back 13.5 inches. If, however, one examines the tables of runoff of the Hudson at Mechanicville, and of precipitation in the catchment, it is seen that much greater yields can be expected in an average year. From this point of view, it may be asked, Why not make the reservoirs somewhat larger than merely sufficient for the wants of the year of minimum flow and carry some water over from one year to another, thus more nearly attaining an absolute regulation of the river—not for a single year, but for a series of years? The chief objection to this method of procedure is that experience with other large reservoir systems is against other than a moderate development on this line, it having been repeatedly found that however high the flow line, reservoirs are likely to be nearly empty at the beginning of the storage period of the minimum year. Experience indicates that the rainfall and stream flow move in cycles, there being in each cycle several successive years of flow above the average. The demands for water tend to increase during the years of plenty, until those in charge apparently forget there will ever be a deficiency. The best practice, therefore, is to locate the flow line with reference to about the minimum yield, thus forcing an economy in the use of water from the beginning. By proceeding in this way provision may

Plate 15.

A. The dam at Mechanicville with flash boards in place.



B. The present dam at Fort Edward.

be made for carrying over moderate quantities of water from the latter end of the year more effectually than in any other way. An exception has been made to this general proposition in the case of Schroon valley reservoir, discussed in detail on another page.

TABLE NO. 86—MEAN PRECIPITATION ON THE UPPER HUDSON CATCHMENT AREA
(In inches)

MONTH	Albany	Glens Falls	Keene Valley	Mean of Albany, Glens Falls and Keene Valley	Western Massachusetts	Northern plateau	Lowville academy	Johnstown academy	Cambridge academy	Fairfield academy	Granville academy	Mean of all
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
December	2.71	3.19	2.75	3.01	4.31	3.57	2.14	2.91	2.36	2.78	2.48	2.92
January	2.75	3.16	3.00	3.03	3.36	3.88	2.35	3.30	3.36	2.69	2.08	2.99
February	2.49	3.03	2.22	2.64	2.83	3.60	2.43	2.86	2.61	2.06	1.42	2.56
March	2.72	2.72	2.24	2.50	2.94	2.52	1.78	3.63	2.12	2.36	1.74	2.48
April	2.80	2.15	2.09	2.14	2.02	2.39	1.91	2.93	3.36	2.53	2.13	2.43
May	3.62	3.10	3.05	3.14	3.17	4.46	2.79	3.45	3.65	3.04	3.47	3.38
Storage period	17.09	17.35	15.35	16.47	18.63	20.42	13.40	19.08	17.46	15.46	13.32	16.76
June	4.07	2.83	2.89	2.99	3.24	3.88	3.42	4.20	4.66	4.29	3.21	3.67
July	4.29	3.25	3.61	3.53	3.44	3.83	3.67	4.01	3.91	4.21	3.63	3.78
August	3.96	4.17	4.21	4.20	3.91	5.07	2.85	3.14	3.98	3.66	2.97	3.79
Growing period	12.32	10.25	10.71	10.75	10.59	12.78	9.94	11.35	12.55	12.16	9.81	11.25
September	3.43	2.96	3.00	3.13	3.51	3.57	2.84	2.87	3.27	3.08	2.67	3.12
October	3.58	2.36	2.49	2.60	3.41	3.06	3.29	3.20	3.60	3.56	2.90	3.15
November	3.08	3.24	3.56	3.26	2.84	3.46	2.94	3.33	3.29	2.46	2.88	3.11
Replenishing period	10.09	8.56	9.05	8.99	9.76	10.09	9.07	9.49	10.16	9.11	8.45	9.38
Yearly total	39.50	36.16	35.11	36.22	38.98	43.29	32.41	39.92	40.17	36.73	31.58	37.39

The figures in the above table are obtained by averaging the results obtained at Albany from 1825 to 1895; at Glens Falls, from 1879 to 1895; at Keene Valley, from 1879 to 1895; in western Massachusetts, from 1887 to 1895; in northern plateau, from 1889 to 1895; at Lowville academy, from 1827 to 1848; at Johnstown academy, from 1828 to 1845; at Cambridge academy, from 1827 to 1839; at Fairfield academy, from 1828 to 1849; at Granville academy, from 1835 to 1849; the mean of Albany, Glens Falls and Keene Valley, from 1879 to 1895. Although the foregoing figures are here given in detail, later studies indicate that the mean rainfall of the northern plateau as defined by the State Meteorological Bureau is the best rainfall record to apply to the upper Hudson area.

The proposed regulation of the Hudson river has been provisionally arranged on the basis of maintaining a flow of at least 4500 cubic feet per second at Mechanicville, where, as has been seen, the catchment area is 4500 square miles, such a regulation being equivalent to producing at Mechanicville a constant flow of 1 cubic foot per second per square mile.

As regards the change in the regimen of the stream due to storage, it may be remarked that the reservoirs have been designed on the basis of giving to the stream at least 0.5 inch on the catchment area per month.[1] With 0.45 cubic foot per second per square mile always flowing away from the controlled catchment area, the natural flow of the unregulated portion will usually furnish an additional amount sufficient to keep the river, during the storage period, up to nearly the assumed 4500 cubic feet per second at Mechanicville; or in case of extreme low water in winter other reservoirs may be relied upon to assist in the manner already pointed out.

On the basis of 12 to 14 inches available storage, there may be, with 0.5 inch per month always going to the stream, a possible total requirement for the year of from 15 to 18 inches.

Table No. 61 shows that the total flow for the year 1895 was only 17.46 inches, or in that year there might have been a shortage, if the reservoir system had been in operation, of perhaps 0.5 inch. Any such shortage would necessarily have been carried over from the year 1894, when, in November, there was a runoff of 1.58 inches. Allowing 0.5 inch to the stream from the November rainfall alone there would have been 1.08 inches remaining in the reservoirs to be carried over to 1895.

Summary of Hudson river reservoirs. In conclusion, it may be said that it is entirely feasible to construct a system of reservoirs in the upper Hudson valley, and such system may be designed with reference to the full capacity storage of at least 1300 square miles of area, or 47 per cent of the total area above Glens Falls. Such control would result in the material reduction of floods at Glens Falls and other points.

The proposed total storage of 45,593,000,000 cubic feet would maintain 4500 cubic feet per second flow, as well as supply the other necessary demands, in the driest season of the gaging period. The discharge measurements show that whereas the minimum unregulated flow at Glens Falls is as low as 700 cubic feet per second for a monthly mean, with the storage carried out, the probable monthly mean flow at Glens Falls will be at least 3000 to 3600 cubic feet per second. The minimum regulated flow of 4500 cubic feet per second at Mechanicville will increase the low-water depth in the Hudson river at Albany about 1.5 feet.

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[1] This is the same basis as discussed on a preceding page for Salmon river reservoir. 0.5 inch per month is 0.45 cubic foot per second per square mile.

The diversion of water for the use of Champlain canal is an injury to the waterpower at Glens Falls and lower points on the river. Since waterpower is much cheaper than steampower, the taking of the water of the river away from the manufacturers is a serious matter. In the fourteen years from 1882 to 1895 the use of waterpower on Hudson river increased 237 per cent.

The upper Hudson storage system is estimated to cost in 1904 from $80 to $100 per million cubic feet stored, a sum considerably less than the cost of many other systems.

Storage Reservoirs on Schroon River

In 1900 the writer reported to the Merchants' Association of New York in regard to a reservoir for a water supply to that city to be located on Schroon river. The scope of this report was as follows:

1) The discussion of a project for supplying five hundred million (500,000,000) gallons daily (775 cubic feet per second) of pure water from a single large reservoir to be located on Schroon river.

2) The supplying of the same quantity from Lake George and Schroon river.

3) In addition to the storage reservoirs, from which the city supply of pure water would be drawn, these two projects further included compensating reservoirs large enough to compensate for amount of water abstracted for supply of Greater New York.

4) The discussion of a project for supplying a large quantity of stored water to Hudson river, in order to hold the point of upward flow of salt water through tidal action as far down stream as practicable.

The following are the main points embodied in the report to the Merchants' Association:

Schroon river flows into Hudson river just above Thurman bridge and about fifteen miles north of Hadley. The catchment area at its mouth is 570 square miles. It issues from a region with a permanent population of from 12 to 14 per square mile. The prevailing rocks are granitic, with large areas of fine sand; there are only limited swamp areas.

In order to show the approximate relative proportions of virgin forest, culled area, from which merchantable softwood timber has been removed, together with the cleared and water areas of Schroon river catchment, the following data have been compiled from several of the United States Geological Survey's topographical sheets, including territory either wholly or partly within Schroon river catchment:

Topographic sheet	Virgin forest, square miles	Culled area, square miles	Cleared area, square miles	Water area, square miles	Total area, square miles
Bolton	......	153.00	43.55	19.85	216.4
Paradox lake	......	171.55	38.60	5.35	215.5
Schroon lake	1.10	182.10	35.80	6.50	215.5
Total	1.10	506.65	117.95	31.70	647.4

The large water area of the Bolton sheet is due to the fact that this sheet includes a considerable portion of Lake George. Aside from this, the Bolton, Paradox lake and Schroon lake sheets, covering a total area of 647.4 square miles, are considered to be—as regards forestation—fairly illustrative of Schroon river catchment area. The figures show that the cleared area is only about 18 per cent of the whole. The northern part of Schroon river catchment area, which is included in Mount Marcy and Elizabethtown sheets, is substantially all in timber, and for the entire catchment area probably the cleared surface does not exceed about 15 per cent.

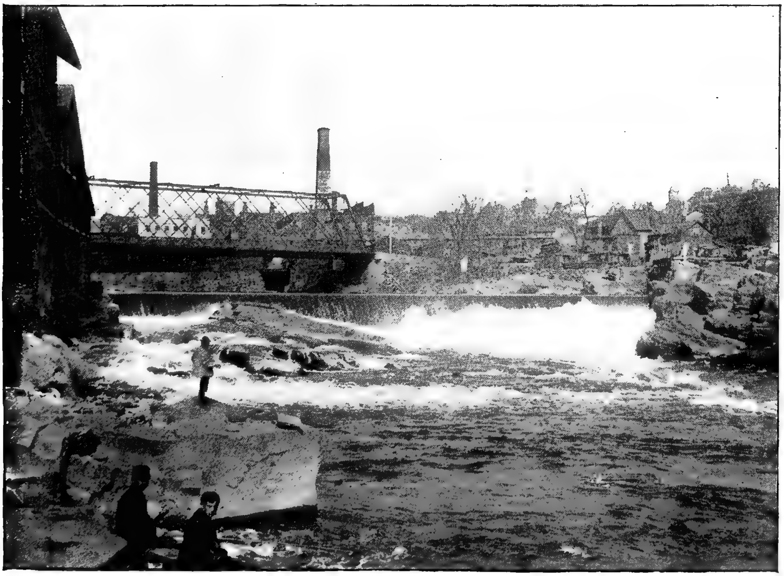
The topography of Schroon river catchment area is rugged. The low-water surface elevation of Schroon lake is 807 + T. W., and the extreme northern tributaries issue from the base of the highest mountains of the State.

The foregoing brief statements in regard to physical characteristics of Schroon river catchment area show that it is an ideal region from whence to draw a municipal water supply. The forest covered granitic rocks and interspersed sand areas insure a water of extreme purity, and when we further take into account the economy of reservoir construction which can here be attained we have a combination of favorable conditions only rarely excelled.

An approximate estimate made in 1895, before all the conditions were known, placed the cost of Schroon valley reservoir—

Plate 16.

A. Dam on Schroon river at Warrensburg, with flash boards in place.



B. Dam where gagings are made at Little Falls.

when developed up to a storage of 13.5 inches on the catchment area—at $840,000. This was for a water storage reservoir purely, and did not include clearing and stripping of margins any further than that cutting and burning of standing timber was provided for. Investigations made in 1896 indicated more expense for foundation of dam at Tumblehead falls than assumed in 1895. Moreover, for a storage reservoir for regulation of stream flow purely, nothing was allowed for sanitary protection of catchment or for removal of buildings along or near new margins.

The estimates herewith submitted take into account all these several items, as well as an allowance for present labor conditions and price of materials in the State of New York.

In the first report on upper Hudson surveys (1895) the writer discussed extensively the question of proper hight of flow line for upper Hudson reservoir system, reaching the conclusion that for stream regulation 13.5 inches in depth on the catchment area was the approximate figure. This is about as large a storage as can be ponded at the several upper Hudson sites. At Tumblehead falls, however, there is apparently no reason why the development may not be carried higher, and the present study for a pure-water reservoir has accordingly been based upon a development of storage up to 18 inches in depth on the tributary catchment area of 518 square miles. Such development gives a total storage of 21,662,000,000 cubic feet (162,248,380,000 gallons) and will utilize, during a series of years, substantially the entire flow of the stream.

To accomplish this result the uniform outflow from the reservoir has been taken at 500,000,000 gallons in twenty-four hours; or, for even figures, at 775 cubic feet per second. It is easy to furnish this quantity from a single reservoir, although it is necessary to fix the flow line higher than 13.5 inches.

In order to show the effect of drawing 775 cubic feet per second continuously from such a reservoir in Schroon valley, table No. 87 has been prepared. The data are (1) the runoffs of Hudson river for the twelve years 1888-1899, inclusive; and (2) evaporation at Rochester. The computation has been made by years, beginning with an assumed depth of 4 inches on the catchment area in reservoir at the end of November 1887, and is

TABLE No. 87.—SHOWING STATE OF WATER STORAGE IN SCHROON VALLEY RESERVOIR FOR THE WATER YEARS 1888-1899, INCLUSIVE. BASED ON AN ASSUMED STORAGE CAPACITY OF THE RESERVOIR OF 18.00 INCHES AND A DIVERSION OF 775 CUBIC FEET PER SECOND FOR WATER SUPPLY OF GREATER NEW YORK

(In inches on tributary catchment of 518 square miles)

WATER YEAR	Inflow to reservoir as per Hudson river record	Total outgo excepting waste	Waste from reservoir	Amount stored in reservoir at beginning of water year	Amount stored in reservoir at end of water year	Yearly depletion of reservoir = difference of columns (5) and (6)	Increase in amount stored = difference of columns (6) and (5)	LOWEST CONDITION OF RESERVOIR DURING YEAR		
								Month at end of which lowest water occurred	Inches in reservoir at end of month	Cubic feet in reservoir at end of indicated month
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1888	23.64	21.89	0.00	4.00	5.75	....	1.75	March	3.38	4,068,000,000
1889	21.71	21.84	0.00	5.75	5.62	0.13	....	October	5.40	6,498,000,000
1890	28.94	21.84	0.00	5.62	12.72	....	7.10	December	7.24	8,713,000,000
1891	20.56	21.84	1.22	12.72	10.22	2.50	....	November	10.22	12,299,000,000
1892	33.08	21.89	5.70	10.22	15.71	....	5.49	December	10.72	12,901,000,000
1893	21.91	21.84	2.35	15.71	13.43	2.28	....	November	13.43	16,162,000,000
1894	19.37	21.84	0.00	13.43	10.96	2.47	....	November	10.96	13,189,000,000
1895	17.46	21.84	0.00	10.96	6.58	4.38	....	October	6.24	7,509,000,000
1896	23.63	21.89	0.00	6.58	8.32	....	1.74	February	7.08	8,520,000,000
1897	26.19	21.84	0.00	8.32	12.67	....	4.35	February	6.92	8,328,000,000
1898	27.12	21.84	2.72	12.67	15.23	....	2.56	December	14.57	17,534,000,000
1899	19.54	21.84	1.82	15.23	11.11	4.12	....	November	11.11	13,370,000,000
Mean and total	23.60	.....	13.81	.....	.....	....	....	....	.....	....

carried along through each water year, to the end of November 1899.

This computation shows that for a storage of 18 inches on the catchment area and a uniform outflow of 775 cubic feet per second the total waste in the twelve-year period would have been only 13.81 inches. A similar computation has been made for a storage of 13.5 inches and uniform outflow of 650 cubic feet per second, in which the waste would have been 55.36 inches. amounting to a mean waste per year of 4.61 inches.

The distance from Hadley to proposed site of Schroon valley barrage at Tumblehead falls—measured along the thread of Hudson and Schroon valleys—is about 29 miles. Of this about 14 miles is in Schroon valley. The village of Warrensburg, with a population of about 1000 in 1900, lies on Schroon river, three miles above its mouth. At and in the vicinity of this place waterpower to the extent of 1627 net horsepower (2167 gross horsepower) has been developed on Schroon river. The largest block of power at a single point is at the dam of the Schroon River Pulp Company, one and one half miles below Warrensburg, where 1086 net horsepower are in use. Owing to the equalizing effect of Schroon lake, these powers are all fairly permanent except at the pulp mill, which is sometimes short of water in late summer and fall months.

The water-surface elevation of Schroon river at its mouth, near Thurman, is approximately 620 + T. W. At Tumblehead falls the elevation is about 780 + T. W. There is, therefore, a total fall of 160 feet between Tumblehead falls and mouth of stream. Of this 39 feet is included in the dams at Warrensburg village and the Schroon River Pulp Company's power, leaving 121 feet still undeveloped. It seems very desirable, in case Schroon valley reservoir is constructed, that the waterpower possibilities of the stream be preserved. A uniform outflow of 775 cubic feet per second would yield, on 121 feet fall, 10,639 gross horsepower.

In order to preserve present waterpowers and ultimately utilize the undeveloped fall, it would be necessary to let the water discharged from the reservoir at Tumblehead falls flow down the present channel of Schroon river to a diversion weir, to be located just above the mouth, at which point a conduit of 775 cubic feet per second capacity would begin. This diversion weir would be sixteen miles above Hadley, but it is considered that the additional cost of extending the conduit this distance would be compensated for by the keeping of pure Schroon river water entirely separate from balance of Hudson river water.

In proposing such separation it is not intended to imply that Hudson river water at Hadley is not suited for a public supply. In any case upper Hudson water is very pure, but due to relatively somewhat more extensive swamp areas to north of mouth of Schroon river, Hudson river water at Hadley, as a whole, is not equal to that of Schroon river. The purifying effect of wind and sunlight on the extended water areas of Schroon, Brant and Paradox lakes is taken into account in reaching this conclusion.

Another important reason for extending conduit to diversion weir just above mouth of Schroon river may be found in considering that much the cheapest way to reimburse waterpower owners on Hudson river for diversion of 775 cubic feet per second will be by constructing compensation reservoirs. Some of these would be located on Sacandaga river, which flows into Hudson river at Hadley, but nevertheless several would be on main North river above Thurman. If proposed additional water supply of Greater New York were taken at Hadley, then all compensating reservoirs should be thoroughly cleared and stripped, the same as is proposed for Schroon valley reservoir. Even after completion of such extensive work, the conditions at several reservoir sites to north of Thurman are not such as to yield an ideal water without filtration. There are extensive muck areas which now discolor the water and taint it with an offensive odor. Filtration would, of course, make any of these waters ideal, and probably for a thorough study of the project in all of its phases estimates should be worked out showing approximate cost of taking 775 cubic feet per second at Hadley, with all stripping of reservoirs omitted, but including the cost of a filtration plant capable of handling 775 cubic feet per second. As regards quality of the municipal supply, such treatment would place this project essentially on a par with the Vyrnwy supply for Liverpool, where the water of a sparsely populated mountainous area is filtered, largely to remove vegetable discoloration.

If Schroon river water is taken into conduit just above mouth of stream, the sewage of Warrensburg village and the manufacturing establishments would be properly carried in a close conduit or pipe to a point below the diversion weir. The estimates for sanitary protection include the cost of the necessary special constructions for this purpose.

There is considerable summer population about Schroon, Brant, Paradox and other lakes of Schroon area, and the estimates for sanitary protection further include cost of properly caring for waste products at hotels, cottages, etc.

The following presents the main points of comparison for dams at Tumblehead falls, storing 13.5 and 18.0 inches on the catchment area, respectively:

Storage, in inches on catchment area	Storage, in cubic feet	Elevation of flowline contour	Hight of dam, in feet	Area of water surfaces of full reservoir	
				Acres	Sq. miles
(1)	(2)	(3)	(4)	(5)	(6)
13.5	16,246,000,000	840.6	60.0	14,800	23.1
18.0	21,662,000,000	850.5	70.0	16,900	26.4

By reference to the United States Geological Survey's topographic sheets, the significance of these figures may be easily appreciated.

In order to insure thorough control of the margins, it is suggested that an area of 50 square miles should be taken. The estimate includes such taking.

The following is the estimated cost of constructing Schroon valley pure water reservoir and diversion weir, with necessary gate houses, sanitary protection and other special constructions:

Land damages	$1,000,000
Clearing and stripping	500,000
Dam at Tumblehead falls	600,000
Diversion weir	250,000
Sanitary protection	300,000
Miscellaenous	350,000
Amount	$3,000,000

The data for the preceding estimate are not very complete, but it is believed that the sum of $3,000,000 is large enough to meet somewhat adverse conditions.

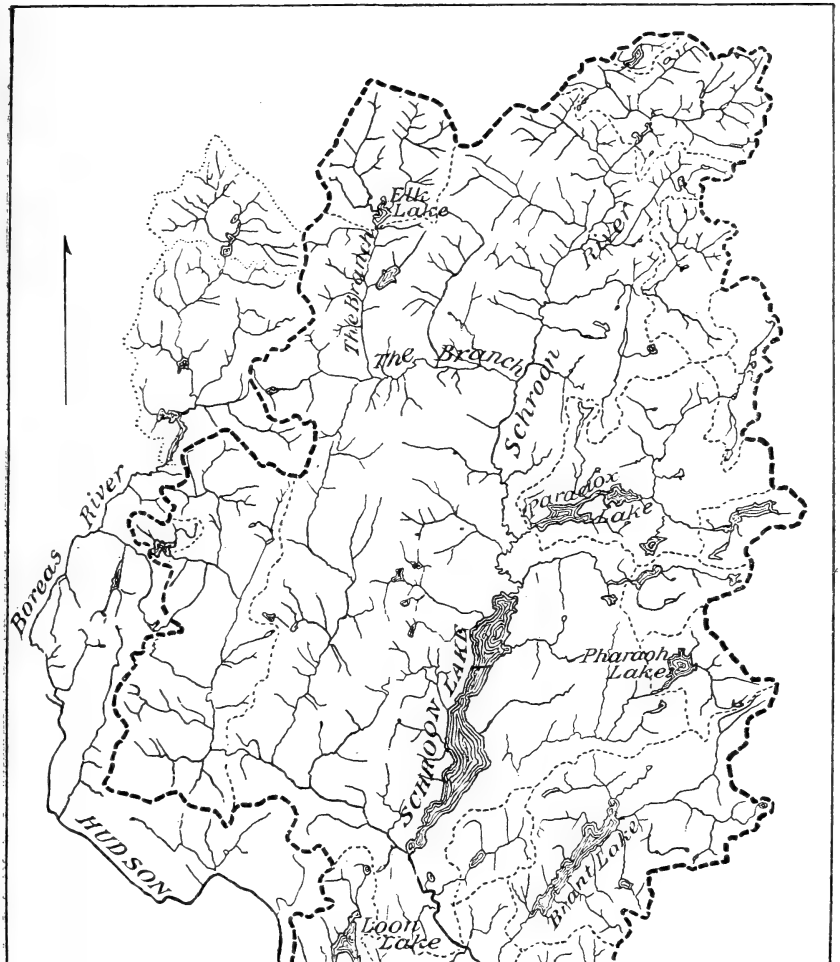
The construction of Schroon valley reservoir as here proposed would submerge several villages, of which the cost is included in land damages.

With a total storage of 21,662,000,000 cubic feet and total cost of $3,000,000, the cost per million cubic feet stored becomes roundly $138.50. In the same way the cost per million gallons stored becomes about $18.50.

Schroon valley reservoir no injury to waterpower on Hudson river. The foregoing discussion of Schroon valley reservoir project shows that not only may all injury to existing waterpower in Schroon valley be obviated, but that 10,639 gross horsepower may be permanently created there. With Hadley dam ultimately constructed, as proposed in the upper Hudson report of 1895, there would be stillwater in Hudson river from mouth of Schroon river to Hadley. Inasmuch as Hadley dam is intended as a regulator of upper Hudson reservoir system, without any special waterpower development connected therewith, no injury to waterpower above Hadley on account of diversion of 775 cubic feet per second would occur. But from the regulating dam down the Hudson river waterpowers would suffer, but not to the extent of the value of 775 cubic feet per second for the whole year. Broadly, the proposition takes this form: On account of large temporary storage on Schroon, Brant and Paradox lakes, the mean summer flow of Schroon river is higher than it would otherwise be for the given catchment area. Taking into account this natural advantage, what injury can be done to Hudson river waterpowers from Hadley to Troy by the continuous diversion of 775 cubic feet per second, the quantity so diverted to be drawn, not from the natural flow of the river, but from a large storage reservoir substantially regulating the entire flow for a series of years?

In answering this question we must take into account the character of the waterpower development on Hudson river. The most of it is 24-hour power used for pulp-grinding and paper-making. Pulp may be ground in high-water flow and stored for use in months of minimum flow. This circumstance has led to

Plate 17.



Catchment area of Schroon river.

development of Hudson river waterpowers to far beyond the low-water flow of the stream.

Without going into an elaborate discussion at this time, it is considered that under existing conditions to substantially divert the entire flow of Schroon river would be fairly equivalent to taking from 500 to 600 cubic feet per second from all waterpowers on the Hudson river from the George West paper mill at Hadley to Troy. This does not mean that 600 cubic feet per second would be taken away in the low-water months, but that for an average of all years the runoff of Schroon catchment area is equivalent to about 500 to 600 cubic feet continuously when applied to Hudson river waterpowers. As a provisional figure, accurate enough for present purposes, we may use 550 cubic feet per second. The following tabulation shows in column (4) the net power at 75 per cent efficiency of 550 cubic feet per second of water on the stated heads:

Designation of Dam (1)	Working head on wheels (2)	Approximate net horsepower actually developed in 1899 (3)	Net power at 75 per cent efficiency of 550 cubic feet per second (4)	Difference of columns (3) and (4) (5)
George West, Hadley....	18	1,350	845	505
Palmer's Falls...........	83	14,500	3,897	10,603
Canal feeder dam.......	10 to 12	1,450	515	935
Glens Falls..............	16 to 38	7,931	1,784	6,147
Sandy Hill	12	1,293	564	729
Baker's Falls............	58	3,500	2,724	776
Fort Edward............	18	6,393	845	5,548
Fort Miller..............	10	1,485	469	1,016
Saratoga dam	*18	3,130	845	2,285
Stillwater................	6	514	282	232
Mechanicville	16	3,355	751	2,604
Hudson River Power Co.	18	3,000	845	2,155
Troy	7	1,345	329	1,016
Total................	314	49,246	14,695	34,551

*The head at the Thomson Pulp and Paper Company's mill is 18 feet; at the Thomson and Dix sawmill it is from 8 to 10 feet.

The foregoing tabulation shows that on the assumed basis of 550 cubic feet per second the total decrease in waterpower would be 14,695 net horsepower, amounting to nearly 30 per cent of the whole.

Let us now examine rapidly as to the approximate value of Hudson river waterpower.

In the fall of 1898 the writer gathered the statistics of waterpower on Black river, where a total of 55,360 net horsepower is in use in 93 manufacturing establishments of various sorts and kinds. Of these 36 are papermills using 46,587 net horsepower. The approximate total value of the annual product of the 36 paper mills was found to be $5,242,620, whence the average value of the annual product per net horsepower becomes $112.50. Similar statistics have not been gathered for Hudson river, where the mills are fewer in number, but so much larger than on Black river that the annual product approximates $8,000,000 in value. Undoubtedly the cost of manufacturing in large, thoroughly equipped modern mills is less than in small mills, and the writer provisionally places the value of the annual product of Hudson river paper mills, per net horsepower actually used, at $135. On both Black and Hudson rivers the mills themselves grind a large proportion of the pulp used, and when this is done the net profits of the paper business, over and above interest on invested capital and all other fixed charges, may be assumed to range from 10 to 15 per cent. We will take 12 per cent as an average. On this basis the net annual profit on each net horsepower in use at Hudson river papermills becomes $16.20, which at 5 per cent represents a capitalized value of $324. In the absence of more exact data, and for the purposes of this discussion, we will use this figure as representing the approximate value of a net horsepower on Hudson river.[1] At this rate, the value of 14,695 horsepower becomes $4,761,180, which is the approximate damage to the Hudson river waterpowers from Hadley to Troy to result from taking the mean quantity of 775 cubic feet per second from Schroon valley catchment area.

Compensating reservoirs on Hudson river. However, reservoirs capable of supplying 500 to 600 cubic feet per second compensation could be constructed on headwaters of main North river and Sacandaga river for less than $4,761,180.

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[1] At Troy there is a small amount of miscellaneous manufacturing to which a larger figure could be properly applied.

On Black river, in eight machine shops, the average value of the annual product per net horsepower is $1728; in nine flour and feed mills, $627.20, etc.

Thus far the trend of legal decisions in the State of New York and in the United States generally has been against compensation in kind in water diversion cases.[1] Our courts have usually held that money compensation may be exacted in such cases. But on the Hudson river, where water rights are not only appreciating in value rapidly, but are furthermore mostly held by strong manufacturing corporations, it is possible that the principle of compensation in kind could be applied by simple agreement with the present owners. At any rate, we may assume for present purposes that this is true, and accordingly briefly discuss a system of compensating reservoirs large enough to supply 500 to 600 cubic feet per second, either continuously or so far as might appear necessary after a more thorough study of the regimen of the stream.

With Hudson river runoff, the capacity of a reservoir capable of certainly furnishing 650 cubic feet per second continuously should be, roundly, 16,000,000,000 cubic feet. To furnish 550 cubic feet per second continuously about 12,000,000,000 cubic feet would answer. The location and approximate cost of a series of reservoirs for this purpose would be as follows:

Name of Reservoir	Location, on what stream	Estimated capacity in cubic feet	Tributary catchment area, in square miles	Estimated cost
Conklinville....	Sacandaga river.	10,000,000,000	900	$1,400,000
Lake Pleasant..	Sacandaga river.	1,400,000,000	45	110,000
Piseco lake.....	Sacandaga river.	1,725,000,000	55	100,000
Arietta flow....	Sacandaga river.	1,400,000,000	40	80,000
Wakely flow...	Cedar river......	1,819,000,000	58	150,000
Boreas and Cheney ponds....	Boreas river.....	1,411,000,000	45	160,000
Total......	....	17,755,000,000	....	$2,000,000

Taking into account the large catchment area tributary to the proposed Conklinville reservoir, it is considered that the foregoing total storage of 17,755,000,000 cubic feet would considerably more than compensate—on the basis already outlined—for the permanent diversion of 775 cubic feet per second.[2]

See case of Black river cited on page 539.

[2] The stated tributary catchment area of 900 square miles above Conklinville is exclusive of Lake Pleasant, Piseco lake and Arietta flow catchments. The total, with these included, is 1040 square miles.

The total estimated cost, as per the preceding, of $2,000,000 is based on present labor conditions, etc. in the State of New York. So far as the writer can determine with the data at hand, $2,000,000 will construct the compensating reservoirs proposed in the foregoing.

Inasmuch as four of these reservoirs are located in Sacandaga river catchment, which stream is tributary to the Hudson river below proposed Hadley regulating reservoir, that reservoir is not included in present series.

The following shows the difference in cost between paying waterpower damages and providing a system of compensating reservoirs:

Waterpower damages	$4,761,180
Cost of compensating reservoirs	2,000,000
Difference	$2,761,180

With the system of compensating reservoirs the total estimated cost of reservoir system for supply of 775 cubic feet per second becomes $4,000,000. But if waterpower damages were to be paid in money, as per the foregoing, the approximate figure becomes $7,761,180. For even figures, we may take the latter at $8,000,000.

If, however, we assume that, owing to legal difficulties, not only the principle of compensation in kind can not be applied, but that a partial taking of the properties is impracticable, it follows that the amount to be paid on account of the proposed diversion of 775 cubic feet per second—supplied from a single large reservoir substantially controlling the entire flow of Schroon river—becomes considerably greater. The data are not at hand for accurately estimating the full value of the several properties affected, but from casual examination the provisional figure of from $12,000,000 to $15,000,000 may be assumed. In any case, if the entire properties were acquired by the City of New York, apparently the rational procedure would be to make such reservations as might seem necessary in order to secure the city's right to 775 cubic feet per second, or any other quantity fixed upon, and to then sell the properties subject to such reservation. By proceeding on this line the City of New York ought to be able to acquire the right to draw 775 cubic feet of water per second at a cost not exceeding the sum of $4,761,180, previously found. As an alternative proposition, the city might build the compensation storage and realize the full value of the property when sold.

Water supply for New York city from Lake George. About 1880 the New York and Hudson Valley Aqueduct Company was incorporated to construct a water supply from Lake George and upper Hudson for New York and other cities of lower Hudson valley. Reports on this project were made by Col. J. T. Fanning, chief engineer, under dates of December 1881, and November 1884. Colonel Fanning proposed to divert Hudson river above Glens Falls, utilizing the extended area of Lake George for storing flood-flows. In this way it was considered that a supply of 1,500,000,000 gallons per day could, if necessary, be obtained (2315 cubic feet per second). Since Colonel Fanning's reports are readily obtainable, space will not be taken to give his conclusions in detail. The following are the main elements of the Lake George project, as deduced from the topographic sheets of the United States Geological Survey:

Elevation of lake surface above tidewater..	323.0 feet
Catchment area, including water surface..	229.0 square miles
Area of water surface....................	43.4 square miles
Area of 340 contour......................	49.2 square miles
Storage between 323 + T. W. and 340.....	21,043,308,540 cubic feet

Lake George is surrounded by mountains rising to an altitude of from 1500 to 2700 feet above tidewater. There is little special knowledge of the rainfall, but it can not be materially different from that of the Hudson river catchment area. The outlet is at the northern end of the lake, and has a fall in a distance of about a mile of 222 feet, which is largely utilized in paper making, information at hand indicating a total development of from 4000 to 5000 net horsepower. Taking the value of waterpower as previously used the damage to Lake George outlet waterpowers may be computed at $1,458,000. But since the entire properties would be taken we may, in this case, estimate that the final damage would not be less than $2,000,000.

There are many large hotels and summer resorts about Lake George which would be mostly destroyed by raising the lake surface from 17 to 20 feet. The taking of an additional strip, for sanitary protection, as in Schroon valley, would include nearly all of these, as well as the village of Caldwell.

Basing the Lake George project on 775 cubic feet per second supply, the same as for Schroon valley, it is found that from 300 to 350 cubic feet per second would come from the Lake George catchment area. The balance can be obtained from Schroon valley by a tunnel through the intervening ridge at a point above Warrensburg, where the distance across is only 3.25 miles (17,160 linear feet). A diversion weir with proper regulating headworks would be required on Schroon river. The elevation of Schroon river at the point of diversion is about 670 feet. With Lake George taken at 323 feet, the difference becomes 347 feet.

For several months of each year the runoff of Schroon river exceeds 550 cubic feet per second, the mean runoff for four years being 1112 cubic feet per second. Hence, a mean of 550 cubic feet per second could be diverted into Lake George and still leave Hudson river waterpowers substantially unimpaired. The connecting tunnel should therefore have a capacity of about 2600 to 2800 cubic feet per second in order to divert the full flood-flows.

The following is an approximate estimate of cost of Lake George storage with diversion tunnel from Schroon valley, etc.:

Land damages, Lake George	$1,500,000
Dam at foot of Lake George	200,000
Water rights on Lake George outlet	2,000,000
Sanitary protection	400,000
Clearing and stripping	300,000
Diversion weir and headworks on Schroon river	100,000
Diversion tunnel	1,500,000
Compensation reservoirs	200,000
Miscellaneous	500,000
Total	$6,700,000

A comparison of this estimate with the foregoing for Schroon valley project fairly leads to the conclusion that independent of lack of elevation at Lake George, the Schroon valley project is preferable. The quality of Lake George water—the same as Schroon river—is unexceptionable.

Reservoir system for river regulation only. This project proposes the development of storage on headwaters of the Hudson river in order to hold low-water flow at as high a point as possible, thereby driving salt water further downstream and consequently permitting of taking a supply from the lower Hudson by pumping lower down than would otherwise be possible.

In the first report on the upper Hudson surveys it is shown that a reservoir system may be developed capable of maintaining a flow at Mechanicville of 4500 cubic feet per second. The following tabulation gives the main elements of such a system of reservoirs so far as worked out, together with the approximate cost of the same, all based on 13.5 inches on the catchment except Schroon valley, which is taken at 18 inches:

Name of Reservoir (1)	Location, on what stream (2)	Estimated capacity in cubic feet (3)	Tributary catchment area in square miles (4)	Estimated cost (5)
Conklinville	Sacandaga river	10,000,000,000	900	$1,400,000
Lake Pleasant	Sacandaga river	1,400,000,000	45	110,000
Piseco lake	Sacandaga river	1,725,000,000	55	100,000
Arietta flow	Sacandaga river	1,400,000,000	40	80,000
Hadley	Main North river	4,000,000,000	....	750,000
Thirteenth pond	Main North river	439,000,000	14	160,000
Chain lakes	Main North river	1,819,000,000	58	45,000
Catlin lake	Main North river	784,000,000	25	50,000
Lakes Rich, Harris, Newcomb, etc.	Main North river	2,603,000,000	83	250,000
Lake Henderson	Main North river	565,000,000	18	40,000
Tahawus flow	Main North river	2,101,000,000	67	240,000
Boreas river, etc.	Boreas river	1,411,000,000	45	160,000
Wakely flow	Cedar river	1,819,000,000	58	150,000
Tumblehead falls	Schroon river	21,662,000,000	518	1,700,000
Total	....	51,728,000,000	....	$5,235,000

The capacity of Indian lake reservoir of about 5,000,000,000 cubic feet should be added to the foregoing total of 51,728,000,000 cubic feet, giving a final total of 56,728,000,000 cubic feet. Further examination will probably show that a somewhat greater storage can be obtained, but thus far the data for final conclusions have not been gathered. A moderate amount of storage may also be constructed on headwaters of Mohawk river, but only general statements can be made for lack of definite data. Probably enough storage can be made here to give a final storage on Hudson and Mohawk rivers of about 75,000,000,000 cubic feet.

The foregoing estimates of cost also take into account present labor conditions, etc. in New York State. The approximate cost per million cubic feet of storage is found to be $101.

The advantages of such a system of reservoirs to Hudson river waterpowers have been so fully set forth in the preceding pages as to render further discussion under that head unnecessary in this place.

Leaving for the present the possible storage of the upper Mohawk river out of account, and basing conclusions on 56,728,000,000 cubic feet storage on the upper Hudson, we may say, taking into account low-water flow of the Mohawk river and other tributaries of the Hudson river below Mechanicville, that the fresh water inflow of the lower Hudson river may be kept up to over 6000 cubic feet per second. At present it is occasionally somewhat less than 2000 cubic feet per second. The effect of flows of 5000 to 6000 cubic feet per second on the depth of water at Albany may be obtained from a series of diagrams of tidal fluctuations at Albany for the summer seasons of 1895–1898, inclusive. The first of these diagrams is plate VI of the first Upper Hudson Storage Report (1895), and the second, plate VII of the Report on Water Supply of Summit Levels to United States Board of Engineers on Deep Waterways (1899).

DEVELOPMENT OF WATERPOWERS

Power Development at Niagara Falls

The possibility of waterpower development at Niagara Falls has attracted attention for many years, the first utilization there having been made in 1725, when the French erected a sawmill near the point where the Pittsburgh Reduction Company's upper works now stand for the purpose of supplying lumber for Fort Niagara. Between 1725 and the early years of the present century little is known of the use made of Niagara Falls power further than that sawmills were in operation there during the whole period. In 1805, however, Augustus Porter built a sawmill on the rapids, and in 1807 Porter & Barton erected a gristmill. In 1817 John Witmer built another sawmill at Gill creek, and

Plate 18.

View of head of canal of the Niagara Falls Hydraulic Power and Manufacturing Company.

in 1822 Augustus Porter built a gristmill along the rapids above the falls. From that year to 1885, when the lands along the river were taken for a State park, a considerable amount of power was developed by a canal which took water out of the river near the head of the rapids and followed along the shore nearly parallel with the bank of the river. Mills were built between this canal and the river, and a part of the 50-foot fall between the head of the rapids and the brink of the American Falls was thus utilized. A papermill was built on Bath island at an early date.

In 1842 Augustus Porter, one of the principal mill owners at Niagara Falls, proposed a considerable extension of the then existing system of canals and races, and in January, 1847, in connection with Peter Emslie, he published a formal plan which became the subject of negotiations with Walter Bryant and Caleb S. Woodhull. An agreement was finally reached by which they were to construct a canal and receive a plot of land at the head of the canal, having a frontage of 425 feet on Niagara river, together with a right of way 100 feet wide for the canal along its entire length of 4400 feet, and about 75 acres of land near the terminus, having a frontage on the river below the falls of nearly a mile. The canal constructed under this agreement passes through what is now the most thickly settled part of the city of Niagara Falls.

Ground was broken by Messrs Bryant & Woodhull in 1853 and the work carried on for about sixteen months, when it was suspended for lack of funds. Nothing further was done until 1858, when Stephen Allen carried the work forward for a time; later, in 1861, Horace H. Day took up the matter and completed a canal 36 feet wide, 8 feet deep, and 4400 feet long, by which the water of the upper river was brought to a basin near the brink of the high bluff of the lower river and at an elevation of 214 feet above the lower river. Upon the margin of this basin various mills have been constructed, to the wheels of which water is conducted from the canal and discharged through the bluff into the river below. The first mill built on this hydraulic canal was a small gristmill, erected by Charles B. Gaskill in 1870 on the site of the present large flouring mill of the Cataract Milling Company.

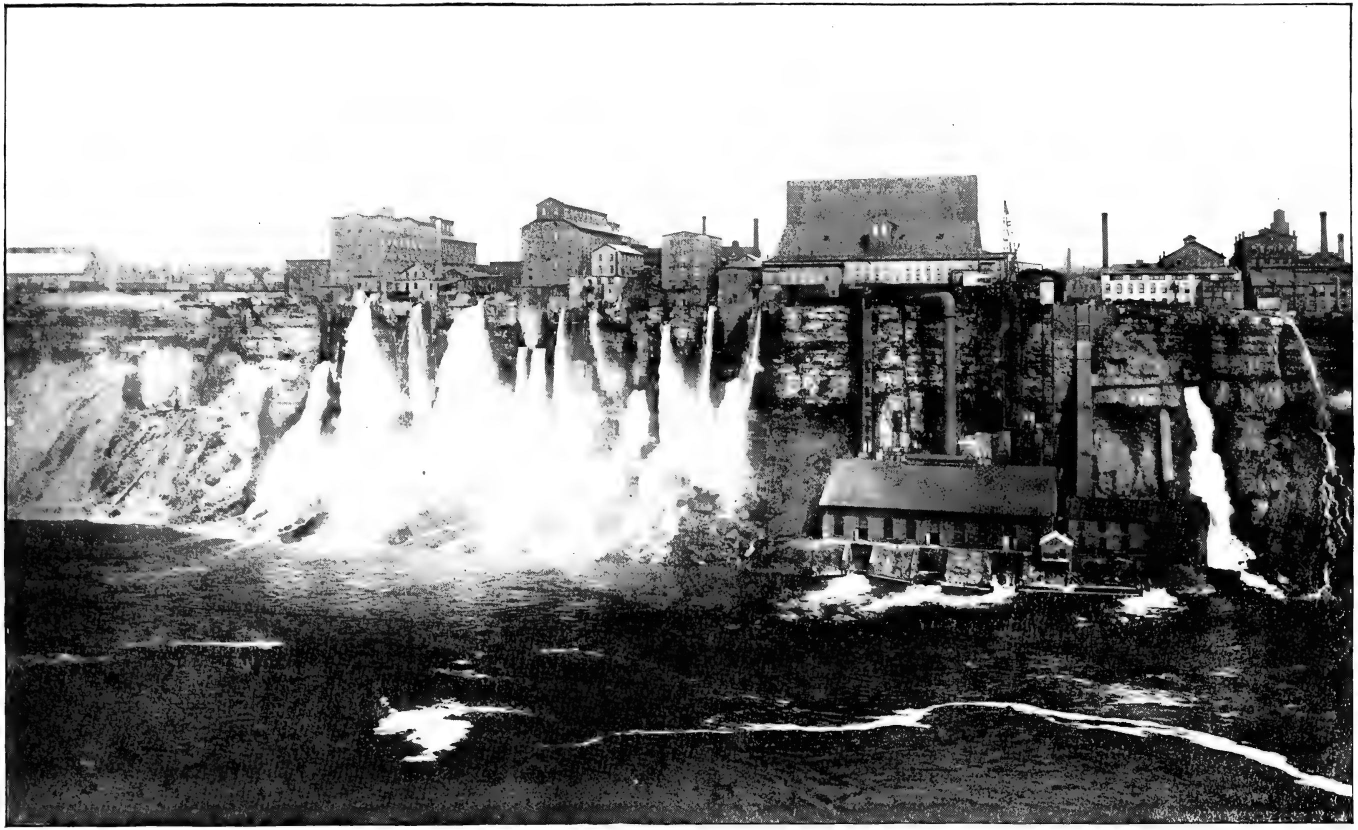
Niagara Falls Hydraulic Power and Manufacturing Company. In 1877 the hydraulic canal and all its appurtenances were purchased by Jacob F. Schoellkopf and A. Chesbrough, of Buffalo, who organized the Niagara Falls Hydraulic Power and Manufacturing Company. The following is a list of companies either supplied or to be supplied with power by the Niagara Falls Hydraulic Power and Manufacturing Company:

POWER FURNISHED BY NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY IN 1897

Company	Business	Horse-power
(a) Hydraulic power		
Central Milling Co.	Flouring mill	1,000
N. Wood Paper Co.	Paper and pulp	500
Schoellkopf & Mathews	Flouring mill	900
Pettebone Cataract Manufacturing Co.	Paper and pulp	2,000
Cataract Milling Co.	Flour	400
Niagara Falls Waterworks		200
Thomas E. McGarigle	Machine shop	25
Cliff Paper Co.	Paper and pulp	2,500
Total		7,525
(b) Electric power		
Pittsburg Reduction Co.	Aluminum	3,500
Niagara Falls and Lewiston R. R. Co.		400
Cliff Paper Co.	Paper and pulp	300
Lewiston and Youngstown R. R. Co.		200
Buffalo and Niagara Falls Electric Light and Power Co.	Light and power	600
Niagara Falls Brewing Co.		150
Rodwell Manufacturing Co.	Silver plating, etc.	75
Sundry small customers in Niagara Falls		100
Francis Hook and Eye Co.	Hooks and eyes	15
Kelly and McBean Aluminum Co.	Aluminum	15
The National Electrolytic Co.		1,000
Total		6,355
(c) Mechanical power furnished on shaft		
Oneida Community, Limited	Silver-plated ware and chains	300
Carter-Crum Co.	Check books	60
Total		360
Grand total		14,240

The contract made in 1852 between Augustus Porter, Walter Bryant, and Caleb S. Woodhull only conveyed lands to the edge of the high bank of Niagara river, but did not include the talus or slope between the edge of the high bank and the river, and only

Plate 19.



Power-house of the Niagara Falls Hydraulic Power and Manufacturing Company.

granted the right to excavate 100 feet down the face of the bank. In 1852, when this contract was made, the use of waterpower under higher heads than 100 feet was, so far as the United States was concerned, entirely unknown. Until recently the mills at Niagara Falls have not attempted to use more than 50 or 60 feet head; hence it resulted that although the capacity of the Niagara Falls Hydraulic Power and Manufacturing Company's canal, as at first constructed, was sufficient, by development of the whole head, to produce about 15,000 horsepower, under the original agreements its capacity was exhausted when about 7000 horsepower was produced.

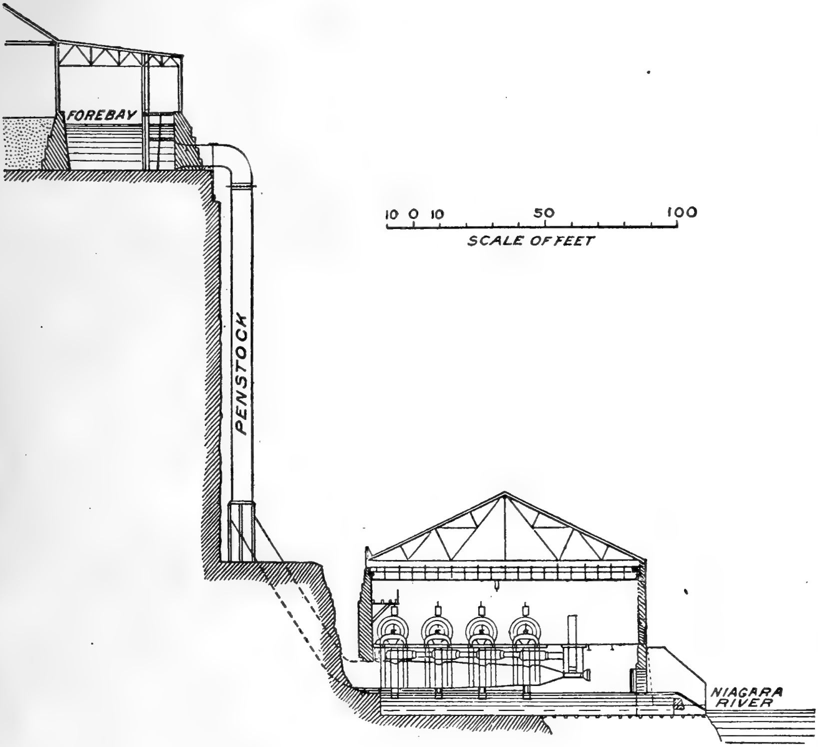


Fig. 41. General plan of development of the Niagara Falls Hydraulic Power and Manufacturing Company.

In 1892 the Niagara Falls Hydraulic Power and Manufacturing Company began an enlargement and improvement of its canal. The plan adopted was to widen the original channel at one side to 70 feet, and make the new part 14 feet deep. This work is cut entirely through rock, below the water line. The enlargement of one side was completed in 1896. The canal as enlarged to date has a capacity of about 3000 cubic feet per second, giving under present conditions a total of from 40,000 to 50,000 horsepower, the cross-section being about 400 square feet.

In a letter from John Harper, engineer of the company, written under date of May 24, 1904, it is stated that the total present development of this company is 43,000 horsepower, and that work is now in progress on an additional 100,000-horsepower plant to be entirely located below the cliff. Of this quantity 10,000 horsepower is by water from the company's waterway.

This company has a grant from the State of the right to draw from Niagara river as much water as can be taken through a canal 100 feet wide and 14 feet deep.

To July 1, 1897, about 100,000 cubic yards of material had been taken out at a cost of $250,000, the average cuttings in the original canal from the surface of the ground to the surface of the water being about 8 feet.

The development by this company is very interesting. A bulkhead is located at the top of the high bank with a forebay back of it connected with the main hydraulic canal by a shortbranch canal. From the forebay a large penstock leads vertically down the cliff to a powerhouse located directly on the shore of the lower river. In this power-house horizontal turbine water wheels are placed, with dynamos directly connected, the power therefrom being transmitted either to the mills on the bluff above or to establishments at a distance. Without taking into account the cost of water in the canal, the cost of the development of power in the way in which it is now being developed by this company may be placed at $35 per horsepower.[1]

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[1] For further details of the Niagara Falls Hydraulic Power and Manufacturing Company, see (1) Power Development of Niagara Falls, other than that of the Niagara Falls Power Company, by W. C. Johnson: Trans. Engineers' Society of Western New York, Vol. I, No. 6 (Feb. 3, 1896); (2) Niagara Falls Hydraulic Power and Manufacturing Company's New Work, by Orrin E. Dunlap: Electrical Engineer, Vol. XX (Dec. 4, 1895); (3) Old Hydraulic Power Plant at Niagara Falls Transformed for Electrical Trans-

Plate 20.

View of interior of station of Niagara Falls Hydraulic Power and Manufacturing Company.

Niagara Falls Power Company. The Niagara Falls Power Company has developed an extensive plant on quite different lines from that of the Niagara Falls Hydraulic Power and Manufacturing Company. In 1883 to 1885 Thomas Evershed, who was at that time division engineer of the western division of the New York State canals, was called on to survey Niagara Falls Park Reservation, as provided for by act of the Legislature. This led Mr Evershed to spend considerable time at Niagara Falls, during which he conceived the project of constructing a tunnel to begin at the level of the lower river and extend under the city of Niagara Falls for a distance of about 2½ miles. This tunnel was to be generally parallel to the Niagara river, but at some little distance from it. At its head and at various points along the river from above Port Day it was proposed to construct branch canals connecting

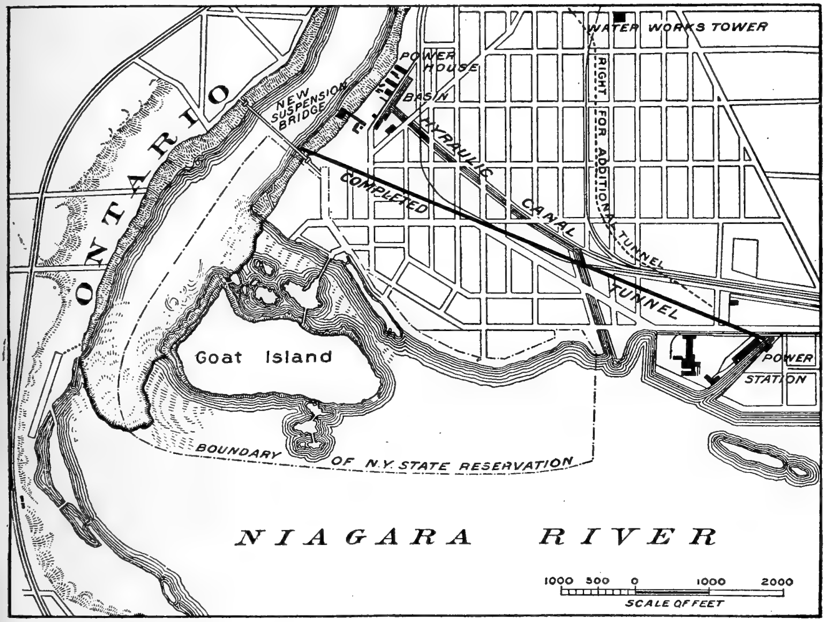

Fig. 42 Niagara Falls and vicinity, showing location of the great tunnel.

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mission, by Orrin E. Dunlap: Western Electrician, Vol. XIX (Dec. 5, 1896); (4) Pulp Mill of the Cliff Paper Company of Niagara Falls, New York, by W. C. Johnson: Trans. Am. Soc. Civil Eng., Vol. XXXII (Aug., 1894).

with the river and through which water could be taken, to be discharged upon turbine wheels placed in vertical wheel pits and connected with the tunnel at various points.

The Niagara River Hydraulic Tunnel, Power and Sewer Company of Niagara Falls was incorporated in 1886 for the purpose of constructing and operating, in connection with Niagara river, a hydraulic tunnel or subterranean sewer for public use in the disposal of sewage and drainage and for furnishing hydraulic power for manufacturing purposes in the town of Niagara Falls. In consideration of the public service of sewerage and drainage, this company was authorized to acquire land by condemnation.

The general plan of development is described by Mr Evershed in a report made July 1, 1886, in which he states that the main tunnel would begin at a point on the lower river immediately north of the State reservation, with its mouth as low as high water below the falls would permit. From this point to half a mile above Port Day it should have a rise of 1 foot in 100, or 52.8 feet per mile, and a section above Port Day equivalent to a circle 24 feet in diameter, the tunnel gradually diminishing in size in accordance with the number of mills emptying tail-water into it, until at the upper end it would have the same area of cross section as the connecting cross tunnels.[1]

The matter remained in abeyance until 1889, when the Niagara Falls Power Company was organized to carry out, in effect, Mr Evershed's plan. The actual work of construction was undertaken by the Cataract Construction Company, composed of William B. Rankine, Francis Lynde Stetson, Pierpont Morgan, Hamilton McK. Twombly, Edward A. Wickes, Morris K. Jesup, Darius Ogden Mills, Charles F. Clarke, Edward D. Adams, Charles Lanier, A. J. Forbes-Leith, Walter Howe, John Crosby Brown, Frederick W. Whirtridge, William K. Vanderbilt, George S. Bowdoin, Joseph Larocque, John Jacob Astor and Charles A. Sweet. This company has modified the original plans in some particulars, although the general scheme has been carried out.

The plan finally determined on comprised a surface canal 250 feet in width at its mouth on the river, 1¼ miles above the falls,

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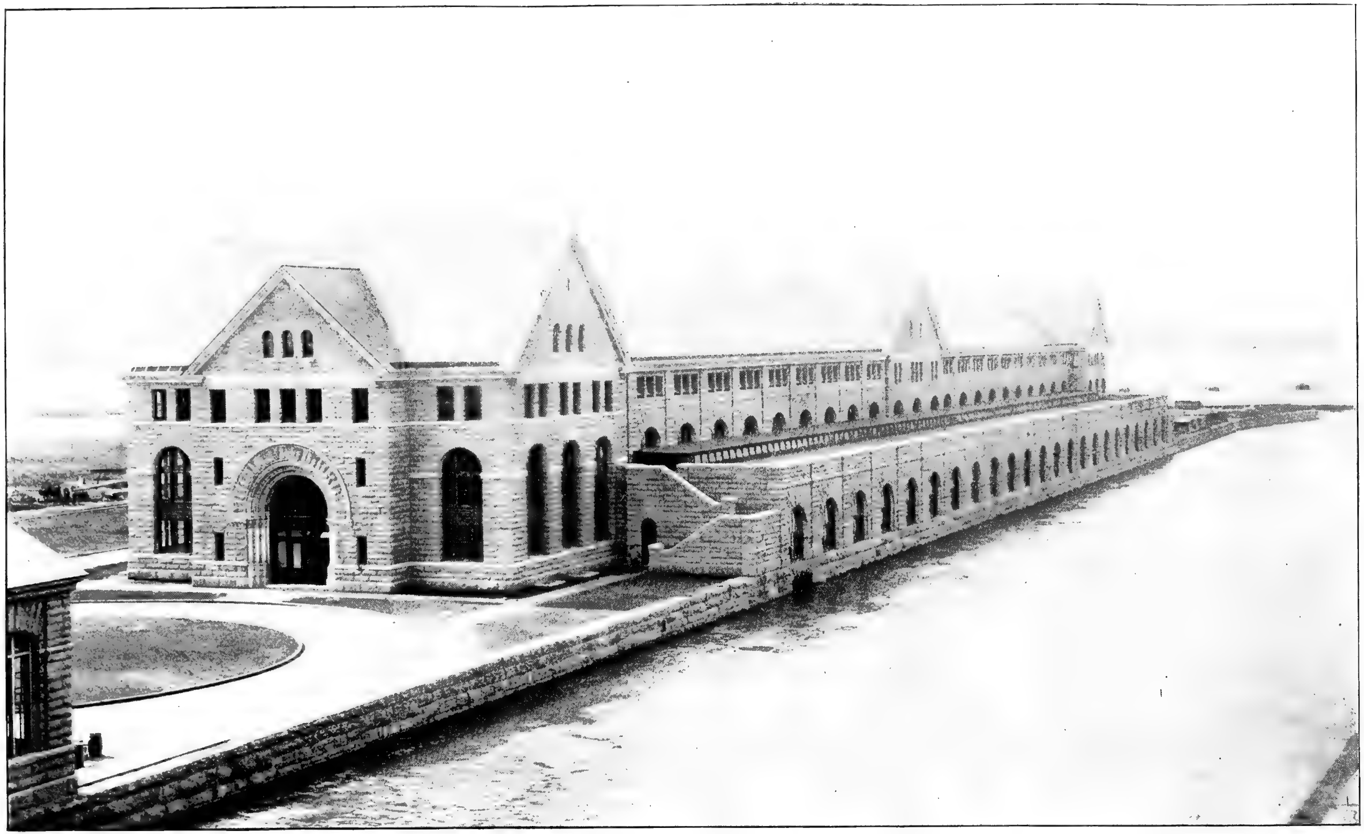
[1] See pamphlet, Water Power at Niagara Falls, prospectus of the Niagara River Hydraulic Tunnel, Power and Sewer Company (1886).

Plate 21.



Power-house of the Niagara Falls Power Company.

extending inwardly 1700 feet, with an average depth of 12 feet, and computed to furnish water sufficient for the development of about 120,000 horsepower. The masonry walls of this canal are pierced at intervals with inlets, guarded by gates. Some of these are used to deliver water to tenants who construct their own wheel pits and set their own wheels, while 10 of them are arranged on one side of the canal for the purpose of delivering water to the wheel pit of the Niagara Falls Power Company's power station, where dynamos, placed at the top of turbine vertical shafts, generate electricity for transmission. The wheel pit at the power station is 178 feet in depth and connected with the main tunnel by a short cross tunnel. The main tunnel as carried out has a maximum hight of 21 feet and a width of 18.82 feet, making a net section of 386 square feet. The slope of this tunnel is 6 feet to 1000.

The most careful consideration was given to the subject of the turbines to be used, as well as to the question of power transmission. In 1890 Edward D. Adams, who was then president of the company, established an International Niagara Commission, with power to offer $20,000 in prizes. This commission consisted of Sir William Thomson (now Lord Kelvin), Dr Coleman Sellers, Lieut. Col. Theodore Turretini, Prof. E. Mascart, and Prof. W. C. Unwin. Inquiries concerning the best-known methods of development and transmission of power in England, France, Switzerland and Italy were made, and competitive plans were received from twenty carefully selected engineers and manufacturers of power plants in England, Europe and America. These plans were submitted to the commission, which awarded prizes to those considered worthy. The most important result was the selection of the designs of Faesch and Piccard, of Geneva, for turbines computed to yield 5000 horsepower each. Three wheels have been built from these designs and are now in place and regularly operated.

Without going into details of the electrical work, it may be stated that the Niagara Falls Power Company adopted the two-phase alternating current system as best adapted to its work. In the dynamos employed the field magnet revolves instead of the armature. As advised by the company's electrical engineer, Prof. George Forbes, of London, three such dynamos, of 5000 horsepower each, constructed by the Westinghouse Company, of Pittsburg, have been installed. During the summer of 1896 a transmission line was constructed from Niagara Falls to Buffalo, and since November of that year some of the street railways in Buffalo have been operated electrically by power from Niagara Falls.

According to a statement of William B. Rankine, secretary of the Cataract Construction Company, the power furnished or contracted for by the Niagara Falls Power Company July 1, 1897, was as follows:

POWER FURNISHED BY THE NIAGARA FALLS POWER COMPANY IN 1897

Company	Business	Horse-power
(a) Hydraulic power		
Niagara Falls Paper Company	Paper	7,200
(b) Electric power		
Pittsburg Reduction Company	Aluminum	3,050
The Carborundum Company	Abrasives	1,000
Acetylene Light, Heat and Power Company	Calcium carbide	1,075
Buffalo and Niagara Falls Electric Light and Power Company	Local lighting	500
Walton Ferguson	Chlorate of potash	500
Niagara Electro-Chemical Company	Peroxide of sodium	400
Buffalo and Niagara Falls Electric Railway	Local railway	300
Niagara Falls and Suspension Bridge Railway Company[1]	Local railway	250
Buffalo Street Railway Company	22-mile transmission	1,000
Acetylene Light, Heat and Power Company[2]	Calcium carbide	4,000
Mathieson Alkali Works[3]	Soda ash	4,000
Buffalo Street Railway Company		1,000
Buffalo General Electric Company[4]	Lighting	3,000
The Carborundum Company[5]	Abrasives	1,000
Niagara Falls Water Works Company		45
Power City Foundry and Machine Company		25
Albright and Wilson	Electro-chemicals	400
Total hydraulic power sold at Niagara Falls		7,200
Total electric power sold at Niagara Falls		16,545
Total electric power sold at Buffalo		5,000
Total		28,745

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[1] All from October 1, 1896.

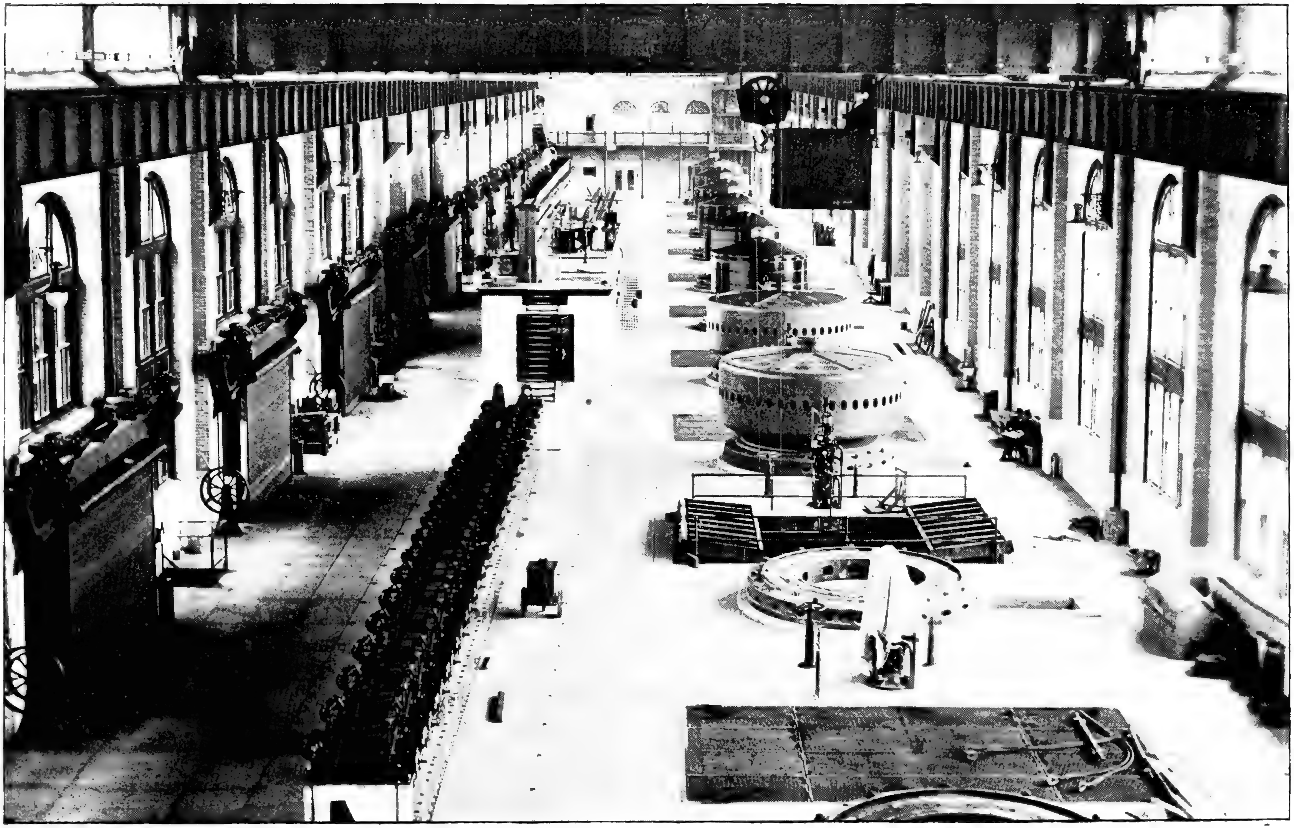
[2] From delivery, say, November 1, 1897.

[3] From June 1, 1897.

[4] From November 15, 1897.

[5] From June 1, 1897.

Plate 22.



View of interior of power-house of the Niagara Falls Power Company.

Recapitulation of the total power in use or furnished from Niagara Falls January 1, 1898, shows the following amounts:

	Horsepower
Hydraulic power:	
Niagara Falls Power Company	7,200
Niagara Falls Hydraulic Power and Manufacturing Company	7,525
Electric power:	
Niagara Falls Power Company	21,545
Niagara Falls Hydraulic Power and Manufacturing Company	6,355
Mechanical power:	
Niagara Falls Hydraulic Power and Manufacturing Company	360
Total	42,985

The officers of the Niagara Falls Power Company in 1904 are D. O. Mills, president; Edward A. Wickes, first vice-president; William B. Rankine, second vice-president and treasurer; E. L. Lovelace, secretary, and W. Paxton Little, assistant secretary and assistant treasurer.

This company has largely extended its power-house within the last two or three years. In a letter from William B. Rankine, under date of March 21, 1904, it is stated that eleven dynamos in the new power-house are now in place so that the units installed in both power-houses have a rated capacity of 110,500 horsepower, and that the company is delivering to its consumers at Niagara Falls, Buffalo and intermediate points a maximum of 75,000 horsepower.

The 110,500 horsepower now developed represents the full capacity of the present tunnel. This company has secured the right of way for a second discharge tunnel, so that when the demand for power renders it necessary, the present plant may be duplicated, thus furnishing 200,000 horsepower. In addition to this large development on the American side, originally the Canadian Niagara Power Company, an allied corporation, held from the Canadian government an exclusive franchise granting to it the right to develop on the Canadian side at least 250,000 horsepower, but this has been modified and in 1904 additional developments are in process on the Canadian side by the Ontario Power Company and the Electrical Development Company of Ontario. The Canadian Niagara Power Company proposes to limit its development to 110,000 horsepower while the Ontario Power Company will develop 180,000 horsepower. The Development Company of Ontario has a capacity of 125,000 horsepower. The total possible power which may be developed in the future at Niagara Falls is about as follows:[1]

	Horsepower
Niagara Falls Power Company's present tunnel	100,000
Niagara Falls Power Company's second tunnel	100,000
Niagara Falls Hydraulic Power & Manufacturing Company's canal	150,000
Canadian Niagara Power Company's tunnels	110,000
Ontario Power Company	180,000
Development Company of Ontario	125,000
Total	765,000

The developments in progress at Niagara Falls are being carried out on very broad lines and probably furnish the best examples of modern hydraulic work. They certainly lead so far as the United States and Canada are concerned. A complete account of the works, giving details of all the engineering features, would make a large-sized monograph.[2]

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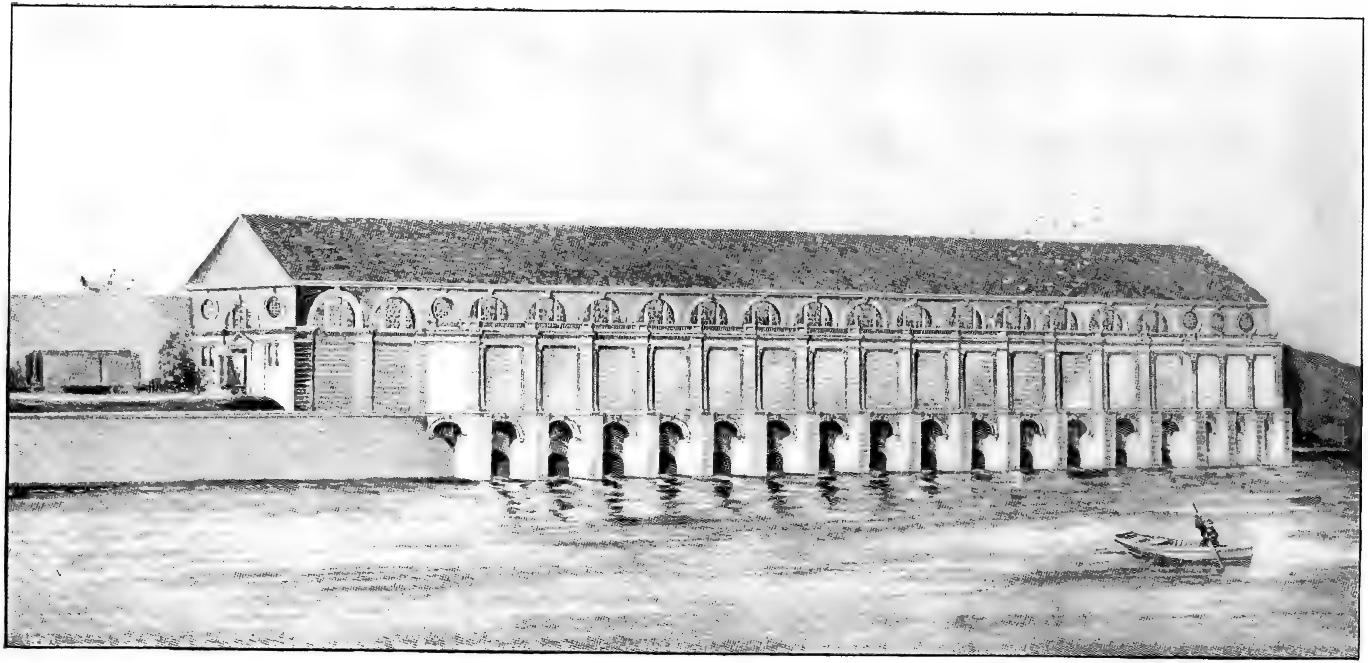
[1] For an interesting discussion as to the effect of diverting large quantities of water from Niagara river for power purposes, see report of Clemens Herschel, made December 12, 1895, on the Diversion of Water from the Niagara River for Power Purposes by the Niagara Falls Hydraulic Power and Manufacturing Company and by the Niagara Falls Power Company, and the Unimportant Effect of such Diversion upon the River. Mr. Herschel bases his discussion on the data of the lake survey of an ordinary and usual flow of 265,000 cubic feet per second. Reasoning from this premise he concludes that even when 300,000 or 400,000 horsepower are in use the effect upon the depth of the river will be insignificant. It seems clear enough that this proposition is open to discussion.

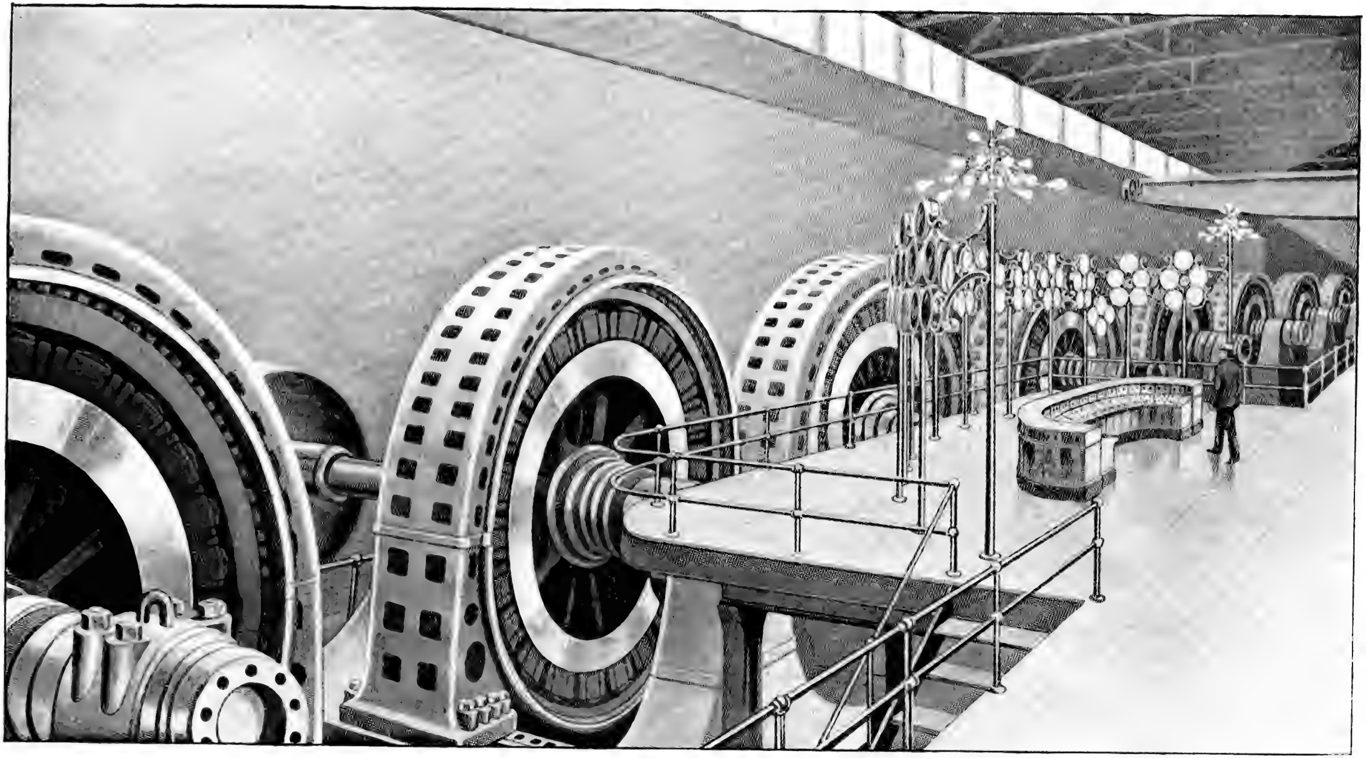
[2] The main facts in regard to the plant of Niagara Falls Power Company have been furnished by L. H. Groat, former secretary of the company. For more extended information the reader is referred to 1) Cassier's Magazine,

Plate 23.



Power-house of the St Lawrence Power Company.

Plate 24.



Interior of power-house of the St Lawrence Power Company.

Power Development on St Lawrence River

The St Lawrence Power Company. Among the large power developments under construction in the State of New York is that of the St Lawrence Power Company at Massena, on St Lawrence and Grasse rivers. The plant includes the excavation of a canal leading from the St Lawrence river to Grasse river, a distance of three miles, the building of a power-house, together with the installation of electric generators and the necessary equipment of turbine water wheels. The furnishing of the electric apparatus was awarded to the Westinghouse Electrical & Manufacturing Company.

The plan of development is to divert a portion of the water of St Lawrence river from its natural channel by means of a canal, carrying it 3 miles across to Grasse river, where, after operating turbines, it will pass by way of Grasse river to the St Lawrence at a point lower down stream. Just below where the canal takes water from St Lawrence river are Long Sault rapids, which have a fall of about 50 feet. Grasse river runs nearly parallel to the St Lawrence for several miles, flowing into it a short distance below the foot of Long Sault rapids. To the south of the St Lawrence river, and between it and the valley of Grasse river, there is a comparatively level plateau.

The average width of Grasse river from its mouth to above where the power canal will intersect it is from 250 to 300 feet, and its water surface, for that portion, is substantially on a level with St Lawrence below the rapids; hence the surface of Grasse river at the point where the power canal strikes the stream is from 45 to 50 feet below the surface of the St Lawrence at the head of the canal. The power station will be located on the north bank of Grasse river, the tail-water dropping into that stream, which thus becomes, in effect, a tailrace for this power develop-

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Vol. VIII (July, 1895), where may be found an account of nearly every phase of the Niagara Falls Power Company's development; 2) The Electrical World, Vol. XXX (Oct. 23, 1897), which may be consulted for a description of the extension of the wheel pit; 3) Niagara Falls publication of the Niagara Falls Chamber of Commerce, issued in 1897; 4) the various numbers for 1897 of Greater Buffalo, a monthly publication devoted to promoting the prosperity of Buffalo and Niagara Falls. Engineering News and other technical journals may also be consulted.

ment. Making some allowance for increased depth of water in Grasse river between the power station and its mouth, when receiving the tail-water, and also some allowance for inclination of the water surface of the head canal, it is considered that a permanent power of about 40 feet will be obtained.

The work of constructing the canal and preliminary work on the foundations of the power-house was started in 1897, at which time it was expected that the work would be completed in 1899. The St Lawrence Power Company, by whom the work has been done, was organized under the laws of New York with a capital stock of $6,000,000.

For the present, work upon the canal was completed in 1903. It has an average depth of 18 feet and a surface width of 200 feet. It is constructed throughout its entire length in excavation and is approximately straight throughout. At the head of the canal there is a slight promontory, which protects it from ice and drift in the St Lawrence river.

At the Massena end, with the foundations carried to rock, a power-house designed by John Bogart of New York and Messrs Kincaid, Waller and Manville of London, has been constructed. It will be nearly 700 feet long when completed, with a width of 150 feet. Victor turbines to the extent of 42,000 horsepower have been installed. The wheels are controlled by an electric governor in the power-house. The exciter wheels are 27 inches in diameter, two to each exciter, discharging through one draft-tube and operating at 275 revolutions per minute.

The dynamos are of 6000 horsepower, 2200 volts, 3000 alternations, 3-phase revolving field type, with external armature. The speed is 150 revolutions per minute. The efficiency at full load 96 per cent. The heating at full load, continuous, 35 degrees rise. Weight of revolving element, 80,000 pounds, and total weight of the dynamos, 350,000 pounds.

The switchboards for the alternating current machines and for the feeders are operated electro-pneumatically, and for the exciters a standard, direct current switchboard has been installed, with hand-operated switches.

In a letter from Mr Bogart, consulting engineer to the company, under date of March 23, 1904, it is stated that the Pitts-

Plate 25.

Effect of water at the Hudson River Power Transmission Company's works.

burg Reduction Company have built on the banks of the power canal a large establishment for the manufacture of aluminum and have arranged to take from the St Lawrence Power Company 10,000 horsepower. This power was sold upon the shaft of the turbines, the Pittsburg Reduction Company putting in their own generators, which are direct current and not alternating.

At present there are seven sets or units of turbines installed, each of three pairs of Victor wheels, with an output of 6000 horsepower per unit. Two of these units are those referred to as equipped with direct-current generators for the Pittsburg Reduction Company; three other units have 5000-horsepower alternating current Westinghouse generators, fully installed, with all connections, bus-bars, switchboards and other appurtenances; the two remaining turbines are not yet equipped with electric generators.

The village of Massena is lighted by the Power Company and St Lawrence water is supplied from the canal under pressure.

Aside from the Pittsburg Reduction Company, no other industries are yet established.

Power Development on Hudson River

The Hudson River Power Transmission Company. Among the important developments on the Hudson river mention may be made of the plant of the Hudson River Power Transmission Company, two miles below Mechanicville. This plant is eleven miles from Troy, eighteen miles from Albany, and seventeen miles from Schenectady.

The Hudson river is here divided by an island into two channels with a total width of about 1200 feet. The dam and power-house were constructed in 1897 and 1898. The western channel of the river is used for power head and tailrace. The dam is 15 feet high above the river, 8 feet thick a short distance below the crest and 16 feet through the face. The original length of the spillway, which was situated on the east side of the island, was 707 feet, but since the original construction an additional spillway, 143 feet long, has been added by removing the earth and rock from the river bank, one foot lower than the crest of the main dam. The power-house of concrete is at the west end of the dam and may be considered as a continuation thereof. The length of the power-house is 257 feet and width 56 feet. The headworks are protected by piers, so placed in the river as to force ice and logs to follow the course of the main river over the dam. The electricity generated is transmitted to Schenectady for use in the General Electric Company's works.

This plant is developed for 5000 horsepower, although in extreme low water it is not capable of supplying as much as this. There are auxiliary engines to supplement the lowwater power.

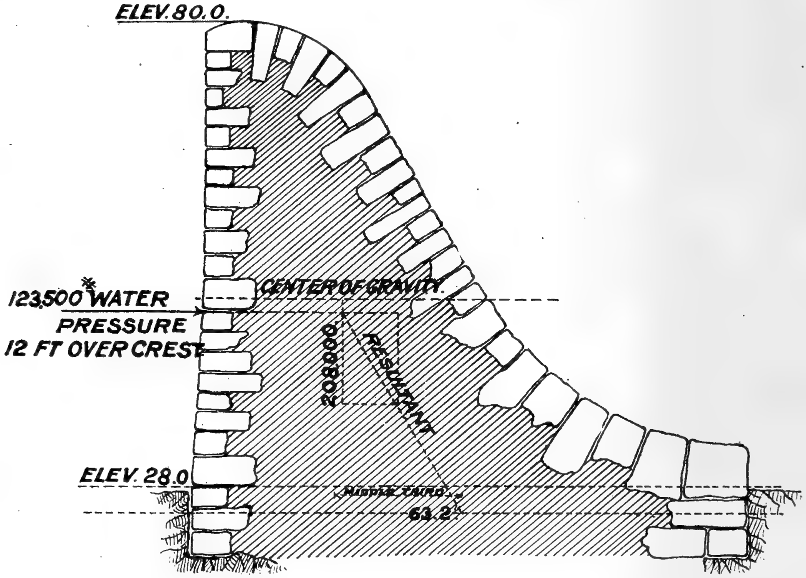
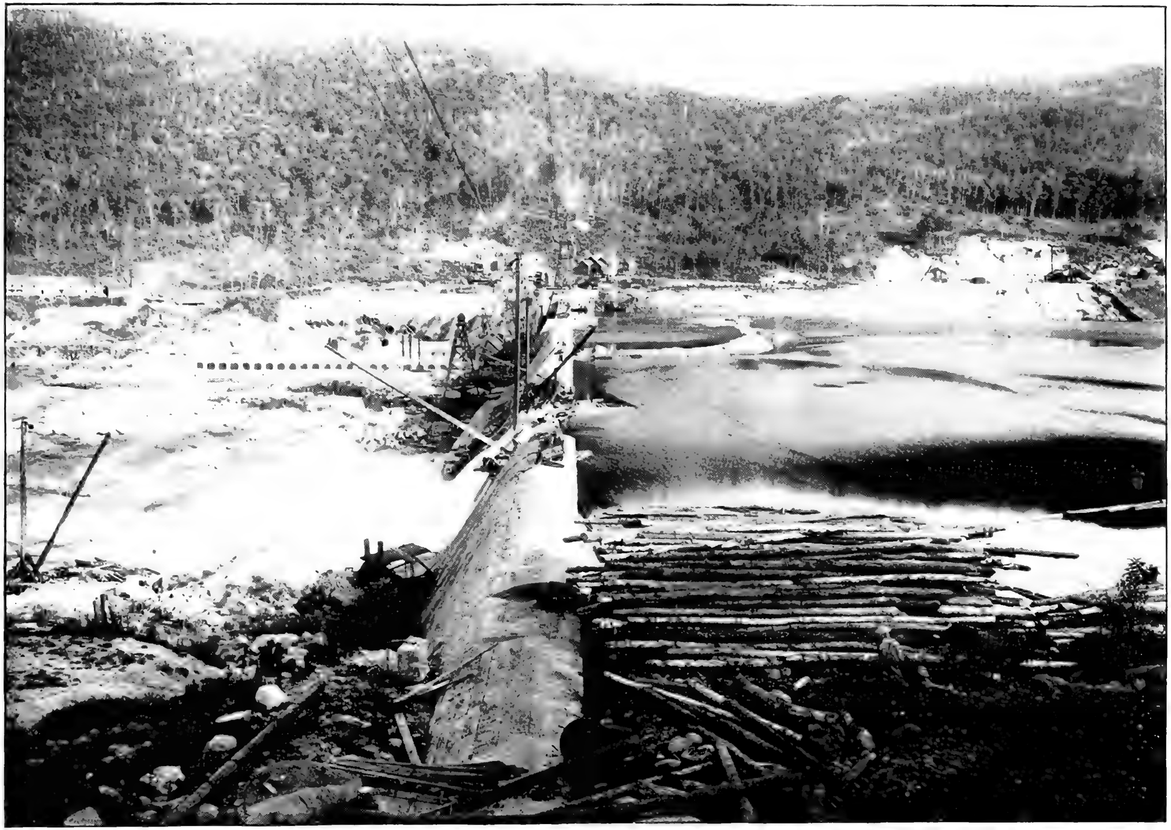


Fig. 43. Section of overfall of Hudson River Water Power Company

The Hudson River Water Power Company. This company began an extensive development at Spier Falls in 1900, which has involved the excavation of 270,000 cubic yards of rock and the building of 130,000 cubic yards of concrete and rubble masonry. The masonry has been laid at the rate of 8000 cubic yards per month.

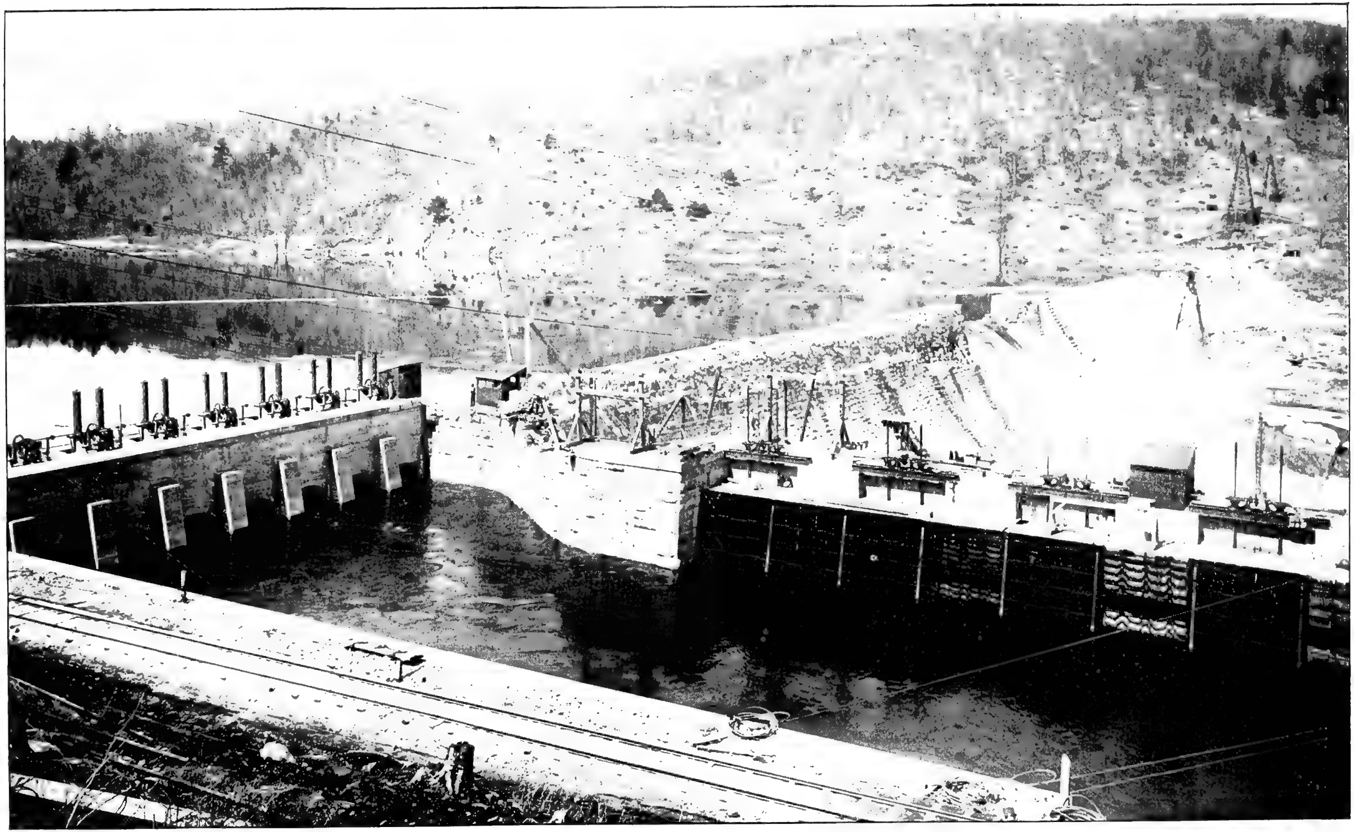
The location of this power is on the Hudson river, nine miles southwest of Glens Falls. The reservoir created by the dam is 5 miles long, 1-3 mile wide and with 80 feet head. Ten turbines, capable of developing 5000 horsepower each, drive dynamos whereby electricity can be supplied to Saratoga Springs, Sche-

Plate 26.



View of works of Hudson River Water Power Company in August, 1903.

Plate 27.



View of works of Hudson River Water Power Company in April, 1904.

nectady, Glens Falls, Troy and Albany. The company states that at times of low water the minimum power development will be 20,000 horsepower.

It is understood the company has in contemplation the construction of a large storage reservoir at Conklinville and at other points on Hudson river.

The power-house is divided into three sections—the wheel room, generator room and transformer and switchboard room. In the wheel room there are ten pairs of turbines, each with capacity of 5000 horsepower under 80 feet head. These wheels are set 12 feet above the level of tail-water, each pair outletting to one draft-tube. The generator room contains ten 3350-horsepower 3-phase 2000-volt, 40 cycle, direct connected General Electric Company's generators, running at 240 revolutions per minute. There will also be three 265-horsepower exciters, each direct connected to its own water wheel. In the transformer room there will be thirty 1000-horsepower high potential transformers, besides motors and blowers, and high and low potential switchboards.

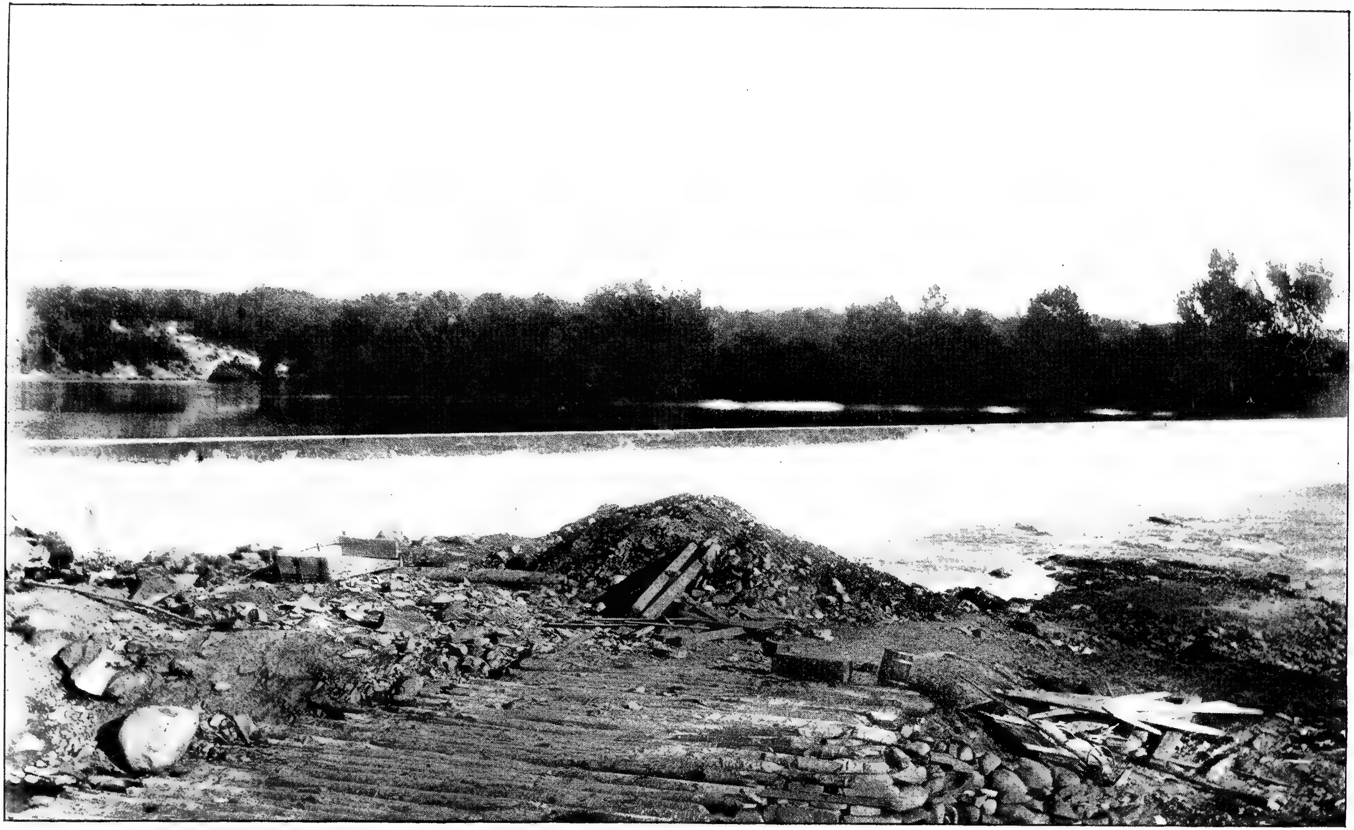
On the pole line five feeder circuits have a capacity of 50,000 horsepower, the longest one being 42 miles.

The following statement of the financial resources of the Hudson River Water Power Company is taken from the company's prospectus:

Contracts with General Electric Co.:		
No. 1 (5000 horsepower)	$112,500 00	
No. 2 (5000 horsepower)	134,375 00	
		$246,875 00
Contract with Glens Falls Portland Cement Co.:		
1000 horsepower guaranteed		22,500 00
Contract with United Traction Co., Albany (through the Hudson River Electric Co. and the Hudson River Power Transmission Co.) minimum estimate:		
No. 1 (4000 horsepower)	$72,500 00	
No. 2 (2000 horsepower)	90,000 00	
		162,500 00

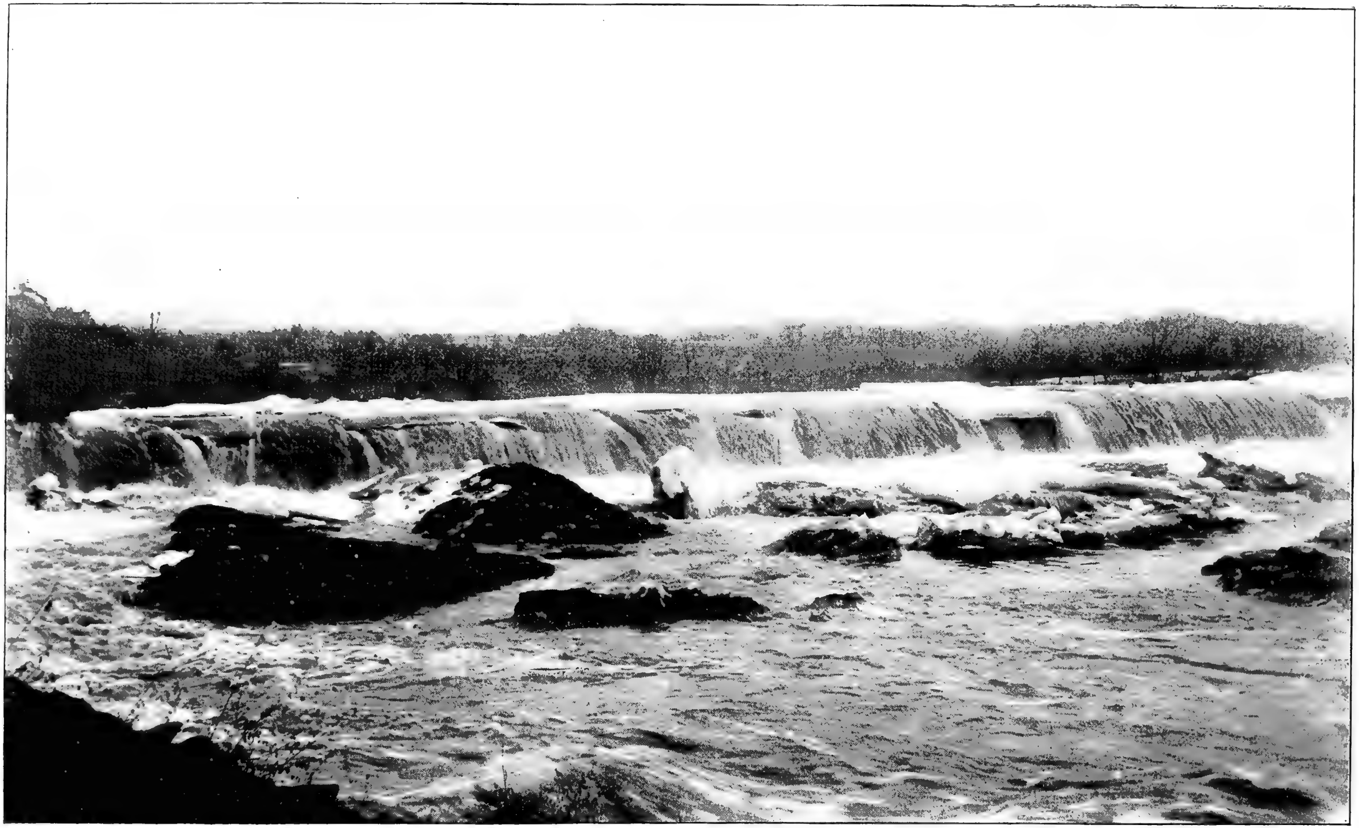
Contract with the Municipal Gas Co. of Albany, to be supplied immediately that gas company may secure necessary apparatus:		
Light, 4000 horsepower, at $60 net	$240,000 00	
Power, 2000 horsepower, at $63.40 net	126,800 00	
		$366,800 00
Contract with the Troy Lighting Co., to be supplied immediately that lighting company may secure necessary apparatus:		
Light, 3000 horsepower, at $60 net	$180,000 00	
Power, 3000 horsepower, at $63.40 net	190,200 00	
		370,200 00
Net earnings of the Saratoga Gas, Electric Light and Power Co		42,506 00
Net earnings of the Ballston Spa Light and Power Co		4,968 00
Watervliet power contracts		25,000 00
Gross receipts of Hudson River Water Power Co		$1,241,349 00
Annual operating expenses	$100,000 00	
Annual interest charge on $2,000,000 Hudson River Water Power Company's 5 per cent bonds	100,000 00	
Annual interest charge on $2,000,000 Hudson River Electric Company's 5 per cent bonds outstanding	100,000 00	
Annual interest charge on Hudson River Power Transmission Company's bonds and operating expenses of company	56,000 00	
		356,000 00
Net surplus		$885,349 00

Plate 28.



Empire State Power Company, showing dam; general view.

Plate 29.



Empire State Power Company, showing outgoing ice.

Annual receipts from sales of 6297 additional horsepower actually applied for in the following cities:

Saratoga	$58,250 00	
Glens Falls	45,717 00	
Ballston Springs	20,000 00	
Sandy Hill	25,000 00	
Fort Edward	15,000 00	
		$163,967 00
Net surplus earnings after meeting operating expenses and interest charges		$1,049,316 00

This statement shows a net surplus of over $1,000,000 for annual dividends on the stock and for further operations of the company. On the foregoing showing this is a good project and worthy of consideration by anybody desiring to invest in water power.

In addition to the Hudson River Water Power Company, associated companies are the Hudson River Electric Company, the Hudson River Power Transmission Company, the Saratoga Gas, Electric Light and Power Company, and the Ballston Springs Light and Power Company.

Power Development on Schoharie Creek

The Empire State Power Company. In 1899 the Empire State Power Company began the development of an extensive plant on Schoharie creek. The original project included the development of power plants at 1) Burtonville; 2) two miles below Burtonville; 3) Schoharie falls; 4) Mill Point, and 5) a short distance above Fort Hunter.

Site No. 1. The plant at Burtonville, as originally proposed, was to have 85 feet fall. In order to create this power a masonry dam 47 feet high was to be constructed, with a power canal on the east side leading 6000 feet down the stream. As an alternative proposition, it has been proposed to make this development with only a short canal, placing the power station just below the dam. It has also been proposed to construct a masonry dam at Burtonville village, which will be of sufficient hight to make up for the fall in the river of about 16 feet. In this case the canal would be located on the west side of the river.

Site No. 2. At the time of examining this matter in 1900 borings had not been made at site No. 2, and in the absence of definite information as to the depth of rock it was idle to speculate. This plant included a short canal which could be easily constructed.

Site No. 3. The Empire State Power Company constructed a plant at Schoharie falls in 1899 and 1900. This plant includes a masonry dam and head canal 4000 feet in length, with the power station situated at the foot of said canal. In the original project, owing to erroneous conceptions as to the flow of Schoharie creek, the canal was designed for a maximum flow of 1500 cubic feet per second, although in carrying this amount, friction would consume about two feet of head. Later on it was concluded that 800 cubic feet per second would be perhaps a safer maximum. A cross-section of the dam is shown in figure No. 36. This dam is 12 feet in hight, and by carrying the canal 4000 feet down the stream 40 feet head is secured.

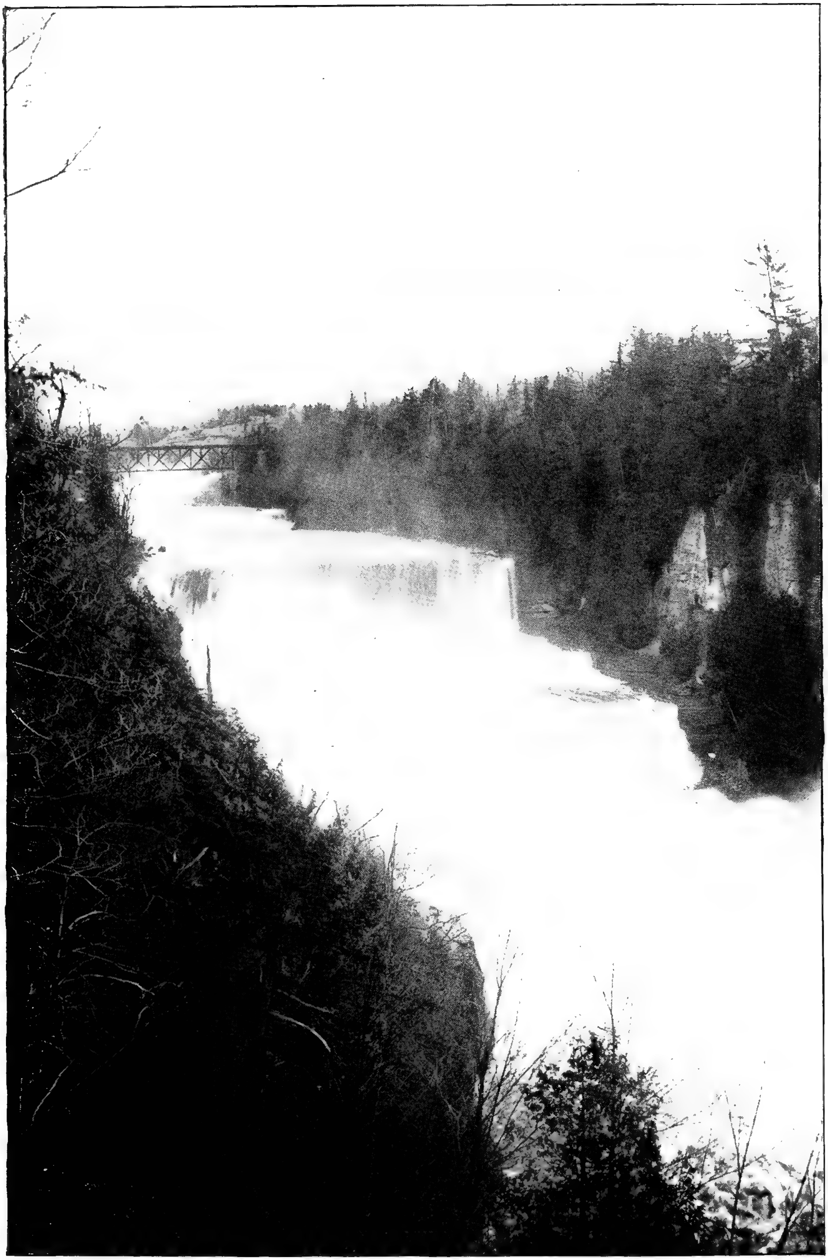
Site No. 4. This plant is at Mill Point, 1½ miles below Schoharie falls. The site is now occupied by a gristmill and sawmill which are owned by the Empire State Power Company. The dam is to be of timber and 8 feet in hight.

Site No. 5. At this plant the dam is to be of timber and presents no difficulties in development. It is situated about one mile above Fort Hunter and will realize practically the entire catchment area of Schoharie creek.

The object in developing these plants on Schoharie creek was to transmit the power electrically to Amsterdam, seven miles distant, where, on account of a large amount of manufacturing by steam power, there was an excellent market for electricity. It was also proposed to transmit 1000 horsepower to the Helderberg Cement Company at Howe's Cave, and pole lines were constructed with reference to these transmissions.

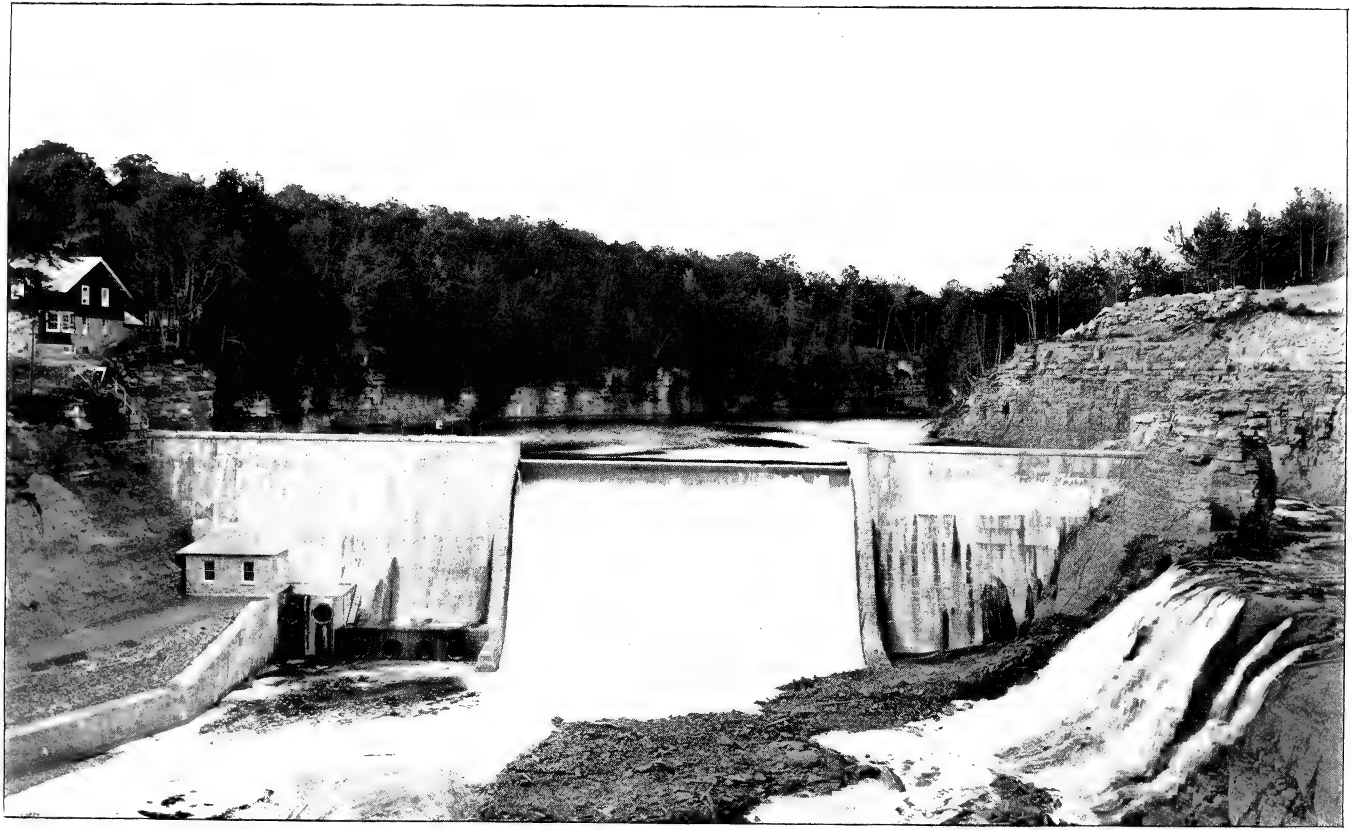
Assuming that storage enough is made to insure a permanent flow of 650 cubic feet per second, it is possible to develop on

Plate 30.



General view of Trenton Falls in time of high water. (West Canada creek.)

Plate 31.



Power dam of Utica Gas and Electric Company on West Canada creek.

Schoharie creek about 9000 horsepower. As to whether the power is to be 10 hour, 12 hour or 24 hour power will also be taken into account. There is, however, some doubt as to whether it is possible to make a storage large enough to secure a flow of 650 cubic feet per second, and until thorough surveys are made this must be considered merely a possibility. In view of this uncertainty and doubt, it is considered safer to assume that not more than 5000 to 6000 permanent power can be developed within commercial limits.

The dam at Schoharie falls is of masonry, backed with timber. It was originally constructed with crest 380 feet long, but in the spring of 1901, in a heavy flood, a portion of the dam and canal was carried away. Damage to the canal was due to inadequate wasteway arrangements—the wasteway originally constructed being only 50 feet in length. Owing to financial difficulties this dam was not repaired until 1902, at which time the cost of repairing it and the raceway and the making of the necessary repairs to power station was estimated at $80,000—the actual cost was somewhat more than this. In the repairs, the dam was made 620 feet in length and the wasteway 100 feet in length. It is understood that in the fall of 1903 the dam was again carried away by floods and that it has not yet been rebuilt. Owing to these unexpected expenditures the company is in financial difficulties and it is uncertain whether the dam is likely to be repaired.

Power Development on West Canada Creek

The Utica Gas & Electric Company. In 1901-2 a power plant was constructed at Trenton Falls by the Utica Gas & Electric Company. The following are some of the particulars of this plant, as derived from a letter from C. A. Greenidge, superintendent of the electrical department of that company, dated April 6, 1904:

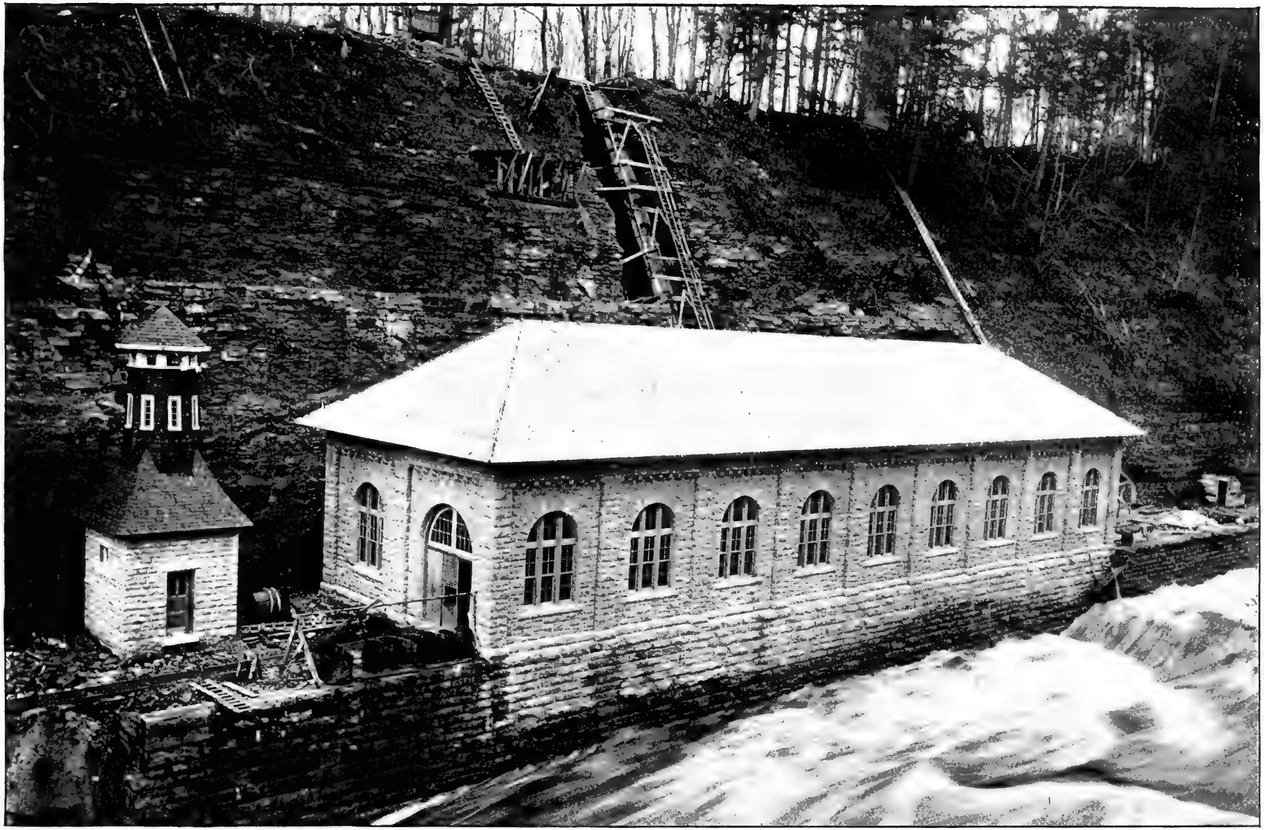
This plant includes a concrete dam, with hight above the bed of the stream of 60 feet and 55 feet thick at the base; 288 feet long and arched upstream on a radius of 800 feet. It is constructed of concrete, partly faced with stone. In its center there is a spillway 100 feet wide and on the right, cut in the rock face of the gorge, another spillway 112 feet wide. At a depth of 40 feet below the surface of the pond there are four 60-inch supply pipes, only two of which are in use at present. These pipes are joined, by means of a cast iron Y, into a 7-foot penstock. The penstock is 3700 feet long, and for 2700 feet is constructed of pine staves banded with ¾-inch round steel bands. These bands are about 6 inches apart. The balance of the penstock of about 1000 feet is constructed of steel varying in thickness ⅜ inch to ⅝ inch; 250 feet from the end of the penstock there is a standpipe 180 feet high. When there is no load on the plant the water rises 150 feet high in this pipe, but falls from 10 to 15 feet as the load varies. The penstock leads into a receiver from which are taken four 48-inch and two 12-inch pipes. Each of the 48-inch pipes supplies an 1800-horsepower outward flow reaction turbine, with vertical shaft. A 1000 kilowatt alternating current generator, running at 360 revolutions per minute, is connected to this shaft. Each of the 12-inch pipes supplies a 110-horsepower turbine, with vertical shaft direct connected to the armature of a 75-kilowatt direct current generator, running at 750 revolutions per minute. The total head is 265 feet, and the maximum load carried during the winter of 1904 was 7600 horsepower. The current is transmitted at 22,000 volts to Utica, 12½ miles distant. The usual step-up and step-down transformers are included. This plant was designed by Wm. A. Brackenridge.

Power Development on Raquette River

Hannawa Falls Water Power Company. There is an important power development at Hannawa Falls on Raquette river, where the catchment area is 967 square miles. This stream has a fall of nearly 300 feet in three miles of its course below the village of Colton, and a further fall of 85 feet in the next two miles of its course.

The land and water rights along this part of the river have been acquired by the Hannawa Falls Water Power Company, who have developed the lower 85-foot fall. A masonry dam has been built at the village of Hannawa Falls, forming a pond 2½ miles long and covering 200 acres. From this pond the water is conducted by a canal 2700 feet long as a forebay, thence by penstocks to the wheels. The tailrace extends 2000 feet from the power-house, being separated from the Raquette river by an embankment of earth and stone. At the point selected for the dam the bed of

Plate 32.



Power station of Utica Gas and Electric Company on West Canada creek.

the river is Potsdam sandstone, the strata dipping at an angle of about 30 degrees downstream. The banks are of sandstone, nearly perpendicular, and about 375 feet apart up to a level of 10 feet below the crest of the dam.

The material for the construction of the masonry work was obtained from quarries near-by. It is Potsdam sandstone which comes out from the quarry with nearly level beds, and no cutting was done except to level the crest of the dam after the stone was in place. For the downstream face of the dam stones from 12 to 18 inches in thickness, 2 to 4 feet wide and 3 to 4 feet long, were used, the beds being laid normal to the surface. For the upstream face a rubble wall about 3 feet thick was laid of smaller stone. The space between was filled with large bowlders and irregular shaped quarry stones, with concrete rammed in around and between. This dam was completed in the fall of 1899 and has had 4½ feet of water over its crest in two different seasons. The dam is perfectly water-tight.

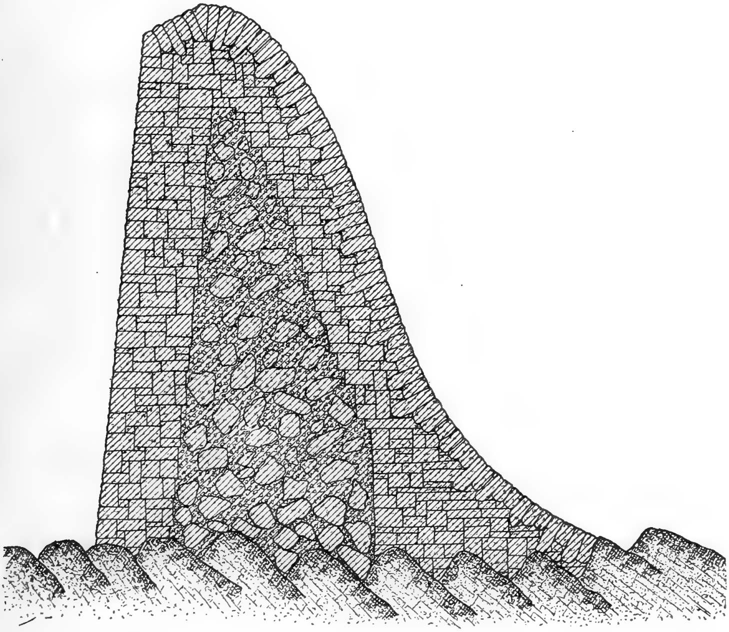


Fig. 44 Cross-section of dam at Hannawa Falls.

The canal is about 2700 feet long and 20 feet deep from the top of the banks, the bottom being 14 feet below the crest of the dam. The bottom width of the canal is 30 feet and the top width 110 feet.

The Hannawa Falls Water Power Company, in cooperation with other waterpower owners on the Raquette river, expect to construct reservoirs which will maintain a constant flow of 2500 cubic feet per second in the river.

The power station is constructed of Potsdam sandstone and steel. The penstock pipes are of steel, $\frac{5}{16}$-inch and $\frac{3}{8}$-inch in thickness. At present (1904) there is only one water-wheel set for the electrical equipment. This wheel is a 1250-horsepower horizontal water-wheel, built by James Leffel & Company. At each end of the horizontal shaft there is a direct connected 350-kilowatt three-phase 4400-volt generator. There is also an opportunity to set three other similar wheels.

The two 350-kilowatt generators are connected to the wheel shaft by plate couplings, having a movable plate between the faces. They are of the revolving field type, having 24 poles and delivering three-phase current at a frequency of 60 periods per second and a pressure of 4400 volts. They run at 300 revolutions per minute and are excited by two belted exciters, each of sufficient capacity to supply both generators.

The switchboard of Vermont marble consists of two generator panels with indicating instruments, one exciter panel with switches and instruments for both exciters, two 4400-volt feeder panels, with relay, circuit breakers, oil break switches, and wattmeters, one 220-volt panel with seven distributing switches, one transformer panel, and one 20,000-volt panel with three quick-break switches having marble barriers.

The Hannawa Falls Water Power Company owns the electric lighting plant in the village of Potsdam, 4½ miles from the station, with which village it is connected by a double line, which consists of three cables of seven strands each, of aluminum wire. This line was computed to transmit 375 kilowatts with a drop of 400 volts, delivering 4000 volts at Potsdam, where it would be stepped down for transmission to consumers. The 20,000-volt line

Plate 33.

Power dam of the Hannawa Falls Water Power Company on Raquette river.

is intended to run to the village of Canton, 10½ miles from Hannawa Falls, and finally to the city of Ogdensburg, 19 miles farther.

It is also intended to utilize a portion of the power to be developed here for grinding wood-pulp, and accordingly a ground wood-pulp plant of 100 tons capacity per day is included.

In the grinder room two pairs of 4000-horsepower water-wheels, built by the S. Morgan Smith Company, are placed on horizontal shafts and supplied with water from two independent 10-foot penstocks, discharging into a common tailrace.[1] From the foregoing it appears that in 1904 about 9000 horsepower is developed at this station, although the writer is unable to state whether or not the full capacity of the pulp-grinding machinery is utilized. These works were designed by W. C. Johnson.

Waterpower of Erie canal

When the Erie canal was first constructed the policy was adopted of leasing the so-called surplus water for power purposes. Under the terms of the act of 1825 leases were made during 1826 and subsequent years to a number of persons at Black Rock, Lockport and other localities.

Power at Black Rock. The granting of these leases and the resultant development of large manufacturing interests at several points have raised certain economic questions which will now be briefly discussed. The waterpower at Black Rock, for which several leases were granted, will be first mentioned. This power is created by the difference in level between the water in the Erie canal and the Black Rock harbor and that in the Niagara river outside the harbor wall, this difference of water-level amounting to from 4 feet to 4.5 feet. As measured in the spring of 1896, at a point near the ship lock, it was about 4 feet. According to the report of the Assembly Committee of 1870, there were formerly ten mills in operation at Black Rock, using 2744 second-feet of water. The power developed by these mills, and all operating at full capacity, is estimated at not exceeding 520 horsepower. Owing to the decline of the milling business in

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[1] Abstract from paper, Water Power Development at Hannawa Falls, by W. C. Johnson. Trans. Am. Soc. of Mech. Engrs., Vol. XXIII.

New York State a number of these mills have passed out of existence.

The four mills still in existence require about 1200 cubic feet of water per second to operate them at the full capacity of the wheels now in place.

The use of water by the Black Rock mills has always been a detriment to navigation. When all were running the amount of water actually drawn through the canal and harbor for their supply, and for the supply of the canal to the east of Buffalo, was fully 3300 cubic feet per second.[1]

When all the Black Rock mills were in operation the great draft of water so obstructed the navigation that the Legislature finally authorized the construction of a division wall in Black Rock harbor, by which it was expected that the water supply for the mills would be entirely taken from the harbor, leaving the channel of the canal pretty nearly free for the purposes of navigation; but after the greater part of the wall was completed it was ascertained that because of the silting of the upper harbor with sewage mud, as well as drifting sand from the lake, there would be difficulty in obtaining the full supply for the mills through the harbor, without extensive dredging. The division wall was, therefore, never completed, two gaps, amounting, in the aggregate, to several hundred feet, having been left below Terry street. There was thus an expenditure of about $350,000 for the benefit of the milling interests which is entirely without effect for lack of completion. Under the present conditions, however, of entire decline of the Black Rock milling interests, there is, of course, no reason why the wall should be completed, and the matter is discussed here merely for the purpose of bringing out clearly the struggle between the navigation interests and the manufacturing interests, which has been in progress in New York State for the last seventy-five years.

Power at Lockport. At Lockport the construction of the Erie canal through the mountain ridge created a fall of 58 feet at a single point, and since the use of water for lockage purposes is

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[1] The Assembly Committee of 1870 give the following figures as then applicable: Lower Black Rock mills, 1887 second-feet; upper Black Rock mills, 858 second-feet; for supply of canal, 583 second-feet; total, 3328 second-feet.

only a small part of the whole flow, the balance required to feed the canal to the east of Lockport is necessarily discharged around the locks into the lower canal by means of sluiceways. Under the laws of 1825 a public auction was held in the village of Lockport, in the fall of that year, and the right to use this surplus water sold to Messrs Richard Kennedy and James H. Hatch, whose successors at the present day constitute the Lockport Hydraulic Power Company.

Lockport has usually been considered more purely a result of the canal development than any other point in western New York, for the reason that while nearly all other towns in the region had some growth before the Erie canal was located, it was only in 1821, after the present location for the canal had been definitely decided on, that the nucleus of a village was formed here by the contractors and their workmen employed on the canal. In 1820 there was no frame house or barn within 5 miles of Lockport, and there were less than 600 acres of cleared land in the 4 square miles, of which the city of Lockport is now the center. Moreover, there are no natural advantages which would have naturally led to the growth of an important town at this point.

When once started, however, under the impulse of the canal development, Lockport grew rapidly until, in 1829, with a population of 3000, it was incorporated as a village, and in 1865 as a city. The population in 1890 was 16,038; in 1904 it is estimated at over 17,000.

The total investment in manufacturing plants at Lockport dependent on the Erie canal water supply amounts to $2,531,000. The total number of establishments is 33, employing 1880 operatives. The total power now in use on the Erie canal proper is 2625 net horsepower.

A short distance to the east of the foot of the locks a small stream known as the west branch of Eighteenmile creek crosses under the canal. This stream, although having a catchment area of only 1 or 2 square miles to the south of the canal, has cut a deep valley with rapid fall for a considerable distance to the north of the canal. In order to provide for discharging the surplus waters from the canal, an overflow into Eighteenmile creek was constructed at an early day. A mill was also permitted to take water from the lower level and discharge its tail-water into the creek. Finally the Jackson Lumber Company was permitted to construct a sluiceway on the tow-path side, through which it drew for many years about 600 cubic feet per second, and which was all discharged into Eighteenmile creek. Complaints having frequently been made that boats were drawn against this sluice on the tow-path side, the Superintendent of Public Works, in 1892, granted a formal permit to the Jackson Lumber Company to construct a sluice and subway under the canal bottom, by which this water is now drawn from the berme side. Under this permit a substantial masonry sluice was constructed in 1893. In the meantime the Jackson Lumber Company has gone out of existence and this waterpower has passed into the hands of the Traders' Paper Company, which now occupies the site with its pulp-mill No. 1.

The west branch of Eighteenmile creek descends about 175 feet within the limits of the city of Lockport, of which 148 feet have been utilized for power during recent years.

The following are the companies now using power on this creek and the horsepower used by each:

	Horsepower
Traders' Paper Company	1,060
Lockport Paper Company	230
Niagara Paper Company	115
Westerman & Company	320
Cascade Pulp Company	925
Cowles Smelting Company	1,185
Total	3,835

The output of the establishments on the west branch of Eighteenmile creek is about $2,000,000 a year; but this sum includes the output of the Indurated Fibre Company, which, while operating by steampower, depends largely for a supply of pulp on the Cascade Pulp Company. In any case the figures show the magnitude of the manufacturing interests which have been fostered in the valley of the west branch of Eighteenmile creek by discharging into that stream about 300 second-feet of water from the Erie canal.

With 2625 net horsepower in use on the canal proper, and 3835 on the west branch of Eighteenmile creek, the total actually in use at Lockport, and dependent on Erie canal for its water supply, is 6460 net horsepower.

No statements as to the value of the annual product of the manufacturing establishments on the raceways of the Lockport Hydraulic Power Company have been given. It is therefore impossible to state accurately the value of the total annual product at Lockport. As several of the establishments there are very extensive, including the Holly Manufacturing Company, it may be assumed that the annual output of this portion of the Lockport manufactories has a value, at least, of $1,000,000; hence we reach a total value of the annual product for the whole city of about $3,000,000.

The annual rental paid to the State, under the terms of the original lease, is only $200. At first sight it appears that there is here a most marked case of what could only be termed blundering on the part of State officials, although on analyzing the matter it is found that this extreme view is hardly correct. In the first place it must be remembered that this lease was granted not only by authority of an act of Legislature, but was only granted after a public auction had been held, at which Messrs Kennedy and Hatch were the highest bidders. As already shown, had not the special conditions created by the Erie canal existed at Lockport, there would, in all probability, have been no thriving city at that point, but the area on which Lockport now stands would have been farming land, with no more value than now attaches to farming lands in the adjoining township of Lockport.

In order to show the results of this lease, at $200 a year, a study has been made of the growth of Lockport from the year 1865, when Lockport became a city, to 1896. From such study it appears that the valuation of the city has increased from less than $3,000,000 to over $6,700,000, and that the total State tax collected up to and including the year 1896 has amounted to over half a million dollars. If this had remained a farming community the State tax would probably not have been more than 3 per cent of this amount. Using this tax return as a basis, it has been computed that there has been an actual increase of wealth to the people of the State by the existence of Lockport of over one and a half million dollars, not including in this the actual increased value of the city itself. The conclusion is drawn that the benefit to the State at large has been very great on account of this expenditure for internal improvement, irrespective of questions of navigation. This question is also discussed on page 239.

Power at Medina. The Oak Orchard feeder and the waterpower at Medina present somewhat different points for consideration from those at Lockport.

About 1820 the Canal Commissioners caused a cut-off channel to be constructed through Tonawanda swamp between Tonawanda and Oak Orchard creeks, whereby the early summer flow of Tonawanda creek is diverted into Oak Orchard creek. Oak Orchard creek passes under the Erie canal at Medina, and the original feeder channel at that place was an artificial channel leading from a dam thrown across the creek and entering the canal near the west branch of Oak Orchard creek at Medina. At some period subsequent to 1823 a raceway was constructed by private parties leading from a second dam higher than the feeder dam and conducting water into the central part of the village, where, after it is used, it is finally allowed to pass into the canal. During the enlargement of 1836 to 1862 the water-surface level of the canal at Medina was raised, and inasmuch as this change necessitated raising the feeder dam somewhat, it was finally concluded to discontinue the feeder and depend entirely on the raceway for such supply as the canal might receive at this point.

Oak Orchard feeder has been considered as furnishing about 27 cubic feet of water per second to the canal, although measurements made in 1850 show about 37 cubic feet per second. Since then the clearing up of forests and the drainage of Oak Orchard and Tonawanda swamps have tended to reduce materially the low-water flow until it is probably less than 27 cubic feet per second. Moreover, for the future, the dry-weather yield from this catchment area may be expected to be somewhat less than in the past, because of the deepening of the channel of Oak Orchard creek and of the crosscut authorized by the laws of 1893. The act provided for deepening the channel of Oak Orchard creek from a point 2½ miles below where the Tonawanda creek enters the Oak Orchard and for the cleaning, improving, widening, and deepening of the channel of the east branch of Oak Orchard creek. This work has been done as a sanitary measure, and its effect will probably be to run the water out of the swamps more rapidly in the spring, thus materially decreasing the dry-weather flow.[1]

According to a statement furnished by Mr A. L. Swet, President of the Business Men's Association of Medina, the number of operatives employed in 1896 in manufacturing enterprises dependent on water power at Medina was 515; the amount of capital invested in establishments actually in operation was $371,000, while the value of the annual product of the same establishments was $575,000. These figures do not include the Medina Falls flouring mill, which was idle at the time these statements were made.

The total developed waterpower at Medina, on the raceway and on the Oak Orchard creek, is estimated at 827 horsepower, which includes the wheels at the Medina Falls flouring mill. Deducting these wheels, amounting to 338 horsepower, the total actually in use in 1896 was 489 horsepower. The use of water at the establishments on the creek varies from 110 cubic feet per second to 49 cubic feet per second, the former quantity being due to the Medina Falls flouring mill, where the head is 33 feet. Relative to the fine power at Medina Falls, it may be stated that it is improbable, considering the amount of power available at this location, that it will remain unutilized for any great length of time. The trouble at the Medina Falls flouring mill is the same as that affecting the large flour mills at Black Rock and other places in New York—the competition of cheap grain and transportation from western mills.

Without going into the historical part of the subject, it may be said that the mill owners at Medina claim that by reason of the granting of a right of way for the cut-off between Tonawanda and Oak Orchard creeks, and the gift of 100,000 acres of land to the canal fund by their original grantor, the Holland Land Company—a part of the consideration for which was an improvement of the water power of Oak Orchard creek—they have an equitable

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[1] For extended account of Oak Orchard creek and its relations to the feeder, see Report of the Drainage of the Oak Orchard and Vicinity Streams, in the Fourth An. Rept of the State Board of Health (1883), p. 45-116.

right to the use of the water of the feeder. If, therefore, the effect of the drainage authorized by the laws of 1893 has been to decrease the low-water flow of Oak Orchard creek, it is maintained that the mill owners are entitled to enough water from the canal to make good the deficiency.

There are a number of other points on the Erie canal where waterpowers have been fostered under the provisions of the laws of 1825, but lack of space precludes discussion of that phase of the subject.[1]

HISTORY OF NEW YORK WATER SUPPLY

The first waterworks of the City of New York were constructed in 1774, when the population of the city was 22,000. In order to pay the expenses of the works the city issued paper money amounting to £2500, calling it "waterworks money." Bonds were also executed for lands and materials to the amount of £8850 more.

A reservoir was constructed on the east line of Broadway between what is now Pearl and White streets and a well sunk in the vicinity of the pond called the Collect. The Revolutionary war began in 1775, and the occupation of New York by British troops caused the abandonment of the work.

In 1799 the Manhattan Company was incorporated to supply the city with pure and wholesome water. This company sank a number of wells within the city limits. They constructed a well 25 feet in diameter and 30 feet deep in Centre street, between Reade and Duane streets, pumping the water to a tank on Chambers street, from which it was distributed through bored logs. In 1823 the population was 150,000 and the daily pumpage was 691,000 gallons.

In 1830 the city constructed a well at Thirteenth street, near Broadway, 16 feet in diameter and 112 feet deep, 97 feet being through rock. At 100 feet below the surface two lateral galleries were tunneled out from the main well, each 75 feet long. This well furnished only 10,400 gallons per day of hard water. The Manhattan Company also sank a well at Broadway and Bleecker

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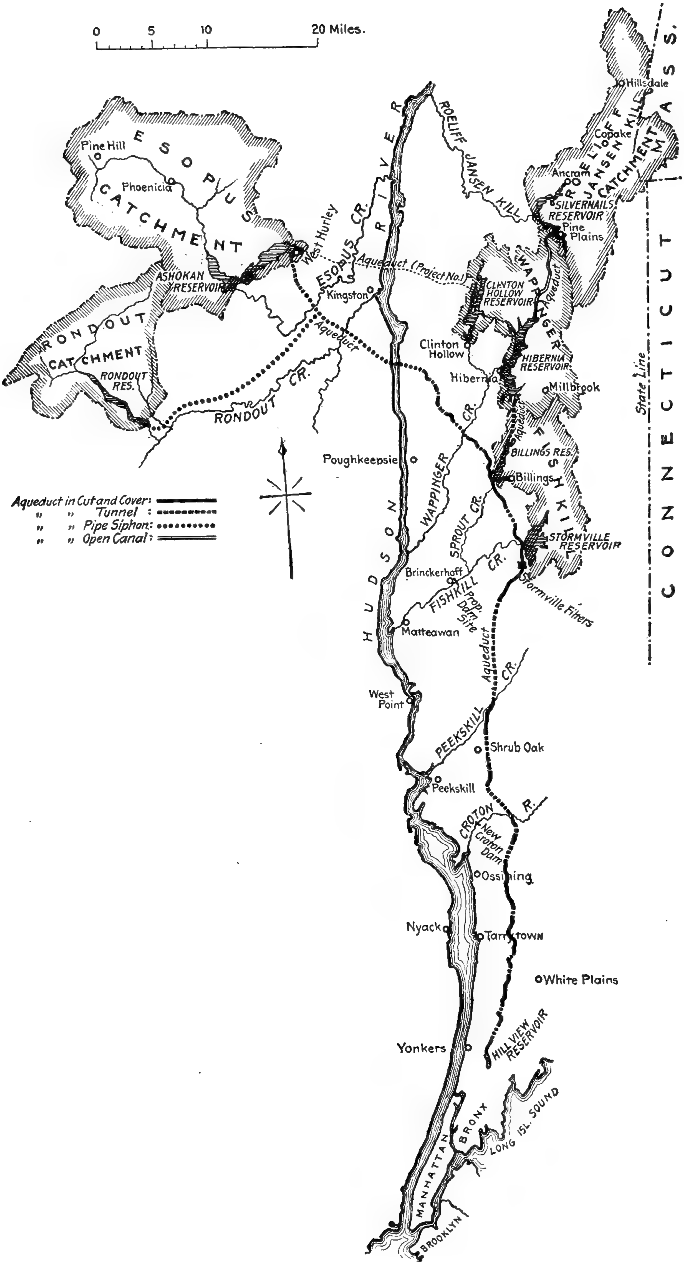
[1] Waterpower on the Erie canal is treated at considerable length in a Report on the Water Supply of the Western Division of the Erie Canal. An. Rept of State Engineer for 1896.

Plate 34.



Map illustrating additional water supply for Greater New York as proposed by the Commission of 1903.

street 442 feet deep, which yielded 44,000 gallons per day. In 1834 the city increased the depth of the Thirteenth street well 100 feet, thereby increasing the supply from this source to 21,000 gallons per day. Nevertheless, the supply from these various sources was so very limited that considerable water was brought in daily from wells in the country, selling at an average price of $1.25 per hogshead; 415 hogsheads of water were also daily imported from wells in Brooklyn to supply shipping.

The inadequacy of the supply led to examinations for the introduction of water from other sources, and in 1835 a plan for procuring water from the Croton river was adopted by the Common Council and later ratified by a popular vote of 17,330 in favor of, to 5963 against. The work of construction was immediately begun and water was introduced into the city through the Croton aqueduct in June, 1842. The population at that time was 375,000. The aqueduct then constructed is still available for use, with a carrying capacity, after sixty-two years of service, of 90,000,000 gallons per day.

For twenty years after the introduction of the Croton water the natural flow of the Croton river assisted by the storage of Croton lake of 2,000,000,000 gallons (266,666,000 cubic feet) supplied the needs of the city, although it became evident at an early date that ultimately provision would have to be made for storing flood-flows. In 1857 the Croton Aqueduct Board caused a topographical survey of the entire Croton catchment area to be made, and the number of sites for storage reservoirs were selected at that time. The first reservoir constructed was at Boyds Corners, in Putnam county, finished in 1872. Since that time five other storage reservoirs have been built, and another is now building. The storage capacity of these several reservoirs is given on page 380. The safe capacity of the Croton catchment area is estimated at 280,000,000 gallons per day.

Pending the decisions relative to the construction of the new aqueduct on Croton river, the Department of Public Works introduced in 1884 a supply from the Bronx and Byram rivers. This supply is conveyed by a pipe-line fifteen miles long and received into a reservoir at Williams Bridge, in the Borough of Bronx, at an elevation of 190 feet above tide. The catchment area from which this supply is drawn may be safely estimated to yield an average of 17,000,000 gallons per day.

In the Borough of Brooklyn there was no public water supply until after the population had reached 200,000. In 1856 a plan was matured for procuring water from ponds and streams on the south side of Long Island and a company formed to construct the works, but the city took them in hand and constructed them, and water was introduced in 1859. The original supply of surface water has been supplemented by pumping the ground water from driven wells along the line of the conduit which conveys the water of the ponds to the city.

The Flatbush Water Company furnishes water to the former town of Flatbush, as well as to some adjacent property. The Long Island Water Company has for years supplied an area of 1224 acres in East New York and the Blythebourne Water Company an area of 660 acres in the section near Fort Hamilton. The district still unsupplied with water in Brooklyn borough measures about 21,500 acres, or 55 per cent of the total area of the borough.

The Borough of Queens has only a fragmentary supply obtained from wells, which is pumped directly into the mains. Works supplying 2770 acres are owned by the city, and others supplying 5900 acres are owned by private corporations. The area of the borough is 79,347 acres.

The Borough of Richmond, with an area of 36,600 acres, has but a small supply of water for 3130 acres, which is derived from wells.[1]

Aside from gravity conduits from the Croton and Bronx catchments, the water supply of New York is pumped. This condition is made necessary not only by the low elevation of the sources of the Brooklyn water supply, all of which are near sea-level, but further because of the existence of a high service area in the central and northern portions of Manhattan which contain a large and increasing population and which are above the level to which Croton water can be distributed by gravity. There are also areas

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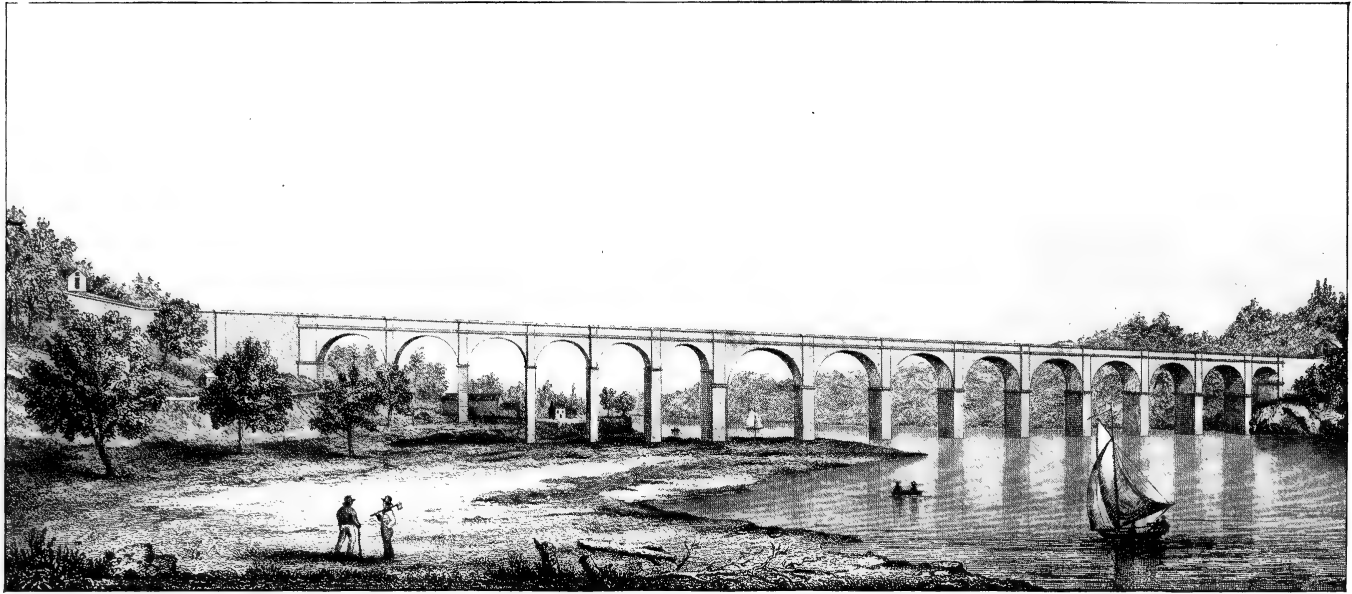
[1] Abstracted from report on The History, Condition and Needs of the New York Water Supply and Restriction of Waste of Water, made to the Merchants' Association, by J. J. R. Croes.

Plate 35.



Croton aqueduct at Harlem river. (From an old engraving).

in the northern and western portions of Bronx borough which are above any distribution of water by gravity from either the Croton or Bronx supplies. The Boroughs of Queens and Richmond are wholly dependent upon water pumped from wells and springs for their public water supply. To a considerable extent the Borough of Brooklyn and to a slight extent, the Borough of Bronx depend upon ground water from driven wells. Of the total water supply of the City of Greater New York, 45 per cent is delivered by thirty-two municipal and nineteen private pumping plants. The total water supply of the city may be taken at the present time at 372,000,000 gallons per day, of which 205,000,000 gallons are distributed by gravity and 167,000,000 gallons distributed by pumping. The relative proportions of surface water and ground water distributed are as follows:

	Gallons
Surface water	311,000,000
Ground water	61,000,000
Total	372,000,000

The following is a statement of the private companies, together with the borough in which they operate: In Manhattan borough, none. In Bronx borough, New York & Westchester Water Company, daily distribution, 1,000,000 gallons; in Brooklyn borough, Long Island Water Supply Company, daily distribution, 4,330,600 gallons; Flatbush Waterworks Company, daily distribution, 2,155,400 gallons; Blythebourne Water Company, daily distribution, 200,000 gallons, and German-American Improvement Company, daily distribution, 70,000 gallons; total amount distributed in Brooklyn borough by private companies, 6,756,000 gallons per day. In Queens borough, Citizens' Water Company, daily distribution, 4,185,700 gallons; Jamaica Water Supply Company, daily distribution, 1,500,000 gallons; Woodhaven Water Supply Company, daily distribution, 548,000 gallons; Montauk Water Company, daily distribution, 1,800,000 gallons; Queens County Water Company, daily distribution, 1,000,000 gallons; total daily distribution in Queens borough by private companies, 9,033,700 gallons. In Richmond borough, Staten Island Water Supply Company, daily distribution, 3,810,000 gallons; Crystal

Water Company, daily distribution, 1,200,000 gallons; South Shore Water Company, daily distribution, 100,000 gallons; total daily distribution in Richmond borough by private companies, 5,110,000 gallons. The total daily distribution by private companies for the entire City of Greater New York is roundly 22,000,000 gallons.

An aggregate of 348,500,000 gallons of water is delivered daily in Greater New York by the Municipal Waterworks. There is distributed by gravity alone 204,500,000 gallons, and the balance of 144,000,000 gallons is pumped for the supply of the different boroughs as follows:

	Gallons
Manhattan borough	43,952,400
Bronx borough	130,000
Brooklyn borough	95,907,000
Queens borough	3,891,300
Richmond borough[1]	80,000

Storage on Croton River

On a previous page the discharge measurements of Croton river have been given, together with brief references to a considerable storage on that stream. When the new Croton dam, now building, is completed, practical utilization of a catchment area of 360 square miles will be made. In order to accomplish this several masonry dams have been constructed, which are not exceeded for solidity and strength by those constructed anywhere. The new Croton dam, from its great hight, is a specially interesting example.

In 1883 an Aqueduct Commission was authorized, consisting of the Mayor, Comptroller, and Commissioner of Public Works, as ex officio members, together with three citizens. This commission was to construct new works only, and entered upon its duties of constructing a new aqueduct and storage reservoirs at once.

The construction of a new aqueduct was begun in January, 1885. This aqueduct was divided from Croton lake to Central park into seventeen sections, each being awarded as a separate

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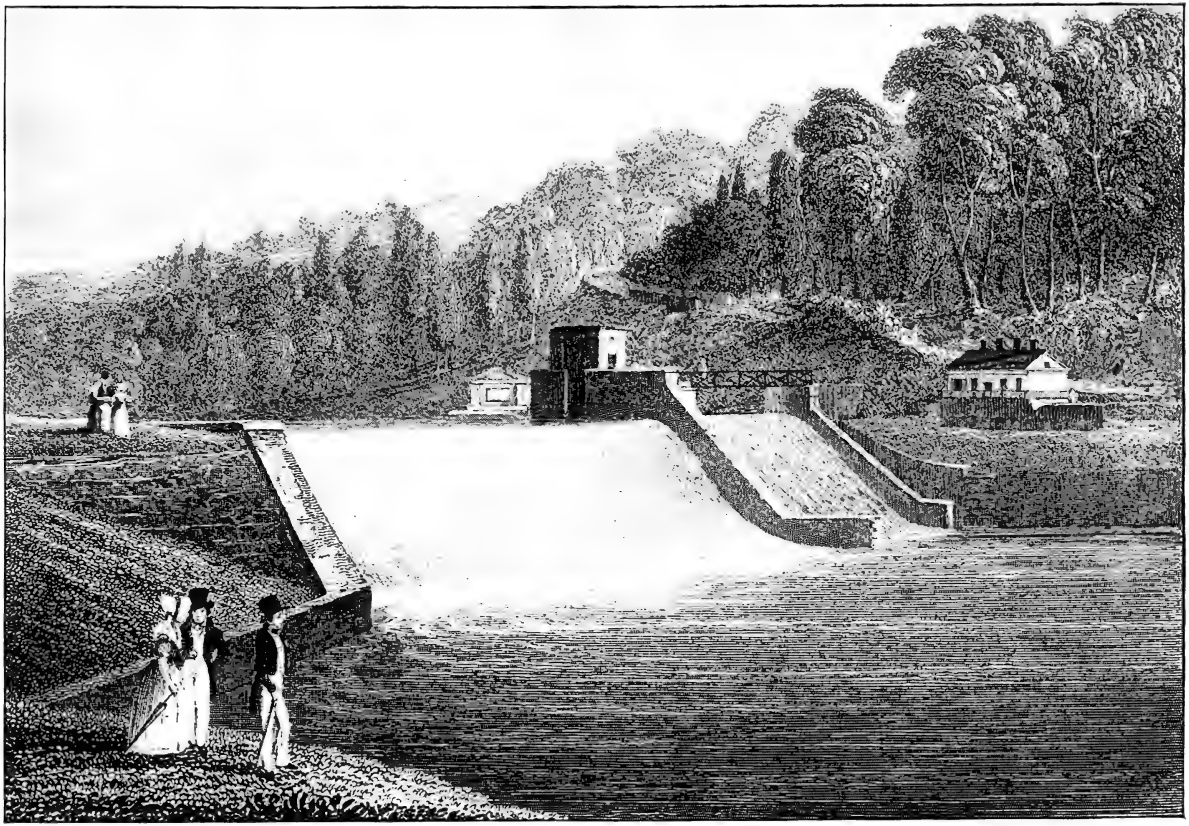
[1] The preceding statistics are of the year 1900, as collected by the late Lebbeus B. Ward, and given in his report on the Pumping Stations Connected with the Water Supply of New York, made to the Merchants' Association.

Plate 36.



View of the Croton dam. (From an old engraving of 1843.)

contract. The work was practically completed in 1891, when the aqueduct and its appurtenances were turned over to the Department of Public Works and put into service.

The new aqueduct consists of three parts, as follows:

1) A masonry conduit, not under pressure, from the inlet gate at Croton lake to a point near Jerome park.

2) A masonry conduit under pressure from the previous point to the gate-house at 125th street and Convent avenue. This portion of the aqueduct forms a long, inverted syphon.

3) A pipe-line from 125th street gate-house to the gate-house at Central Park receiving reservoir. Eight lines of 48-inch cast-iron main are laid from 135th street to 125th street. Four lines are continued to the Central Park reservoir, while the other four are connected to the distribution system at various points in the city.

In the meantime a number of reservoirs, some of which had been started by the Department of Public Works, were constructed by the Aqueduct Commission. Among these are East Branch, Titicus, Carmel and Amawalk reservoirs, all on the Croton river.

Information in regard to storage on the Croton river is very extensive, and the foregoing is a skeleton merely.

Brooklyn Borough Water Supply

Under date of January 24, 1896, I. M. De Varona, Engineer of the water supply of Brooklyn, transmitted to the Commissioner of Public Works an extensive report, including a detailed statement of the works from which Brooklyn derives its water supply. The text of this report comprises the following heads: Introductory, Descriptive, Historical, Financial, Laws, Biographical, Regulations, Bibliography, Tables and Plates.

The Descriptive section includes an account of the five different systems in use for the supply of Brooklyn. The most important of these is the Ridgewood system, originally intended to provide for the entire city. The four other plants are the Long Island, the Flatbush, the New Utrecht and Gravesend systems. These four plants were originally installed to supply the territory they serve before it became a part of Brooklyn. They also derive their supply from open and driven wells, and for convenience are referred to first.

The plant of the Long Island Water Company was built in 1881, under a 25-year franchise, to supply the town of New Lots, which was annexed to Brooklyn in 1886.

The Flatbush Water Company was built in 1882 and incorporated for 50 years. The works are located near the intersection of New York avenue and Avenue E. They were intended to supply the whole town of Flatbush, which is now the twenty-ninth ward of Brooklyn.

The New Utrecht Water Works were formerly controlled by the Coney Island Water Works Company, changed later to the Kings County Water Company, and still later to the New Utrecht Water Company. The plant is located on the corner of East Fourteenth street and Avenue V, and was built in 1880.

The town of Gravesend constructed a driven-well plant in order to provide water for flushing sewers and for furnishing a public water supply in 1891 and 1892. The plant is located on Seventeenth street, between Avenues R and S.

The town of Gravesend was annexed to the city of Brooklyn in June, 1895, and in July the mayor appointed commissioners to appraise the value of the Gravesend Water Works. This commission reported in November, recommending a payment of $423,000, although the plant, by the testimony, was shown to be worth not more than $125,000.

The West Brooklyn Water Company was organized with a capital stock of $50,000. It supplies that section of Brooklyn bounded by Forty-first street, New Utrecht and Hamilton avenues, Fifty-seventh street and Fifteenth avenue.

In 1893 the supply was found to be insufficient, and an 8-foot circular brick well was sunk to a depth of 65 feet, the water rising in it to a depth of five feet. It is understood that this plant is still in use as a private company.

In 1890 the Blythebourne Water Company was incorporated to furnish water in Blythebourne and vicinity. The original plant was situated at Fifty-sixth street and Thirteenth avenue, the supply being derived from two 7-inch wells, driven to a depth of 60 feet. Later a new plant was established at Seventy-fourth street, near Eleventh avenue. This company supplies Blythebourne, Bath Beach Junction, Bay Ridge Park and Leffert's Park. Several of the foregoing plants are not now considered a part of Brooklyn borough water supply.

Plate 37.

Driven wells on the Brooklyn Water Works.

The Ridgewood system comprises the works originally built to supply Brooklyn, and their tributary catchment embraces that portion of Queens county bounded on the north by the ridge forming the backbone of Long Island; on the east, approximately by Suffolk county; on the south by the salt meadows bordering on Hempstead and Jamaica bays, and on the west by Kings county. The original catchment area is 66 square miles, while the new catchment is 89 square miles.

The sources of supply on the old catchment, named in order from the Ridgewood engine house eastward, are as follows:

Spring creek temporary driven-well station, Spring creek driven-well station, Baiseley's driven-well station, Baiseley's pond, Jameco driven-well station, Springfield pond, Forest Stream driven-well station, Simonson's pond, Clear Stream pond, Clear Stream driven-well station, Watt's pond and driven-well station, Valley Stream pond, Smith's pond, Pine's pond, Hempstead pond, Schodack brook and Hempstead storage reservoir.

On the new catchment the sources of supply from the Millburn engine house eastward are:

Millburn pond, Agawam driven-well station, East Meadow pond, Merrick driven-well station, Newbridge pond, Wantagh pond and Massapekua pond.

The supply from the original catchment is collected by a brick conduit, extending from Hempstead pond westerly to the old Ridgewood station, and having a grade of about six inches to the mile.

On the new catchment the supply is collected and carried by gravity to the Millburn station through a brick conduit, seven and one-quarter miles long, and having a grade of one in ten thousand. The two driven-well stations on this catchment are located south of the conduit and discharge into it through cast-iron pipes. New stations will be similarly connected.

In order to show the possibilities of a supply from the sand areas of Long Island, the following may be considered:

Water yield of the Long Island sand areas. Long Island is about 120 miles in length, with a varying width of from 10 to 20 miles. Its watershed line consists of a ridge of low hills running from New York bay to the eastern extremity of the island. The highest points of this ridge are about 350 to 390 feet above sea level. This ridge, which is believed to be a part of the terminal moraine of the great glacier, consists mainly of compact drift and bowlders, running at times into clay and coarse gravel. The considerable number of small ponds along the ridge evidence the compactness of its surface material. The slopes and spurs of the central ridge run into Long Island sound on the north, making an irregular shore line, broken into bays and low headlands. On the south side, the slopes lose themselves in a grassy plain sloping gently toward the coast. In its widest part it is called the Hempstead plains, and stretches for a distance of from 5 to 15 miles between the foot of the central ridge and the Atlantic shore, which is very regular in its outer beach line; but an inner and more irregular beach exists, formed by the shallow waters of Jamaica and Hempstead bays. The Atlantic shore does not anywhere touch the slope of the central ridge, but is separated from it by the wide gravelly plain.

In 1900 Prof. W. O. Crosby reported in relation to the geology of Long Island and its relations to public water supplies, the main purpose of this study being to determine what light the present knowledge of the geologic structure of Long Island throws upon these problems. The main questions considered were:

1) Is it possible to obtain a copious supply of water from deep wells on Long Island, 200 feet or more in depth, passing through the blue clay into the gray gravel and the still deeper water-bearing strata of the cretaceous? A supply of quality suitable for domestic purposes and in quantity sufficient for a substantial addition to Brooklyn's water supply, say 10,000,000 gallons, 25,000,000 gallons, 50,000,000 gallons, or more per day, or the equivalent of the yield of a catchment area of 10, 25, 50 or more square miles?

2) What certainty or probability is there that wells 40 to 80 feet deep, sunk in the yellow gravel but not penetrating the blue clay, in the region east of Massapequa, can be made to yield water of suitable quality for domestic supply and in quantity equal to the total average catch of rainfall on a catch-

ment of the area shown by the surface topography to be tributary to the proposed point of taking?

3) Is there any geologic reason to expect that the yield of ground water available per square mile will be materially different in quality or in quantity from that in the region already developed west of Massapequa?

4) Is there any apparent advantage in one location over another for tapping the subterranean waters of the yellow gravel?

The geologic structure of Long Island consists of the following formations, beginning with the lowest: (1) the primitive or crystalline rocks; (2) the cretaceous formation; (3) the tertiary formation; and (4) the terminal moraine of the continental glacier of northeastern North America.

The water-bearing horizons are limited to yellow gravel above the blue clay, gray gravel below it and certain layers of sand in the cretaceous formation. The yellow gravel, which receives and holds nearly the entire rainfall of the island, ranks first in importance, while the gray gravels and cretaceous gravels are second in importance. The supply from the gray and cretaceous gravels, if heavily drawn upon, is likely to become brackish, and is also likely to become stale or mineralized.

In regard to deep wells, it is stated in Professor Crosby's report that while here and there a deep well may tap a supply of good, potable water, sufficient for the supply of a small village or factory, the geologic formation gives no hope of finding any large, permanent deep-well supply sufficient in volume to form a substantial increase to the water resources of Brooklyn or add materially to the volume that can be obtained from shallow wells.

Before the real facts in regard to the geologic formation of Long Island were understood it was considered that probably a large volume of the fresh water found its way over to Long Island from the mainland by percolating through the deep, porous strata, but in the light of more extended information Professor Crosby considers that whatever yield of fresh water comes from the deep wells must have its origin from rain falling upon Long Island alone—there is no water coming to Long Island from the mainland.

In regard to Long Island water supplies, they may therefore be considered in two lights: (1) There are numerous small brooks, originating on the south slopes of the central ridge, which deliver their waters to the Atlantic ocean; and (2) from the shallow wells extending into the yellow gravel, already discussed. As to the proper place for locating these wells, Professor Crosby considers that they should be on a line along the south shore far enough back from the sea to avoid the indraft of brackish seawater. The inclination of the water-bearing yellow gravel, with its impervious floor of blue clay, is from the north towards the south. The surface supplies from the brooks are none of them very large. On the largest of them gristmills were established at an early date, with ponds of from 8 to 40 acres of water surface and from 5 to 9 feet depth of water. These ponds were the original water supply of Brooklyn.

The fall at the dams rarely exceeds 8 feet. The original municipal water supply of the city of Brooklyn, as constructed about 1856 to 1859, had its source in the Hempstead plains, several of the large brooks, flowing from the central ridge to the Atlantic being appropriated for this purpose. A distributing reservoir was established on the central ridge at an elevation of 170 feet above tide, with the water of the brooks forced thereto by pumping. These brooks were all mainly fed by springs delivering directly into their ponds and channels. The length of these watercourses from where the water was taken to the summer sources rarely exceeds 4 miles. In the original construction the waters of these ponds were conveyed by small branch conduits to a large main conduit extending from the most easterly pond or reservoir to the pump well at the engine house, which was located at the foot of the ridge on which the Ridgewood distributing reservoir was situated, not far from the east line of the city of Brooklyn. The main conduit was so located that the water flowed to the engine house by gravity. The following are the statistics of the six ponds originally taken for the Brooklyn city supply, the minimum deliveries here given being as ascertained by measurements during the months of September and October, 1856 and 1857. The figures represent the natural delivery of each stream at its lowest stage of water, and do not include any encroachment upon the stored water which each pond retained, when full.

Pond	Area of surface (acres)	Minimum flow (cubic feet in 24 hours)	Elevation of overflow above tide (feet)
Jamaica	40.00	419,315	7.90
Brookfield	8.75	265,098	15.40
Clear stream	1.07	100,448	11.50
Valley stream	17.78	325,291	12.80
Rockville	8.00	353,388	12.60
Hempstead	32.52	1,054,713	10.60

The same streams were measured in October and November, 1851, and the aggregate result then was 3,137,500 cubic feet. With the exception of Clear stream, they were again measured in October, 1852, the result then being 2,606,300 cubic feet in 24 hours.

According to a survey made by Theodore Weston in the fall and winter of 1859, the catchment area of the streams originally taken for the municipal supply of Brooklyn was found to measure 46.8 square miles, but subsequent measurements have placed it at 49.9, which is the figure now used.[1]

The drainage grounds lie mainly on the Hempstead plains, although a small portion may be considered as lying on the southern slope of the central ridge. The ridge slopes are composed of clay and alluvial earth, with little power of retaining water. Hempstead plain, on the other hand, consists of a very uniform deposit of sand and gravel with occasional thin veins of clay; hence Hempstead plain is largely receptive and retentive of water. The sand and gravel on this plain serves two purposes as regards the rainfall sinking into it: (1) It retains the water, only gradually delivering it to the surface in the valleys of the brooks or on or near the seashore in the form of springs; (2) it filters and purifies it, the gravel and sand performing the function of a natural filter bed. It is considered that but a small portion of the ground water of this gravel plain has been derived from the rainfall of any single year. The greater portion of it is considered to have collected during a series of years. Borings and open wells show that this ground water has a nearly uniform inclination toward the south shore of about 12 feet per mile.

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[1] As to the difficulty of determining just what the catchment area of any one of these streams actually is, see De Varona's History and Description of the Brooklyn Water Works, 1896.

Upon the low ridges lying between the several streams crossing Hempstead plain the inclination of the ground water varies with the width of the ridge, and is steeper in these parts than on the main slope toward the sea, the resistance of the retaining material there being proportionately less. So long as the slope of the ground water is left undisturbed by pumping, as from a series of wells, the permanent slope of the ground water is determined by the resistance of the material through which it flows. As regards the minimum flow of the streams receiving these underground waters, the longer the time occupied by that portion of the rainfall which sinks into the ground in reaching the outlets the greater will be the minimum flow of the stream as compared with its total flow; on the other hand, the shorter the time the smaller the minimum flow. In the case of Long Island streams the maximum flows are not very large, a fact which indicates that the permanent regimen of these streams is probably maintained by the accession of the absorbed rainfalls of several years. It follows that so long as the basins are not drawn upon very greatly in excess of their flowage capacity the permanency of Long Island ground-water supplies is only moderately affected by variations in the yearly rainfall.[1]

In his Report on the Future Extension of the Water Supply of Brooklyn, Mr De Varona gives the total monthly and average daily quantities of water pumped into the Ridgewood reservoir for the years 1860 to 1896, inclusive.

Table No. 88 has been condensed from this report, giving in calendar years the total rainfall upon the catchment and the per cent of this utilized by pumping at Ridgewood. The average yield utilized is also expressed in cubic feet per second per square mile of catchment. This was originally 49.9 square miles, but was increased in 1872, being in subsequent years 52.3 square miles until 1883, when it was increased to 64.6 square miles, and in 1885 to 65.4 square miles. Considerable additions were made in 1891, and from that time on the area is given as 154.1 square miles. In 1860 the rainfall was 37.65 inches, and the total amount

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[1] The foregoing statements relating to the water-yielding properties of the Long Island sands are mostly derived from Kirkwood's History of the Brooklyn Water Works and Sewers, published in 1867. For a more recent, as well as more extended, discussion of the same subject see De Varona's History and Description of the Brooklyn Waterworks.

of water pumped was equivalent to a depth of 1.44 inches on the catchment, or 3.82 per cent of the total rainfall. In 1896 the total rainfall was 38.82 inches. The amount of water pumped during that year would cover the catchment to a depth of 11 inches, this being over 28 per cent of the total rainfall. The average yield as obtained by pumping was 0.81 cubic foot per second per square mile of catchment.

TABLE NO. 88—TOTAL ANNUAL RAINFALL, PER CENT UTILIZED, AND AVERAGE YIELD PER SQUARE MILE OF CATCHMENT OF BROOKLYN WATERWORKS

YEAR (1)	Rainfall in inches (2)	Per cent utilized (3)	Cubic feet per second per square mile (4)
1860	37.65	3.82	0.11
1861	45.65	3.92	0.13
1862	38.02	5.73	0.16
1863	32.76	8.39	0.20
1864	32.00	10.53	0.25
1865	46.14	8.39	0.28
1866	51.68	8.88	0.34
1867	54.61	9.39	0.38
1868	38.58	17.29	0.49
1869	43.13	17.20	0.55
1870	39.25	19.82	0.57
1871	51.26	15.78	0.60
1872	39.75	23.47	0.67
1873	47.99	20.88	0.74
1874	45.83	21.49	0.73
1875	40.90	26.89	0.81
1876	41.77	27.08	0.83
1877	40.18	30.29	0.90
1878	48.66	25.15	0.90
1879	39.61	33.40	0.97
1880	40.76	30.23	0.90
1881	39.53	29.42	0.86
1882	39.83	30.73	0.90
1883	37.22	33.05	0.91
1884	45.39	27.89	0.93
1885	36.85	37.94	1.03
1886	51.38	28.32	1.07
1887	45.66	32.59	1.10
1888	48.45	33.19	1.18
1889	56.54	29.54	1.23
1890	52.15	33.90	1.30
1891	39.18	44.82	1.29
1892	37.75	24.53	0.68
1893	39.62	26.27	0.77
1894	36.88	26.33	0.72
1895	35.64	28.98	0.76
1896	38.82	28.31	0.81

Generally the Brooklyn Water Works have not been so designed as to furnish records of the quantity drawn from these several different sources. There are also no records of the hights of the ground water at different points in the catchment area. If such were to be kept for a series of years, the records of the Brooklyn Water Works would possess a value not easily estimated. They would give a far more positive indication of the amount of water that can be drawn from such sandy areas than can now be gained from them. A few tests, however, of some of the driven-well plants have been made in the last few years. The Greater New York Water Supply Commission of 1903 has measured the hight of ground water in about fifteen hundred wells included in 1000 square miles of territory.

At a test of the old driven-well plant at Spring creek, made from October 22 to November 20, 1894, water was pumped at an average rate of 4,091,551 gallons in 24 hours. The elevation of the underside of the discharge valve of the pump was 12.3 feet above datum. On October 22, at the beginning of the tests, the average elevation of the water in the wells was 4 feet below datum. The quantity pumped in 24 hours, on October 22, was 4,488,275 gallons. On November 20, the date of the conclusion of the test, the elevation of water in wells was 7.7 feet below datum, and the quantity pumped on that day in 24 hours was 4,112,663 gallons. The total quantity pumped during the entire period from October 22 to November 20 was 122,746,525 gallons. The taking of this quantity of water from the wells resulted, therefore, in lowering the ground water a total of 3.7 feet.

A new driven-well plant at Watts pond was subjected to a test of capacity extending continuously from January 3 to February 2, inclusive. In 1895 a rather extended series of tests were made of a number of the wells of the Brooklyn water supply in order to determine the yield as well as the extent of the underground supply. The following particulars of these tests have been derived from Mr De Varona's report, as contained in the annual report of the commissioner of city works for the year 1895.

The flowing wells at Jameco were tested from January 3 to 14, inclusive. During this period the wells were operated singly and in groups of 2, 3, and 4, in all possible combinations, and observations were taken to determine the elevation of the ground water. Upon completion of the tests a series of observations was taken, extending to January 30, to determine the normal water level. It was shown that the average yield from one well alone was only 1,000,000 gallons daily, decreasing pro rata up to a total yield of 3,500,000 gallons daily when four wells were in operation. The lowering of the ground water was approximately 5 feet when pumping 1,000,000 gallons, increasing up to approximately 10 feet when pumping at the full capacity developed of 3,500,000 gallons. In this connection it is stated that the water in these test wells is found to rise and fall directly with the tide, thus rendering it difficult to state with accuracy the full effect of the pumping on the lowering of the water. To determine this point fully, Mr De Varona states, would require a more prolonged series of observations than it was possible to make in 1895.

Another test was made at Jameco from December 9 to 20, 1895, inclusive. Between this date and the end of the previous tests an additional well had been sunk at Jameco to the depth of 160 feet. The average daily yield shown during the second test was, approximately, 1,000,000 gallons for a single well, with a proportionate increase for each well connected, the yield for five wells being, approximately, 5,000,000 gallons in 24 hours. The lowering of the water during those tests amounted to slightly over 14 feet at Jameco while pumping the 5,000,000 gallons daily from the five wells. The total amount of water pumped during the test was 61,239,555 gallons. The greatest lowering of the underground water level occurred at test well No. 8, where it amounted to 15.23 feet. At that time, when the water at Jameco was at its lowest level, the fall between test well No. 8 and test well No. 11 was 9.9 feet. The normal water level was not restored until twelve days after the tests had ceased.

The results obtained early in 1895 from the test made at Jameco of supplies from deep wells seemed to warrant further investigations as to the possibility of water from deep wells, and the report states that they have been carried on during the year. A series of test wells were driven, extending from the foot of the hill at Ridgewood reservoir to Forest stream pumping station, each well being carried to a depth sufficient to determine the possibility of obtaining a deep supply from that point. The number of those wells sunk during that year was twelve, and the records of the strata passed through are given in Bulletin No. 138, referred to in the footnote.[1]

Returning to table No. 88, it may be stated that the tributary catchment area in 1875 was 52.3 square miles. The catchment area remained at this figure until January, 1881, in which month, by the bringing of the Springfield pumping station into use, it was increased to 59.4 square miles. In the water year of 1875, with a total rainfall of 41.6 inches, the water utilized amounted to

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[1] For the particulars of the geology of several of the Brooklyn Water Works wells, of which tests were made in 1895, see Artesian-Well Prospects in the Atlantic Coastal Plain Region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, 1896, p. 23-37

10.78 inches, or to an average of 513,165 gallons per square mile per day, or to 0.79 of a cubic foot per second per square mile. In the water year of 1880, with a total rainfall of 40.04 inches, the water utilized amounted to 12.37 inches on the catchment, or to 587,568 gallons per square mile per day, or to 0.91 of a cubic foot per second per square mile. In 1881, with a rainfall of 41.52 inches, the total utilization of water amounted to 11.64 inches on the catchment, or to 554,473 gallons per square mile per day, or to 0.86 of a cubic foot per second per square mile. This drop in the unit of utilization merely shows the effect of the increase in the area of the catchment.

The tributary catchments remained at 59.4 square miles until August, 1883, in which month the Spring creek and Baisley's driven-well stations were started. From this date the tributary catchment area is taken at 64.6 square miles. Spring creek and Baisley's stations marked the beginning of the Brooklyn driven-well system. In the water year of 1884, with a total rainfall of 43.44 inches, the utilization was 12.53 inches, amounting to 594,992 gallons per square mile per day, or to 0.92 of a cubic foot per second per square mile.

In May, 1885, the Forest stream and Clear stream driven-well stations were started, thereby increasing the tributary catchment area to 65.4 square miles. In the water year of 1886, with a total rainfall of 50.43 inches, the water utilized amounted to 14.40 inches, equivalent to 685,521 gallons per square mile per day, or to 1.06 cubic feet per second per square mile.

The catchment area remained 65.4 square miles until June, 1890, when it was increased to 65.6 square miles by the addition of the Jameco park driven-well station. In the water year 1891, with a total rainfall of 40.34 inches, the water utilized amounted to 18.48 inches on the catchment, equivalent to 879,811 gallons per square mile per day, or to 1.35 cubic feet per second per square mile.

Large extensions of the works were made in 1890 and 1891, so that with the beginning of pumping at Millburn on December 17, 1891, the tributary catchment area may be considered as increased from 65.6 to 154.1 square miles, an increase of 88.5 square miles. In the calendar year 1892, with a rainfall of 37.75 inches, the water drawn from the original catchment of 65.6

square miles amounted to 16.81 inches on the catchment, equivalent to 800,191 gallons per square mile, or to 1.24 cubic feet per second per square mile. The water drawn from the new catchment of 88.5 square miles that year amounted to 3.67 inches equivalent to 174,776 gallons per square mile per day, or to 0.27 of a cubic foot per second per square mile. In 1895, with a total rainfall of 35.64 inches, the original catchment of 65.6 square miles yielded 12.62 inches, equivalent to 600,723 gallons per square mile per day, or to 0.93 of a cubic foot per second per square mile. The new catchment of 88.5 square miles furnished in that year 8.64 inches, equivalent to 411,558 gallons per square mile per day, or to 0.64 of a cubic foot per second per square mile.

Summarizing the information in regard to the water yield of the sand plains of Long Island, it may be stated that the available data indicate a large yield. The streams of eastern New York can not be relied upon in their natural condition to yield more than about 0.15 to 0.25 of a cubic foot per second per square mile, while with an ordinary development of storage, the limit may be usually placed at from 0.7 to 0.8 of a cubic foot per second per square mile, or at any rate at not much exceeding one cubic foot per second per square mile. The sand deposits of Long Island may therefore be considered as great natural reservoirs from which, with proper development, large water supplies may be drawn, the same as from reservoirs artificially created on the earth's surface, these natural underground reservoirs possessing the advantage of furnishing a filtered water of high purity. This fact was recognized by the New York Water Supply Commission of 1903, who have recommended the further development of this supply. This commission made extensive observations as to the hight of ground water, etc.

Recent Projects for Water Supply of Greater New York

The rapid growth of Greater New York has compelled a general extension of the water supply, and a number of able reports have been made, which will be briefly referred to.

The first of these is in relation to the Ramapo Water Company, which was organized in 1887 under an act which permitted companies organized under it to supply with water any municipality in the State of New York. In 1890 the act was repealed and a general law enacted which surrounded with new safeguards contracts made with the companies organized under it, except that these safeguards did not apply to the already organized Ramapo company. A few years later, under chapter 985 of the laws of 1895, an act to limit and define the powers of the Ramapo Water Company, the Legislature considerably extended the privileges granted to this company. This act gives the Ramapo company power to contract for supplying to any municipality, or to any corporation, public or private. The act also gives to the company powers of condemnation, and they may select such route as they choose.

At the same time the Legislature considerably restricted the power of New York to acquire an additional supply of water, as indicated by the following: In 1896 the Suffolk county act, preventing Brooklyn from using the underground waters of Suffolk county, was passed. This act was continued in force by the New York charter, which went into effect January 1, 1898. A clause was also inserted in the Greater New York charter preventing the city from taking water from a supply devoted in whole or in part to the supply of any other municipality. In 1898-99 the Ramapo company proposed to supply New York with 200,000,000 gallons of water daily, for which the City of New York was to pay $70 per million gallons. The delivery of water was to begin in 1902.

Very earnest discussion occurred in New York when the Ramapo proposition was understood. An extensive report was made by the Merchants' Association and also by John R. Freeman to the Comptroller, showing that water could be furnished for very much less than the price proposed to be paid to the Ramapo company. An appeal was made to the Legislature and the legislation was modified, allowing the city to construct its own works.

There are a number of available sources from which Greater New York may be supplied without any great engineering difficulties. These sources may be enumerated as:

1) On the east side of the Hudson river, where there are the following: the Housatonic and Ten Mile rivers, which are, however, interstate streams; Fishkill creek, Wappingers creek and the Roeliff Jansen kill.

On the west side of the Hudson river there are:

2) Wallkill river, which is also an interstate stream.

3) The catchment of the Catskill mountains, including Esopus, Catskill, Schoharie and Rondout creeks.

4) Hudson river itself, either at a point near Poughkeepsie or by an aqueduct from the upper catchment area.

The Housatonic river, Ten Mile river and Wallkill river catchment areas are, however, eliminated from consideration by reason of certain legal difficulties due to the first two streams being partly in New York and partly in Connecticut and the Wallkill being partly in New York and partly in New Jersey. There seems to be no doubt that a lower riparian owner in either Connecticut or New Jersey could by an injunction prevent the use of either of these catchment areas to supply the City of New York, and even though Connecticut and New Jersey should, by their legislatures, grant either to the City of New York or to a corporation acting under its authority the right of condemnation, such acts would be unconstitutional. Moreover, it is doubtful in the case of New Jersey whether that State would even attempt to assist the City of New York, because recent legislation in New Jersey has indicated a policy to preserve for its own citizens the waters coming from the catchments in the northern part of the State.

It is also considered that legal complications would arise even if a private corporation should attempt to furnish water from New Jersey. As regards the use of the Wallkill river as a water supply for the City of New York, such use involves the building of a reservoir, the surface of which would be 422 feet above sea level. The Wallkill river, at the location of the proposed reservoir, is about 380 feet above tidewater. The dam would flood an area of 60 square miles, of which one-fifth is in New Jersey. If New York can purchase the lands in New Jersey, it can of course flood them for the purpose of a reservoir intended to supply New York, but there is no way by which New York city can acquire title to these lands by condemnation. Subject, therefore, to this difficulty of purchase, there is no objection to the Wallkill river as a supply for New York.[1]

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[1] Abstracted from Report of Committee on Legislation, in Report of Merchants' Association of New York.

In the Merchants' Association report it is stated that an additional water supply for New York city, adequate until its population shall increase to 18,000,000, can be obtained from the Hudson river above Poughkeepsie, at which point it is proposed to build pumping stations and filter beds on the east side of the river, together with an aqueduct to the northern limits of the city, where a reservoir would be constructed. This plant should be capable of supplying 250,000,000 gallons daily, although it is not proposed to build a plant capable of delivering at first more than 100,000,000 gallons daily.

In order to prevent the water above Poughkeepsie from becoming brackish, by reason of taking so large an amount of water from the river at this point, it is proposed to build in the Adirondacks a number of the reservoirs discussed on a preceding page, in which may be stored flood-flows during the spring months. This water is to be delivered into the river during the dry season, thus keeping the flow uniform throughout the year.

As incidental benefits, the navigation of the Hudson from Troy down will be considerably improved, together with a prevention of floods at Albany and places in the vicinity, as well as provision for a uniform flow for mill owners at various points higher up.

It is also suggested that water be taken from the Hudson at Hadley, as indicated in the discussion of the Schroon valley reservoir.

The annual cost of taking water at Poughkeepsie, including operation and maintenance, will be $28.33 per million gallons for 250,000,000 gallons daily. The annual cost for the same amount from the Adirondacks, including interest, operation and maintenance, will be $30 per million gallons, while to furnish 500,000,000 gallons from the Adirondacks, the yearly cost after construction will become $29.25 per million gallons.

The Committee on Water Supply of the Merchants' Association, however, considered that there are certain advantages in the Poughkeepsie plan over either the Catskill or Adirondack in that:

1) The ultimate first cost of the Poughkeepsie plan would be less.

2) A larger proportion of the ultimate first cost may be deferred by the Poughkeepsie plan than by either the Catskill or Adirondack plan.

3) The time necessary for construction is also less. Water from the Hudson at Poughkeepsie can be delivered in six years; from the Catskills, in seven years, and from the Adirondacks, in seven and one-half years.

4) The Adirondacks and the Hudson together would furnish 1,500,000,000 gallons per day, while the Catskill catchment can not furnish more than 260,000,000 gallons, or, with Schoharie creek, 460,000,000 gallons per day.

5) The length of the aqueduct would be less from Poughkeepsie than from either the Adirondacks or the Catskills. From Poughkeepsie a high level aqueduct would be 60 miles in length; from the Adirondacks, 203 miles, and from the Catskills, 100 miles.

The lesser length of the Poughkeepsie aqueduct is not only an important element in construction, but is quite as important in maintenance and protection.

Water taken at Poughkeepsie would require filtration, and in the modern view it would also require filtration from the Adirondacks, although it may be very appropriately questioned whether a water supply from a seriously sewage-polluted stream is desirable so long as unpolluted sources are available without increasing the cost per unit.[1]

Reservoir on Wallkill river. Among other interesting reservoirs which have been recently proposed for the supply of Greater New York, that on the Wallkill river may be described in detail. This reservoir was reported upon by James H. Fuertes, whose report appears in the Report of the Merchants' Association of New York, made in 1900.

Wallkill river rises in northern New Jersey, a few miles south of Sparta. It flows in a northeasterly direction, entering the State of New York about half way between Liberty Corner and Unionville. It then flows through Orange and Ulster counties, joining Rondout creek, which empties into the Hudson river at Kingston.

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[1] Report of Committee on Water Supply of Merchants' Association of New York.

Just before entering New York State the stream enters a broad, flat valley, extending to Phillipsburg, and varying from one to five miles in width. The floor of this valley is flat, both longitudinally and transversely, with its slope in the direction of the river so slight that the valley is usually flooded during the spring, although later in the season the water drains from the flats through the river channel, as well as through several artificial drainage ditches.

The valley consists of high hills with steep sides. The hills on the west are slaty, slightly covered with soil, while the hills on the east are of granite, marble and limestone. The bottom of the valley is underlaid with calciferous sandstone, generally covered with a few feet of black soil on top of the detritus with which the valley is filled. The geologic structure indicates that there is very little underground flow above Phillipsburg, although Mr Freeman in his report to the Comptroller, also made in 1900, expresses a different opinion. In his view there is a good deal of doubt whether the Wallkill reservoir can be made safe, because of the large leakage from the sides. The writer does not share Mr Freeman's apprehensions, although in the absence of thorough examinations the question is an open one. About 25 per cent of the valley is wooded.

The water of the reservoir on the Wallkill would be as soft and colorless as the Croton water. This conclusion is based on experiments and analyses and on a study of the ground and surface flow of the streams.

It is proposed to erect a dam at Phillipsburg which will impound the waters of the river and flood the valley from twenty to thirty feet in depth. The general elevation is about 390 feet above sea level. If the water level be raised to 410, sufficient storage will be provided for a daily draft of 250,000,000 gallons by drawing the water in the reservoir down 5 feet. The area of the catchment above Phillipsburg is 465 square miles. The area submerged at elevation 405 is 49 square miles, and at elevation 410 it is 51 square miles. Hence, only about 5 per cent of the area would be exposed on drawing the reservoir, enough to give a yield of 250,000,000 gallons daily. The amount of water impounded would be approximately 200,000,000,000 gallons (26,700,000,000 cubic feet) of which 53,000,000,000 gallons (7,100,000,000 cubic feet) would be available, equivalent to a daily yield of over 600,000 gallons of water per square mile of land surface, or 254,000,000 gallons per day. The writer, however, considers this allowance larger than is likely to be realized in the region—probably 500,000 gallons per square mile per day would be a safer figure.

There are two serious objections to a water supply reservoir at this point. The first is the shallowness of the reservoir, which will certainly lead to extensive growths of algae around the edges, and the second is the objectionable bottom. The second objection can be overcome by covering the bottom with gravel which, however, would add very greatly to the expense.[1]

The submerged land is sparsely populated, and with the exception of Florida, Hamburg and Deckertown, there are no villages of any importance near the valley. The sewage of Goshen and Middletown, however, enter streams flowing into the Wallkill above the point where the dam would be located and would have to be taken below the dam by sewers. The sewage of Florida, Hamburg and Deckertown would require purification before discharging into streams tributary to the reservoir. A few other small hamlets of from three to a dozen houses could be taken care of by purchase.

It is proposed to filter the water from this reservoir. The estimates provide for the purchasing of 70 square miles of area, which includes a strip around the edge wide enough to afford protection from contamination. About 20 per cent of the land which it is proposed to submerge is either now or has been under cultivation. The balance is covered with water and rank growths of coarse grass, reeds and underbrush.

The surrounding hills are dotted with dairy farms, and the Lehigh and New England railway and the Pine Island branch of the Erie railroad collect the milk, conveying it to market. These railroads would be relocated along the edges of the reservoir, with crossings, embankments and bridges as required. It would also be necessary to build crossroads over the lake, with bridges and roads along the margins. The expense has been included in the estimates.

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[1] In reference to growths of algae, see paper On the Fresh Water Algae and their Relation to the Purity of Public Water Supplies. Trans. Am. Soc. C. E., Vol. XXI (1889).

There are several dams below Phillipsburg at which power is used for operating mills and factories, although the total power does not much exceed 1000 horsepower. In some instances the plants have a capacity in excess of that needed for the minimum flow of the stream. The principal developed power is at Walden. The population here is from 2500 to 3000 people, and its prosperity depends upon the waterpower which has been developed by two dams, amounting to 500 horsepower at minimum low water flow. To cripple this power would seriously affect the community depending upon it. In the estimates therefore very liberal figures have been used, which are considered sufficiently high to cover any method of compensation which might be adopted.

By increasing the hight of the dam at Phillipsburg to 422 feet above sea level, the flooded area would become 58 square miles and the available storage capacity of the reservoir, when drawn down to elevation 402, would be 219,000,000,000 gallons (29,300,000,000 cubic feet). With such a storage a minimum yield would be 417,000,000 gallons daily. The total amount of water impounded with full reservoir would be 387,000,000,000 gallons (51,700,000,000 cubic feet). It is stated in the report that this reservoir would be the largest artificial lake in the world, but a comparison with Black river reservoir will show that the latter is somewhat larger. Neither, however, is yet built, and New York State can only claim, by reason of its exceptionally favorable topography, to be the site of two of the largest reservoirs thus far proposed anywhere.

Some of the legal objections to the Wallkill river reservoir have already been discussed.

The estimated cost of construction of the Wallkill reservoir for a supply of 250,000,000 gallons daily, the water to be filtered and delivered into a new covered reservoir at New York 310 feet above sea level, is $42,421,000. The annual cost for operation and maintenance is figured at $1,819,770, or at a cost per million gallons for the water filtered and delivered into a reservoir at New York of $19.64. In these estimates labor is taken at $2 per day.

For 460,000,000 gallons daily from the Wallkill river the estimate of cost on the basis of $2 per day for labor is $80,864,000, with an annual cost for operation and maintenance of $3,328,078, or at the rate of $19.82 per million gallons filtered and delivered into covered reservoir at New York, 310 feet above sea level.

The Wallkill river was also reported upon by Mr Freeman. In his report he states that these Drowned Lands appear to be the only adequate reservoir site on the Wallkill—that they were once the bottom of an ancient lake and are described by Dr Heinrich Ries, in his Report on the Geology of Orange County, as follows:

> These swamps occur not only in the limestone region, but also in many parts of the slate area and form perhaps the most important agricultural feature of the county. The rich black soil of the swampy tracts is enormously productive, and some of it is worth $300 an acre. The soil is generally planted with onions, and 700 bushels per acre is not an uncommon yield. Potatoes or corn are generally planted in alternative years to relieve the soil. There are about 40,000 acres of swamp land in Orange county. The largest of these areas is the Drowned Lands in Warwick, Greenville, Minnisink, Wawayanda and Goshen townships, and covers 17,000 acres. Until about sixty years ago the area was covered by several feet of water held in by a dam of glacial drift at the north end. A canal cut through this dam has redeemed the land. From the drowned lands there arise islands of limestone or drift, which are named Pine, Great, Pellets, Gardner's, Merritts, Cranberry, Black Walnut, Fox and Seward's islands. * * * Black soil underlies the surface to a depth of from five to fifty feet, and this, according to Mather, is in turn underlaid by marl. The Wallkill river follows a winding course along the western side of this area, and submerges it entirely during the spring floods.[1]

Mr Freeman states that the population of the catchment area is almost exclusively a farming one, with about thirty villages, ranging in population from 100 to 300, by the census of 1900, together with many more centers of population with less than 100. The cities and towns which had more than 500 inhabitants in 1900, are as follows:

Name of town	Population
Middletown	14,522
Goshen	2,806
Warwick	1,735
Florida	600

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[1] Report on Geology of Orange County, 1895, by Dr. Heinrich Ries, Asst. Geologist.

The following figures for towns in New Jersey are as given by Mr Freeman:

Name of town	Population
Franklin Furnace	913
Deckertown	993
Hamburg	519
Ogdensburg	565
Sparta	501

The outside population on farms is estimated at about twenty to the square mile.

Mr Freeman made some observations as to the quality of reservoir bottom. Samples of soils were collected in clean glass jars and sent to the analyst of the Metropolitan Water Board for examination by the ignition method. A sample from one foot depth showed 69 per cent organic matter; from 3 feet down, 85 per cent, and from 5 feet down, 89 per cent. Another sample from 6 inches in depth showed 49 per cent organic matter, with little or no iron present. Several other samples from 6 inches to 3½ feet down showed from 78 per cent to 90 per cent organic matter. These observations show at once the necessity, in case a reservoir for water supply purposes should be constructed at this point, for covering the bottom with gravel, as already suggested.

Reservoirs on Esopus, Catskill and Schoharie creeks. Reservoirs were considered by Mr Fuertes on Esopus, Catskill and Schoharie creeks. The lowest elevations considered in seeking reservoirs on these streams were for Catskill and Esopus creeks, 500 feet and on Schoharie creek, 1100 feet above sea level. These elevations were decided upon because lower elevations will not economically permit of the delivery of water at New York 300 feet above sea level.

Catskill and Esopus creeks flow in a southeasterly direction, nearly parallel and about twenty-five miles apart. Catskill creek is on the northern side of the Catskill mountains and Esopus creek on the south side. Both streams empty into the Hudson river—Catskill creek at the village of Catskill and Esopus creek at Saugerties. Schoharie creek lies between Catskill and Esopus creeks and flows in the opposite direction, bending towards the north after leaving the mountains, and emptying into the Mohawk river near Amsterdam. The sources of Schoharie creek are over 2000 feet above sea level and not more than ten miles from the Hudson river.

The waters of Catskill and Esopus creeks can be delivered to New York through conduit lines from the reservoirs, but the waters of Schoharie creek can only be brought to the city by the construction of a tunnel from the lowest reservoir on the Schoharie to the nearest point in the Esopus valley.

Topographically, Catskill and Esopus creeks are similar in general characteristics. The tributary streams have steep slopes, offering no sites for storage reservoirs. The main streams, on the contrary, are flatter and afford opportunities for constructing dams.

The conditions on Schoharie creek are different. At its headwaters there are three tributaries, Batavia kill, West kill and East kill, on all of which considerable storage may be secured. As stated in the discussion on the flow of streams, all of these are more or less flashy, rising quickly with heavy rains, with high flood-flows, and subsiding rapidly after rainfalls, with very low minimum flows.

The lowest dam site on Esopus creek is a short distance above the falls at the village of Olive. The creek here flows through a narrow gorge, affording an opportunity for the construction of a masonry dam, 60 feet high and 600 feet long. The area of the catchment above this dam is 245 square miles. The proposed reservoirs on Esopus creek have an available storage capacity of about 27,000,000,000 gallons (3,600,000,000 cubic feet), and are estimated to yield in minimum years about 150,000,000 gallons daily. This corresponds to an average yield of 625,000 gallons of water per square mile per day. The writer, however, considers the same as in the case of the Wallkill river, that this estimate is too large, and on Esopus creek it certainly should not be taken to exceed about 500,000 gallons per square mile per day.

The proposed dams on Esopus creek are: At Olive; Cold Brook station; Lake Hill; one mile above Mount Pleasant station; one-half mile above Phoenicia; one and one-half miles above Phoenicia; one mile above Shandaken; and one-half mile below Big Indian. These dams would all be of earth, with spillways cut in the rock sides of the valley.

The Ulster & Delaware railroad passes through the Esopus valley from one-half mile above the Olive dam to above Big Indian reservoir site. The building of these reservoirs would require relocation of this railroad for its entire length. The construction of the reservoirs would also require the relocation of five villages in the valley. There are also twelve villages which are not interfered with, but as they lie above the various reservoirs, the cost of providing them with sewerage and sewage purification works is included in the estimates. There are a few water powers on the main stream at Olive, Boiceville, Allaben and Big Indian. None of these powers is very important, but the estimates have been made ample to cover the cost.

Table No. 89 gives the particulars of the storage reservoirs on Esopus creek.

TABLE NO. 89—PROPOSED STORAGE RESERVOIRS ON ESOPUS CREEK

Name of Reservoir	Area of catchment in square miles	Approximate elevation of high water in feet above sea level	Approximate elevation of low water in feet above sea level	Hight of dam in feet	Area of reservoir full, in square miles	Total yield in gallons per day	Estimated cost per 1,000,000 gallons capacity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Olive	49.0	510	485	60	0.78	20,000,000	$240
Cold Brook	31.0	690	655	85	1.03	22,100,000	255
Lake Hill	18.6	1,080	1,055	70	0.72	12,700,000	235
Mt. Pleasant	34.9	790	755	80	0.89	23,500,000	245
Lower Phoenicia	22.3	910	885	90	0.25	8,300,000	460
Upper Phoenicia	40.8	985	940	95	1.01	29,400,000	250
Shandaken	.....	1,180	1,150	80	0.37	27,900,000	360
Big Indian	48.9	1,240	1,210	70	0.51	....	295
Total	245.5	.....	.....	....	5.56	143,900,000	....

The main valley of Catskill creek is narrower than that of Esopus creek, affording favorable opportunity for reservoir sites. The lowest dam has been located near the village of East Durham. The area of the catchment above this dam is about 192 square miles. It is proposed to construct reservoirs on Catskill creek at the following points: East Durham; two miles above East Durham; half a mile below Oak Hill; just above the village of Preston Hollow, and on Basic creek, near Greenville. These reservoirs will provide an available storage capacity of nearly 19,000,-

000,000 gallons (2,600,000,000 cubic feet). As in the case of Esopus creek, the safe yield is estimated by the writer at 500,000 gallons per square mile per day.

The East Durham dam would be of masonry, with a spillway over its crest—the balance of the dams on Catskill creek would be of earth, with masonry cores, with spillways cut in the rock sides of the valley.

In constructing the system of reservoirs on Catskill creek the village of Oak Hill would be entirely removed. Aside from Greenville, consisting of eight or ten houses, no other towns are interfered with in this valley, but sewage purification works have been provided for East Durham,. Durham, Potter Hollow, Cooksburg, Preston Hollow, Livingstonville and Franklinton. The water powers on Catskill creek above East Durham are of little importance, and on the lower creek the most important power is at Leeds, where there is head sufficient to develop 500 horsepower with low-water flow.

Table No. 90 gives the particulars of the storage reservoirs on Catskill creek.

TABLE NO. 90—PROPOSED STORAGE RESERVOIRS ON CATSKILL CREEK

Name of Reservoir (1)	Area of catchment in square miles (2)	Approximate elevation of high water in feet above sea level (3)	Approximate elevation of low water in feet above sea level (4)	Hight of dam in feet (5)	Area of reservoir full, in square miles (6)	Total yield in gallons per day (7)	Estimated cost per 1,000,000 gallons available capacity (8)
Greenville.........	30.4	680	650	85	0.45	13,500,000	$240
Lower East Durham	21.8	540	500	60	0.33	11,700,000	255
Upper East Durham	43.3	620	580	100	0.89	27,100,000	245
Oak Hill...........	52.4	720	680	90	0.97	32,000,000	250
Preston Hollow....	44.1	960	900	100	0.44	24,000,000	245
Total.........	192.0	.....	.....	...	3.08	108,300,000	.....

The area of the Schoharie catchment above Gilboa is about 305 square miles. This is as much of the area as could be economically developed for the supply of New York.

The dams of the proposed Schoharie creek reservoirs vary from 50 feet to 110 feet in hight and from 700 feet to 1840 feet in length. They are located at the following points: At Gilboa;

one mile north of Prattsville; one mile north of Lexington, and at Kaaterskill Junction. On the Batavia kill, they are located at the following: Just north of Ashland and Windham and south of Big Hollow; and on the East kill, below East Jewett. These reservoirs would afford about 40,000,000,000 gallons (5,400,000,000 cubic feet) of available storage, and would yield in minimum years, according to the writer's estimate, about 500,000 gallons of water per square mile per day. The dam at Gilboa would be of masonry—the others of earth, with spillways cut in the rock sides of the valley.

Waterpowers on Schoharie creek above Prattsville are unimportant, consisting of but two or three small sawmills. There are several powers at and below Gilboa, but none of them is very important, although the abstraction of the water from Schoharie creek would affect all the powers on the Mohawk river below the mouth of the Schoharie.

Basing a calculation on the power developed at Cohoes in relation to the low-water flow of the stream, the effect of the abstraction of the proposed amount of Schoharie creek water would be about 1800 horsepower.

Table No. 91 gives the particulars of storage reservoirs on Schoharie creek.

TABLE NO. 91—PROPOSED STORAGE RESERVOIRS ON SCHOHARIE CREEK

Name of Reservoir (1)	Area of catchment in square miles (2)	Approximate elevation of high water in feet above sea level (3)	Approximate elevation of low water in feet above sea level (4)	Hight of dam in feet (5)	Area of reservoir full in square miles (6)	Total yield in gallons per day (7)	Estimated cost per 1,000,000 gallons available capacity (8)
Kaaterskill Junction	33.4	1,740	1,700	90	0.47	17,800,000	$305
East Jewett.........	20.6	1,830	1,800	95	0.74	14,700,000	265
Big Hollow..	13.6	1,720	1,675	90	0.29	9,400,000	320
Windham...........	15.5	1,560	1,540	65	0.28	6,300,000	365
Lexington...........	42.2	1,430	1,380	100	0.83	29,100,000	255
Ashland	22.9	1,480	1,455	50	0.49	12,100,000	250
Prattville	76.9	1,280	1,225	105	1.64	57,900,000	240
Gilboa......	80.3	1,100	1,050	110	1.01	47,800,000	220
Total	305.4	.....	.....	....	5.75	195,100,000	.....

The foregoing estimates included in tables No. 89, 90 and 91 do not cover damage to mill property and waterpower.

In addition to the projects herein discussed at length, at various times during the last few years projects have been considered for reservoirs on the following streams:

Mahwah river, diverting the water at Suffern, where there is a catchment area of 20 square miles; Popolepen creek, diverting the water at Fort Montgomery, where there is a catchment area of 28 square miles; Big Moodna creek, diverting the water at Salisbury Mills, where there is a catchment area of 123 square miles; Little Moodna creek, diverting the water at Woodbury Falls, where there is a catchment area of 11 square miles; Shawangunk creek, diverting the water at Bloomingsburg, where there is a catchment area of 47 square miles; Rondout creek, diverting the water at Ellenville, where there is a catchment area of 184 square miles; the Basher kill, diverting the water at Port Orange; Neversink creek, diverting the water at Quarryville, where there is a catchment area of 200 square miles; the Delaware, diverting the water above Port Jervis, where there is a catchment of 3600 square miles. None of these projects has passed more than the preliminary stage.

The New York Water Supply Commission of 1903. In the fall of 1902 the Mayor of New York appointed William H. Burr, Rudolph Hering and John R. Freeman as a commission to consider the best sources of an additional water supply for New York city. The final report of this commission was submitted in December, 1903. The outline for the plan of a new gravity supply is given in the following abstract of the report, as taken from Engineering News for December 24, 1903:

> The commission favors taking a first installment of 60,000,000 gallons from the Fishkill watershed, but developing concurrently the supply from Esopus creek. These two sources would give nearly 320,000,000 gallons per day. Another 100,000,000 gallons per day may be secured from Rondout creek without great additional expense, making a total supply of nearly 420,000,000. The final 80,000,000 gallons or more may be obtained from Wappinger creek by means of a large reservoir at Hibernia, within the catchment area of that creek, thus completing the amount of 500,000,000 gallons per day. If it should be desired, a further large supply can be obtained from the upper watershed of the Jansen kill, on the easterly side of the Hudson, and from the upper waters of Schoharie creek, diverted into the watershed of the Esopus creek, and from Catskill creek.

The waters of the three creeks on the easterly side of the river are much harder than the Croton water, but the waters of Rondout and Esopus creeks are remarkably soft and desirable for city supply. It has been the commission's plan to deliver to the city the soft water of the Catskill mountain streams, so as to reduce the hardness of the combination with the waters on the easterly side of the Hudson, thus securing a supply equally soft as the Croton water.

The commission is strongly of the opinion that after the waters of the streams now recommended for use are taken, Hudson river water should be secured by pumping it out of the river near Hyde Park up to suitable reservoirs and filters, on the high land easterly of the river, so as to deliver it to the city at the required elevation. This, however, is in the remote future, and is set forth as a resource in reserve at that time. In such a development it will be necessary to build large storage reservoirs in the Adirondacks, from which flood waters of the Adirondack streams may be released during the summer flow of the Hudson, so as to prevent any salt water from reaching the point where the pumps would take the river water. It is explicitly stated in the report that the filtration of Hudson river water would render it entirely satisfactory for all purposes.

The following is a summary of the cost of these reservoirs:

The works recommended to be constructed first comprise a section of the Hill View reservoir, of 600,000,000 gallons capacity; the main aqueduct, of 500,000,000 gallons daily capacity, from that reservoir to Stormville reservoir; a section of the Stormville filters, of 50,000,000 gallons daily capacity; the twin aqueduct, one channel of 400,000,000 gallons and the other of 250,000,000 gallons daily capacity, from the Stormville reservoir to the Billings reservoir and these two reservoirs. This construction will afford an additional supply of 60,000,000 gallons per day. Concurrently with the preceding construction, the aqueduct of 400,000,000 gallons daily capacity should be built from the Billings reservoir to the Ashokan reservoir, and at the same time the latter reservoir should also be under construction.

It is estimated that the first part of this work, i. e., extending from Hill View reservoir to Billings reservoir, may be built, under efficient management, within five years, and that the second part of the construction, extending from Billings reservoir to the Ashokan reservoir, may be completed within the same period, if the labor market affords sufficient force and the money is provided.

The summary of costs of this construction is as follows:

Reservoirs	Total cost	Cost per 1,000,000 gallons
Hill View covered reservoir first section of 600,000,000 gallons capacity.	$9,059,000	$15,098 00
Stormville filter plant first installation of 50,000,000 gallons daily capacity.	3,581,000	
Stormville reservoir, 10,000,000,000 gallons capacity	2,503,000	250 00
Billings reservoir 6,800,000,000 gallons capacity	1,806,000	266 00
Ashokan reservoir, 66,500,000,000 gallons capacity	11,734,000	176 00
Total	$28,683,000	
High Level Aqueduct		
From Hill View to Stormville filters..	$18,755,000	
From Stormville to Billings, twin aqueduct	3,584,000	
From Billings to Ashokan, including Hudson river crossing	9,076,000	
Total	$31,415,000	
Total cost of construction...	$60,098,000	

These estimated costs include actual contract and all other expenditures, except those for damages to water rights. These works will afford an additional supply of nearly 320,000,000 gallons daily.

It is estimated that the complete construction of reservoirs, filters and aqueducts for the full additional supply of 500,000,000 gallons per day may be required by 1925. The costs of the remaining construction in excess of that already provided for will be as follows:

Reservoirs	Total cost	Cost per 1,000,000 gallons
Hill View reservoir completed to 2,030,000,000 gallons capacity in 1925	$4,110,000	
Stormville filters completed to 500,000,000 gallons daily capacity in 1925	11,065,000	
Hibernia reservoir, 30,500,000,000 gallons capacity	9,308,000	$305 00
Silvernails reservoir, 17,200,000,000 gallons capacity	5,530,000	321 00
Total	$30,013,000	
Aqueducts		
Additional cost for completed aqueduct between Hill View and Stormville	$1,510,000	
Additional cost for completed aqueduct between Billings and Ashokan	4,369,000	
Aqueduct from Billings reservoir to Hibernia reservoir, 300,000,000 daily capacity	1,573,000	
Aqueduct from Hibernia to Silvernails, 220,000,000 to 330,000,000 gallons daily capacity	1,276,000	
Total	$8,728,000	
Total cost of additional construction	$38,741,000	

These additional costs, like those covering the first portions of the work to be constructed, include all expenditures such as those for land, clearing reservoir sites and other similar costs except water damages along the streams from which the additional supply is taken.

The total cost of the entire works required to deliver the additional high service supply of 500,000,000 gallons per day will be the sum of the two preceding totals: total cost of entire work, $98,839,000.

If instead of developing the Jansen kill it should be considered preferable to take the soft waters of Rondout creek, the preceding estimates of cost would be modified to the extent of substituting the expenditures necessary to secure the Rondout water for those required to secure the Jansen kill water. The commission believes that this procedure will be found to be preferable; but the impossibility of completing the Rondout surveys does not permit accurate estimates to be made for securing the Rondout water.

In regard to a supply for the Boroughs of Brooklyn, Queens and Richmond, the abstract of the final report of the commission states as follows:

For Brooklyn and Queens, an immediate development of the ground-water sources of Queens and Nassau counties is recommended, and that all surface supplies be filtered; also that ultimately these Long Island sources be supplemented by a branch conduit from the proposed 500,000,000-gallon aqueduct from the north of Manhattan.

For Richmond, the commission has approved of a ten-year contract with a private company for the immediate introduction of filtered water from New Jersey.

Queens, the commission says, already urgently needs more water and the Borough of Brooklyn has also reached that point where it must have additional water of good quality. It has already begun to filter its present surface supplies, which are more or less polluted by the increasing population of the southern portion of Nassau county.

The following are the catchment areas of the several reservoirs proposed for construction by the commission in their report of 1903:

	Square miles	
Fishkill creek: Above Stormville dam	49	
Above Billings dam	32	
		81
Wappinger creek: Above Hibernia dam	90	
Above Clinton Hollow dam	26	
		116
Roeliff Jansen kill: Above Silvernails dam		149
Esopus creek: Above Ashokan dam		255
Rondout creek: Above dam		131
Grand total		732

This commission is in favor of using well chosen underground waters, and points out the high character and large amount of underground waters naturally stored on Long Island. Extensive studies have been made of these underground sources, covering 1000 square miles of territory and including observations of the water levels in nearly 1500 wells. The commission states that at the present time no municipality can be considered as satisfactorily supplied with water unless the supply is either filtered artificially or naturally filtered, as in the case of ground water. It also urges that works for the filtration of the Croton supply be demanded at once, and advises that the reservoirs in Central park be cleaned and that they be roofed over as soon as the Croton supply is filtered.

As shown by Plate XXXIV, this commission recommended that Fishkill creek, Wappinger creek and the Roeliff Jansen kill on the east side of the Hudson be taken, together with Esopus and Rondout catchment areas on the west side.

On Fishkill and Wappinger creeks there are situated manufactories employing 7000 people who are greatly alarmed at the prospect of their industries being destroyed. They accordingly went to the legislature of 1904 and secured the passage of an act prohibiting the taking of any of the waters of Dutchess county for the supply of New York city. This act was signed, and it is uncertain whether the work of the New York Water Supply Commission of 1903 may not be considerably modified in consequence.

Water supply of Staten Island. The area of Staten Island is 49 square miles, including the salt marsh at its borders. It contained a population in 1900 of 67,021. A considerable proportion of this population is collected in small villages, which as yet have no public water supplies. There are several villages of considerable size, as Pleasant Plains and Prince Bay, which obtain their water from wells. There are also a number of large manufacturing establishments which are without public water for fire protection or general purposes. The village of Tottenhill, at the extreme south of the island, is supplied from a small plant owned by the municipality.

The present supplies throughout Staten Island are from driven wells. Eighty per cent of the area of Staten Island is stated to be covered by the terminal moraine of the continental glacier, with surface formation very impervious. The conditions, therefore, are quite different here from Long Island, where extensive areas of coarse sand permit a large proportion of the rainfall to sink into the earth. Moreover, the geologic structure is such as to render it improbable that any such large amount of ground water can be obtained as in the adjacent area of New Jersey.

The geology of Staten Island has been reported upon by Professor W. O. Crosby of the Massachusetts Institute of Technology. In this report it is stated that borings in the vicinity of Woodbridge and Perth Amboy show that the traprock and the ridge of crystalline rocks are continued only at moderate depths below the surface, and that in consequence the cretaceous strata underlying the entire lowlands south of the serpentine ridge, and which in New Jersey embrace several good water horizons, are cut off from the catchment areas either on the mainland or on the northern part of Staten Island. Moreover, the fact that the wells penetrating the cretaceous strata are practical failures indicates that the water-bearing strata outcrop on this island only to a very limited extent or not at all.

The gray gravel and blue gray formations of Long Island are, so far as can be observed, wholly wanting on Staten Island, and the yellow gravel, which is an important reservoir of ground water on Long Island, has only a limited development on Staten Island, being practically confined to the cretaceous lowlands, which are the source of such wells as are not failures.

Moreover, the greater portion of the area of Staten Island is covered by bowlder clay, which is of an exceptionally impervious character, as proved by numerous ponds more or less effectually sealing the catchment areas of strata which might otherwise be water-bearing. The bowlder clay is in many places from 50 feet to 200 feet thick.

To summarize, the geologic conditions affecting the storage and flow of ground water are generally unfavorable, because all the formations, excepting the yellow gravel, are naturally of little value as sources of ground water. Unfortunately, the yellow gravel has not only a limited catchment area, but the small areas of it are mainly near the southeastern margin of the island, which still further limits the probability of water in that portion under the terminal moraine. Generally, therefore, the conditions on Staten Island are not comparable with those on Long Island.

AS TO THE POSSIBILITY OF PUBLIC WATER SUPPLIES FROM WELLS IN THE STATE OF NEW YORK

Aside from Long Island, there is little probability of satisfactory well supplies in the State of New York. This fact is of importance because frequently town authorities who are not familiar with water supply engineering, imagine that a satisfactory supply can be obtained from wells at small expense. This matter was reported upon by the writer in considering a ground water supply for Lockport in November, 1903. The following from that report is herewith given:

At the time of the issue of the last edition of the Manual of American Waterworks, in 1897, there were in the State of New York a total of 420 waterworks of which 60 were well supplies. The writer is more or less familiar with the most of these well supplies, and aside from those on Long Island, the statement may be made that they are unsatisfactory in quantity—they nearly all fail in dry time. They are also unsatisfactory in quality. There are a few exceptions to this, but the broad proposition is abundantly true that well supplies in the State of New York, aside from those on Long Island, are not satisfactory. It has been necessary to reinforce the most of them either by taking streams, canals, or by other means, with the result that their quality has been so far deteriorated as to constitute in many cases a distinct menace to the health of the communities using them.

Again, about two-thirds of the well supplies in the State have been constructed by private companies, and almost without exception the works are constructed as cheaply as possible, to their permanent detriment. They have naturally, therefore, adopted a well supply wherever possible as being cheaper than surface supplies. But in making these remarks, it is not to be overlooked that on Long Island, where different conditions prevail, satisfactory well supplies may be obtained at less expense than surface supplies.

The peculiarity of wells penetrating the rock in New York State is that nearly all of them are either salty or contain sulphureted hydrogen or some other objectionable gas. This peculiarity is specially marked in the limestones of the Niagara and Clinton formations. While sulphureted hydrogen, by itself, in very small quantities, although disagreeable, is not specially unhealthful, nevertheless excessive hardness taken in conjunction with sulphureted hydrogen produces unsatisfactory water and the writer would hesitate to recommend a water supply containing large amounts of sulphureted hydrogen, with a high degree of hardness, if it were possible to obtain anything else. Such a water, in short, should only be used as a last resort.

On the other hand, in Illinois and a number of other western States, a very large proportion of the water supplies is derived from wells. We conclude, therefore, that broadly, the question as to whether a well supply is either desirable or possible, is determined largely by locality.

In regard to special conditions at Lockport a large number of wells have been drilled, not only within the city limits but in the surrounding country. A considerable number of these wells are reviewed in detail and none of them yields more than a few thousand gallons of water per day—usually, from a few hundred to two thousand or three thousand gallons is the limit. One of the wells is reported to have flowed when originally bored in 1888. At the present time the water stands permanently from ten to twelve feet below the surface. This fact indicates a permanent reduction of ground water of that amount in fifteen years.

Moreover, the source of all the water, either upon the surface or within the ground, is the rainfall. The average rainfall of the western plateau, which includes western New York west of the valley of Seneca lake, is for the twelve years from 1891 to 1902, inclusive, 37.03 inches, but the rainfall at Rochester for the year 1888 was only 27.34 inches, while in the preceding year of 1887 it was only 20.61 inches. We had, therefore, two years of low rainfall, the rainfall of 1887 being the lowest for the period of thirty-two years during which observations have been kept by the United States Weather Bureau at Rochester. If, therefore, this well actually flowed in 1888, it is certain that the large number of wells put down since that time have materially lowered the ground water and it is extremely doubtful if now more than 100,000 gallons per day are being taken from the ground from wells at or near Lockport. It follows, therefore, from the known facts of wells at and about Lockport, that there is no possibility of obtaining an adequate supply for the city—at any rate, on the basis of present use, which as per a statement made by the superintendent of waterworks under date of January 1, 1903, is at the average daily rate of 4,500,000 gallons.

The problem reduced to its simplest terms is this. If the taking of perhaps 100,000 gallons per day has lowered the ground water 10 to 12 feet in fifteen years, during which time the rainfall has been mostly several inches above the average, how much would the ground water be lowered if either 3,000,000 to 4,000,000 gallons per day were taken, or even as small a quantity as 700,000 gallons per day? It is obvious that the answer must be that it would only be a short time before water would be exhausted from the ground, and any waterworks constructed with a ground water supply, a failure.

As to why it is improbable that this quantity of water can be obtained, there are three reasons:

1) The rocks of the Niagara and Clinton groups as existing at and about Lockport are, above the Medina sandstone, close-textured—there is not much water in them.

2) The overlying surface soil is strong, compact clay, making it impossible that any considerable quantity of rainfall penetrate the soil and to and into the rocks.

3) The inclination of the strata is from northeast to southwest, rendering it impossible that water in or between the strata run towards Lockport. Its natural course is away from the city.

The material for demonstrating these three propositions exists in considerable detail, but as the writer's object is not at present to write a treatise on well supplies but merely to point out saliently a few reasons why such supplies are mostly impossible in New York the matter is not pursued, aside from the paragraphs following, any further at this time.

As bearing on the subject just discussed, in Water Supply and Irrigation paper of the United States Geological Survey, No. 61—Preliminary List of Deep Borings in the United States—by N. H. Darton, there is an extensive list of deep borings scattered over New York. Mr Darton states that in Allegany county there are over 6500 borings, some of them 3000 feet deep. Aside from two or three wells, which yield from 50 to 70 gallons per minute of good water, the balance of the deep wells of the State contain either gas, salt or mineral water. Deep wells, almost without exception, are failures as regards furnishing potable water. There are so many experiments upon this point as to render the boring of a deep well for a water supply in New York State useless, although it should not be overlooked that a few of the wells furnish potable water, but the chance of finding such is so small as to put such wells out of the list for public water supplies. At any rate, it should be understood that the finding of potable water in a deep well is a matter of chance.

It appears, therefore, that aside from occasional limited supplies of spring water and the lakes throughout the eastern portion of this region, there are no natural water supplies to be found, except in the elevated regions of the Allegheny water center, where adequate supplies may be made by storage. Many of the lakes are not available, because they receive so much sewage as to render the water unsafe without filtration. This remark applies to Lakes Erie and Ontario and to the Niagara river.

The preceding remark also applies in some degree to the region east of Seneca lake and south of the Mohawk river.

As to why this is so, it may be remarked in a few words that the geology of the region is not favorable either to subterranean water-supplies, or to large streams flowing on the surface. The formations in an ascending order from Lake Ontario to the south line of the State are Medina sandstone, Clinton sandstone and limestone, Niagara shales and limestone, Salina shales and limestone, the lower and upper Helderberg limestones, Hamilton shales and sandstone, and Portage shales and sandstone. There is also a small area of cretaceous clays and sands in Cattaraugus and Allegany counties, near the south line of the State. None of these formations is favorable for well supplies—the preferable future water supplies of the entire region must be surface water, and made by storage.

INLAND WATERWAYS

Trade and commerce of Hudson river. The importance of the Hudson river as a great waterway of commerce is shown by Charles G. Weir in a report made in 1890. Aside from its own local trade the river absorbs all the traffic of the Erie, Champlain and Delaware & Hudson canals,[1] besides the great coal trade of the Pennsylvania Coal Company at Newburg and the Erie coal trade at Piermont. The average season of navigation of the river is two hundred and forty days. The two principal industries on the Hudson river, which add materially to the total tonnage, are ice and brick. The capacity of the ice houses on and near the river exceeds 4,000,000 tons, and the amount annually harvested is about 3,500,000 tons. The bricks manufactured on the river exceed 850,000,000.

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[1] The Delaware and Hudson canal has been abandoned since the above sentence was written.

In regard to the foregoing statement of the capacity of ice houses on and near the river, as made by Mr Weir, it may be remarked that Charles C. Brown, in a report on the Hudson river, which appears in the Eleventh Annual Report of the State Board of Health, gives a list of ice houses on the Hudson river, with their capacity in 1889. According to Mr Brown, the total capacity in that year was 2,908,000 tons, while the crop harvested frequently exceeds this quantity by 500,000 tons, which is stacked up outside and disposed of before the warm season begins. Mr Weir's statistics, as stated, include the capacity of ice houses on and near the Hudson river, while Mr Brown's include only those actually on the river, which probably explains the apparent discrepancy in the statistics.

The following statistics include the tonnage received at all points above Spuyten Duyvil creek, and of the local shipment between points on the river. That shipped is credited only to the points from which it was shipped, no entry being made to the total tonnage of the amount received at local points from other local points. The total tonnage also includes all through freights shipped from points up the river that passed the mouth of Spuyten Duyvil creek going south.

Total tonnage of all shipping points on Hudson river during 1889, not including the tonnage coming through State canals (tons)	15,033,309
Value of same	$378,196,094
Total tonnage coming to and leaving tidewater through State canals, 1889 (tons)	3,592,437
Value of same	$108,000,000
Increase of same over tonnage, 1888 (tons)	326,466
Grand total tonnage of Hudson river, including tonnage through State canals (tons)	18,582,596
Value of same	$485,733,094
Number of transportation companies for passengers or freight, not including steamboats or pleasure boats	30
Total number of passengers carried, 1889	5,000,000

State Canals

The Erie canal. Erie canal was the first development of the internal water resources of New York State, and grew out of the demand for transportation facilities between the Atlantic seaboard and the Great Lakes. The impulse which it gave to the development of New York State, and of the entire territory tributary to the Great Lakes, can hardly be estimated. Taking into account its far-reaching consequences, it may be considered the greatest public work thus far carried out in the United States. Nevertheless, Erie canal has not only passed its day of usefulness, but, to some extent, stands in the way of future development, the chief cause for this being a too pronounced regard for the canal's former greatness. The historical matter may serve to indicate how strongly the feeling that Erie canal should be maintained in perpetuity has been impressed upon the people of the State of New York. (This paragraph was written in 1897.)

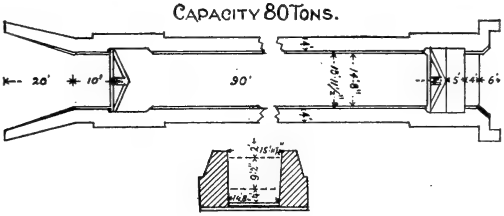

Fig. 45. Original lock used on Erie canal.

By way of illustrating the rise and decline of Erie canal, it may be cited that in 1837 the total freight carried was 1,171,296 tons, valued at $55,809,288; in 1880 the total freight carried was 6,457,656 tons, valued at $247,844,790; in 1895 the total freight carried was 3,500,314 tons, valued at $97,453,021. Statistics show that the great bulk of all the freight now carried on Erie canal is through freight carried for western producers, local business being only a small per cent of the whole. Statistics show that freights are now carried by railways as cheaply as they can be carried by the canal, and this, too, at a profit, while the canal, in order to obtain any freight at all, has been obliged to do away with all tolls, thus making the cost of shipment by canal the bare cost of transportation proper.

In 1895 an improvement of Erie canal was authorized at a cost of $9,000,000. Later, it was found that the cost would be $16,000,000 instead of $9,000,000, as originally expected. On this basis, and throwing out of the account former expenditures, we may say that Erie canal will cost the people of the State of New York annually at least $1,230,000. Assuming a traffic for the canal of 5,000,000 tons per annum, carried an average of 200 miles, we have a total of 1,000,000,000 ton-miles per annum, on which the people of the State of New York must pay in the way of interest and cost of maintenance and operation about 1.25 mills per ton-mile, while canal freights now average about 1.2 mills per ton-mile; hence the people of the State of New York will be obliged to pay under the new conditions over 50 per cent of the total cost of the transportation. At present the local canal freights are only 15 per cent of the total.

Early history of canals in New York. The idea of a water communication between the Hudson river and the west via the valley of the Mohawk had been a favored one with the statesmen of New York for many years previous to the beginning of the present century; the early projects, however, were with reference to improvement of the natural water channels and did not include the construction of artificial channels further than such channels might be necessary as connecting links.

So far as can be learned, the earliest mention of the route between Albany and Lake Ontario was in a report made in 1724 by the Surveyor General to Governor Burnet, the Colonial Governor of the Province of New York. The Surveyor General describes the watercourses and carrying places between Albany and Lake Ontario with about as much accuracy as they can be described today. The carry between the Mohawk river and Wood creek he describes as "a portage only three miles long, except in very dry weather, when the goods must be carried two miles further." He also describes the passage down the Oswego river to Lake Ontario, showing that freight could be carried from Albany to that lake by way of the Mohawk, Oneida and Oswego rivers, cheaper and much more conveniently than they were then transporting it by way of the Hudson, Lake Champlain and the River St Lawrence.

Plate 38.

Erie canal at Syracuse.

Moreover, the supposed near approach of the western waters of New York and of Lake Erie is also referred to in this report of 1724, as follows:

> Besides the passage by the lakes, there is a river which comes from the country of the Senecas and falls into the Oswego river, by which we have an easy carriage into the country without going near Lake Ontario. The head of this river goes near Lake Erie and probably may give a very near passage into that lake and much more advantageous than the way the French are obliged to take by the great falls of Niagara.

In 1768 Sir Henry Moore, the Colonial Governor, in a message to the Assembly, stated that:

> The obstruction of navigation in the Mohawk river, between Schenectady and Fort Stanwix, occasioned by the falls of Canajoharie, had been constantly complained of, and that it was obvious to all who were conversant in matters of this kind that the difficulty could be easily remedied by sluices, by the plan of those in the great canal of Languedoc in France, which was made to open a communication between the Atlantic ocean and the Mediterranean.

In 1788 Elkanah Watson proposed to establish a water communication from the Hudson river and Lake Ontario by way of Oneida lake, Oneida river, and Oswego river, his plan being to connect Wood creek with the Mohawk river by a canal and to improve the Mohawk with locks.

The foregoing quotations show that the possibilities of water transportation had received attention at a very early day. Colden states that Governor Burnet erected a fort and trading houses at the mouth of Oswego river about 1726 "because of its water communication with the country of the Iroquois and for facility of transportation between the lakes and Schenectady, there being but three portages in the whole route and two of them very short." These, no doubt, were the carriages at Little Falls, Wood creek and at Oswego rapids.

A Swedish traveler in this country in the year 1748 speaks of the near approach of the waters of the Hudson and the St Lawrence. Apparently he supposed there was a perfect communication from the former to the latter.

As soon as the Revolutionary war was concluded, Washington saw, in the improvement of the internal communications of this country, that which, after independence, most concerned the prosperity and happiness of the people. Undoubtedly the subject had occupied his mind before the Revolution, although there is no record by which any date can be fixed, but he was without doubt among those who first thought of the advantages and practicability of a navigation between the lakes and the Atlantic. Immediately after the war ended he devoted himself to this subject, and in 1784 personally explored not only what is now the route of the Champlain canal, but the route which later on the Western Inland Lock Navigation Company adopted for their improvement.

The following extract from a letter to the Marquis of Chastellux, in which Washington refers to these travels, is taken from Marshall's Life of Washington:

> I have lately made a tour through the Lakes George and Champlain, as far as Crown Point; then returning to Schenectady, I proceeded up the Mohawk river to Fort Stanwix, and crossed over to Wood creek, which empties into Oneida lake and affords the water communication with Ontario; I then traversed the country to the head of the eastern banks of the Susquehanna, and viewed the Lake Otsego, and the portage between that lake and the Mohawk river at Canajoharie. Prompted by these actual observations, I could not help taking a more contemplative and extensive view of the vast inland navigation of these United States, and could not but be struck with the immense importance of it. . . . I shall not rest content until I have explored the western country and traversed those lines . . . which have given bounds to a new empire.

In 1772 Christopher Colles lectured in Philadelphia on the subject of lock navigation, and in 1784 proposed to the New York Legislature to improve the navigation of the Mohawk river. In 1785, on the reiterated application of Mr Colles, the Legislature granted him $125 to enable him to make an attempt towards the execution of his plan. In the same year he published proposals to establish a company to improve the inland navigation at Oswego and Albany. In this publication he anticipated the advantages which a water communication with the lakes would afford. He states:

> The Allegheny mountains seem to die away as they approach the Mohawk river. The ground between the upper part of this river and Wood creek is perfectly level.

In January, 1791, Governor George Clinton, in an address to the Legislature, urged the necessity of improving the natural water channels in order to facilitate communication with the frontier settlements. Following this address, in February of the same year, a joint committee was appointed to inquire what obstructions in the Hudson and Mohawk rivers it would be proper to remove. As the result of this inquiry, an act was passed March 24, 1791, authorizing the Commissioners of the Land Office to explore and survey the ground from the Mohawk river at Fort Stanwix (now Rome) to Wood creek with reference to constructing an artificial channel, and also to survey the Mohawk and Hudson rivers for improvement by locks and to estimate the cost of the same. A sum not exceeding $500 was appropriated to pay the expense of such survey.

At that time the channel of commerce was by the Mohawk from Albany to Fort Stanwix in boats of about five tons burden. Going west these boats carried from 1½ to 2 tons and on the easterly trip 5 tons. From Fort Stanwix there was a portage of 2 miles across the flats to Wood creek, whence the course lay into Oneida lake and river, and from thence into Seneca and Oswego rivers to Lake Ontario; or, from points farther west, up Seneca river to Lakes Cayuga and Seneca. At that time it cost from $75 to $100 per ton for transportation from Seneca lake to Albany. The time occupied in going from Albany to Seneca lake was twenty-one days, and in returning eight days.

The commissioners appointed under the act of March, 1791, were Elkanah Watson, Gen. Phillip Schuyler, and Goldsborrow Bayner. On the 3d of January, 1792, the commissioners reported the cost of improving the route from Albany to Seneca lake by locks and canals at $200,000, whereupon the Legislature passed an act March 30, 1792, incorporating the Western Inland Lock Navigation Company, for the purpose of opening navigation by locks from the Hudson river to Lakes Ontario and Seneca, and the Northern Inland Lock Navigation Company, charged with performing a like service from the Hudson river to Lake Champlain. The capital stock of each company consisted of 1000 shares of $25 each, but the companies were afterwards allowed a capital stock of $300,000 and an increase of the same from time to time.

Gen. Phillip Schuyler was the first president of the Western Inland Lock Navigation Company.[1]

In March, 1795, an act was passed directing the State Treasurer to subscribe 200 shares to these companies, of $50 each. State aid was again granted by an act passed in April, 1796, by which the Western Inland Lock Navigation Company was loaned $37,500, and a mortgage taken by the State on the company's property at Little Falls. In that year a route was opened from Schenectady to Seneca Falls for boats carrying 16 tons. The locks at Little Falls were first built of wood, then of brick, and finally of stone. The tariff levied for a barrel of flour carried 100 miles was 52 cents, and for a ton of goods, $5.75.

In the report of the directors of the Western Inland Lock Navigation Company to the Legislature of 1796 many interesting particulars are given in regard to this navigation. The following from that report about the canal around Little Falls is of interest:

> The canal is drawn through the northern shore of the Mohawk river, about fifty-six miles beyond Schenectady. Its track is nearly parallel to the direction of the waters of the fall, and at a mean about forty yards therefrom. Its supply of water is from the river, and the canal commences above the falls, in a neat, well-covered basin of considerable depth of water, and reenters the river in a spacious bay at the foot of the falls; its length is 4752 feet, in which distance the aggregate fall is 44 feet 7 inches. Five locks, having each nearly 9 feet lift, are placed towards the lower end of the canal, and the pits, in which they are placed, have been excavated out of solid rock, of the hardest kind; the chamber of each lock is an area of 74 feet by 12 feet in the cleave, and boats drawing three feet and a half of water may enter at all times; the depth of water in all the extent of the canal beyond the locks is various, but not less than 3 feet in any place; near the upper end of the canal a guard lock is placed without lift, to prevent a redundancy of water; when the water in the river rises beyond the lowest state, sluices are constructed, to discharge the surplus water entering the canal, from the two small rivulets which intersect its course; about 2550 feet of the canal is cut through solid rock, and where the level struck above the natural surface of the earth, or rather rock, strong and well constructed walls are erected, supported by heavy embankments of earth, to

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[1] In the original paper " Water Resources of the State of New York " it is erroneously stated that George Washington was the first president of the Western Inland Lock Navigation Company.

confine the water and to keep the level, hence there is no other current in the canal than an almost imperceptible one, when the summit lock is drawn; three handsome and substantial bridges are thrown over the canal, as so many roads which have been intersected by the canal.

The report to the Legislature of 1796 is accompanied by the report of William Weston, the engineer, in which estimates are given of the expense of improving the navigation from tidewater in the Hudson river to Cayuga lake, by means of canals and locks, and removing the obstructions in the rivers so as to render them competent for the transportation of produce in boats of upwards of 20 tons burden.

In the report of the directors of the Western Inland Lock Navigation Company, made by the president, under date of February 16, 1798, it is stated that early in the spring of 1796 the directors commenced operations at Fort Stanwix (Rome) with reference to a junction of the waters of the Mohawk river and Wood creek. The length of the canal at this point was a little over three miles.

With respect to the improvement to the westward of Fort Stanwix, the directors state that from the outlet of Oneida lake to the south end of Cayuga lake, nature has done so much that little is left for art to accomplish. The few obstructions necessary to be removed can all be affected in the course of one summer and at a very moderate expense.

This company did not realize anything like their expectations. After completing the canal around Little Falls and at Fort Stanwix, they were confronted by the difficulty that on account of the excessive tolls charged, these short stretches of canal were not as much used as they had expected. While the commerce from Oneida lake and westward was considerable, the boatmen still continued to carry their cargoes around these obstructions instead of passing through the canals. Undoubtedly the scarcity of ready money had a good deal to do with this, although the tolls for passing through the canals seem rather high. As we have seen, the entire bed of the Mohawk river had been conveyed to this company by the act of 1792, but there was no practical way of preventing navigation on the river.

The company, however, continued in existence until the State entered upon its era of inland water improvement under the auspicies of the State itself in 1817,[1] in which year a commission was appointed to purchase the rights of the Western Inland Lock Navigation Company for the State. This commission reported June 24, 1820, awarding to the company the sum of $151,000, which was to be appropriated among the stockholders of said company, as follows:

> To the individual stockholders, proprietors of stock amounting to $140,000, the sum of $91,616; and for the use of the people of this State, proprietors of stock amounting to $92,000, the sum of $60,204.80.

This report of the commissioners was confirmed by the Supreme Court August 11, 1820. The Western Inland Lock Navigation Company then became the property of the State, and in 1821 the State collected the sum of $450.56 for tolls charged from Rome to the lower lock at Little Falls on account of transportation over the route formerly controlled by the Western Inland Lock Navigation Company.

Chapter 144 of the laws of 1813 incorporated the Seneca Lock Navigation Company for the purpose of constructing a canal from Cayuga lake to Seneca lake. The rights of this company were purchased by the State, pursuant to chapter 271 of the laws of 1825. The two companies, the Western Inland Lock Navigation Company and the Seneca Lock Navigation Company, may be considered the forerunners of the Erie canal.

About $100,000 was expended by the Northern Inland Lock Navigation Company on locks around the falls at Cohoes and for their improvement, all of which proved a total loss, the rights of the company being finally transferred to the State before navigation from the Hudson river to Lake Champlain was actually opened.

The amount expended by the Western Inland Lock Navigation Company up to December, 1804, was $367,743, which was increased to $480,000 in 1813, and to a total of $560,000 before the works were finally transferred to the State. The mistake of first

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[1] The full authority for the construction of the Erie and Champlain canals may be found in two acts, the first being chapter 237 of the laws of 1816, passed April 17, 1816; the second being chapter 262 of the laws of 1817, passed April 15, 1817. There is more or less confusion of these two dates in early canal literature.

constructing wooden locks proved a severe loss to the company, as all the original locks at Little Falls, German Flats, and Rome rotted away in about six years. The facilities afforded by these companies were undoubtedly inadequate to the demands of the rapidly growing western section, and accordingly an active agitation finally began for some more extended means of communication.

The early work was, as we have seen, entirely in the direction of the improvement of natural channels, the extent of artificial channels for the whole route from the Hudson river to Seneca lake being only 15 miles. About 1803, however, the project for an artificial canal connecting Lake Erie with tidewater in the Hudson was broached by Gouverneur Morris, whose name should not be overlooked in an account of early canal history. In 1803 Morris and Simeon DeWitt passed an evening in Schenectady and in the course of the conversation, as detailed by DeWitt, Morris mentioned the project of "tapping Lake Erie" and leading its waters in an artificial river directly across the country to the Hudson river.

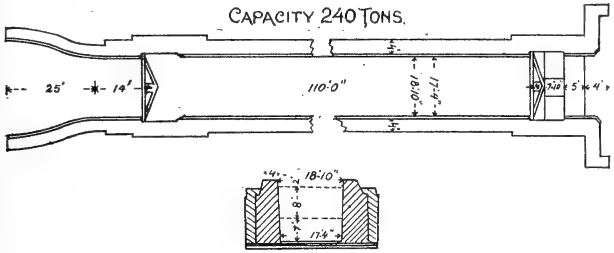

Fig. 46 Enlarged lock used on Erie canal.

DeWitt considered that the intermediate hills and valleys would be insurmountable objects, but Morris's answer was that the object would justify labor and expense.

DeWitt had then long been Surveyor-General of the State and was well acquainted with its topography to the west bounds of the military tract, but had no special knowledge of the country west of the military lands, and he naturally supposed that the rivers ran in deep valleys to Lake Ontario and between them were ranges of hills. In a paper on The Origin and History of the Measures that Led to the Construction of the Erie Canal, George Geddes states that DeWitt was a man of caution, dealing in facts, and had little or nothing of the extraordinary in his nature. Gouverneur Morris was a man of entirely different stamp. He had traveled in Europe and knew the utility of canals, and had long maintained the opinion that ships would ultimately sail from London up the Hudson and across country to Lake Erie. Mr Morris had expressed as early as 1777 his views in regard to internal improvements. At that time he said: "At no distant day, the waters of the great western inland seas will, by the aid of man, break through their barriers and mingle with those of the Hudson."

In 1800 Mr Morris stated: "One-tenth of the expense borne by Britain in the last campaign would enable ships to sail from London, through the Hudson river, to Lake Erie."

In 1807 Jesse Hawley wrote a series of articles on the subject, claiming that the idea of an artificial channel first originated with him, and in 1820 Elkanah Watson published a book for the same purpose. In 1808 the Legislature directed the Surveyor-General, Simeon DeWitt, to make a survey of an artificial channel from the Great Lakes to the Hudson. This survey was made by James Geddes, who reported on January 20, 1809. In 1810 the Legislature appointed commissioners to prosecute further examinations. This commission made its first report in March, 1811. After discussing the route as proposed, from the Hudson river to Lake Ontario, it recommended the inland route to Lake Erie with a direct descent from Lake Erie to the Hudson river. Following this report a bill was passed by the Legislature reappointing the commissioners of the previous year, with the addition of Robert R. Livingston and Robert Fulton, and extending the powers of the commissioners and adding to the appropriation for its work. The war of 1812 came on and the canal project was temporarily dropped until 1816, when De Witt Clinton presented a memorial to the legislature from the City of New York urging action toward the construction of the canal. Finally the act of April 15, 1817, was passed creating a permanent Board of Canal Commissioners,[1] which entered at once upon its duties, and pro-

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[1] The permanent Board of Canal Commissioners of 1817 included the following men: De Witt Clinton, president; Stephen Van Rensselaer, Samuel Young, Joseph Ellicott, and Myron Holley, their appointment having been first authorized by the act of April 17, 1816.

viding for the construction of artificial navigation from Lake Erie to tidewater on the Hudson river, and also from Lake Champlain to tidewater on the Hudson. The dimensions of the proposed canals were fixed by the commissioners as follows: For Erie canal a bottom width of 28 feet, surface width 40 feet, and depth 4 feet, with locks 90 feet long and 15 feet wide; for Champlain canal a bottom width of 20 feet, surface width 30 feet, and depth 3 feet, with locks 75 feet long and 10 feet wide.

Ground was broken for the Erie canal at Rome, July 4, 1817, and the section from Utica to Seneca river completed October 22, 1819, a boat passing from Rome to Utica on that day. Champlain canal was opened in part for navigation November 24, 1819. The route for Erie canal from Seneca river west was also explored in 1819, and the final location, from Seneca river to Rochester, made in 1821. The principal engineers were James Geddes, Benjamin Wright, and Canvass White.

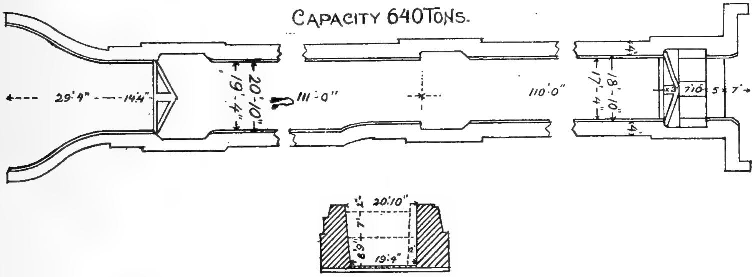

Fig. 47 Proposed lengthened lock for enlarged canal.

The annual report of the Canal Commissioners, dated January 31, 1818, gives details of the system adopted for the construction of the canal. They state that they had decided to complete the middle section first, 58 miles of which were put under contract during the year 1817, this portion being wholly on the summit level. The whole labor performed in 1817 was equal to the completion of 15 miles. In indication of the easy character of the work, the commissioners state that three Irishmen finished 3 rods of canal in 4 feet cutting in five and one-half days, and that on the 58 miles under contract only half a mile required puddling.

The engineer's original estimate of the cost of the middle section, completed in 1819, was $1,021,851. The actual cost was

$1,125,983. This increase, as stated by the commissioners, was due to change of prism and structures.

While the State canals were in progress the Seneca Lock Navigation Company, authorized by chapter 144 of the laws of 1813, had been engaged in constructing a canal between Seneca and Cayuga lakes, including a series of locks at Seneca Falls. On June 14, 1818, a loaded boat from Schenectady, 16 tons burden, passed the newly constructed locks at Seneca Falls. Along the Mohawk river the passage of boats of this size was effected through the locks of the Western Inland Lock Navigation Company, Erie canal not being open for navigation at that date. The locks at Seneca Falls cost $60,000. The toll charged during 1818 was equivalent to 9 cents per ton per mile.

Champlain canal was opened for navigation November 24, 1819, from the Hudson at Fort Edward to Lake Champlain. The estimated cost of this section was $250,000, but on account of changing its dimensions to the same size as the Erie canal the revised estimate amounted to $333,000. The canal was finally completed from Lake Champlain to Albany on September 10, 1823.

Work on the Erie canal proceeded during the years from 1820 to 1825, in the former year 94 miles being in operation and in the latter 363. It was finally completed from Albany to Black Rock on October 26, 1825, on which day the first boat ascended the Lockport locks and passed through the mountain ridge into Lake Erie. Uninterrupted navigation was thus obtained from that lake to the Atlantic ocean for boats of an average of about 40 tons burden. The event was made a gala day the whole length of the canal.

The construction of the Erie canal was due to the unbounded perseverance and genius of one man—Governor De Witt Clinton—who, when one studies the early history of the Erie canal, stands forth as the colossal figure of the enterprise. Nevertheless Clinton does not appear to have been actively interested until about 1810, but his interest once aroused he was easily the leading figure of the enterprise until its completion in 1825.

The total expenditure on the Erie and Champlain canals to January 1, 1826, was $9,474,373.14, from which should be deducted for pay of engineers and commissioners, the acquisition of water rights, land damages, the construction of feeders, repairs, Black

Rock harbor, lowering Onondaga outlet, Salina and Onondaga side cut, Waterford and Troy side cuts, Troy dam, and Glens Falls feeder, the sum of $1,621,274. Hence the actual cost of construction of the canal proper was $7,853,099, which, on the aggregate length of 433 miles, equals $18,136 per mile, or taking into account the various extensions enumerated and the engineering as necessary items of expenditure, the original cost per mile of the Erie and Champlain canals may be placed at $21,881 per mile.

Between 1825 and 1833 work was begun on a number of lateral canals—as, for instance, the Oswego canal, begun in 1826 and completed in 1828; the Cayuga and Seneca canal, begun in 1827 and completed in 1829; the Chemung canal, begun in 1831 and completed in 1832, and the Crooked Lake canal, begun in 1831 and completed in 1833. The total cost of all the canals, including interest on loans up to March 23, 1833, was $11,460,066.77.

Chenango canal was begun in 1833. The total amount expended on all the canals, including original construction, extensions, maintenance, repairs, and interest on loans, to the end of 1834 was $13,798,438, and the total amount of tolls received from 1820 to 1834, inclusive, was $10,000,730.97—that is to say, at the end of ten years from the original completion of the Erie canal the amount returned to the State was nearly 78 per cent of the total cost to that date. This fact is of the greatest interest because it indicates that from the very beginning the New York State canal system was operated as a purely business enterprise. It is clear, then, that in reality the State of New York, in constructing its internal navigation system, went into the transportation business; by that statement it is meant that the State managed the affairs of the canals precisely as a private company would have managed them—that is, the State built its canal system and levied as heavy tolls as the articles transported would stand.

By way of illustrating how thoroughly the State was in the transportation business and on exactly the same basis as transportation companies, it may be cited that in 1830 the Legislature sent a communication to the Commissioners of the Canal Fund asking if it were not possible to increase the rate of toll on many of the articles transported, and stating that it seemed necessary, in order to meet all the interests involved, that the canals yield somewhat greater revenue. The commissioners replied to this communication at length, giving in detail the amount of toll levied on different articles transported, and finally concluded with the statement that it would be impossible to increase the toll materially, because the articles transported were at that time taxed all they would stand. If the rate of toll were made materially greater, many articles would not be transported on the canals, but would go by other channels, as by the St Lawrence river and by the Great Lakes. The State would thus lose the benefit derived from carrying them.

About 1833 to 1835 railroads began to attract attention as means of transportation, and in 1835 John B. Jervis, Holmes Hutchinson, and Frederick C. Mills, the principal canal engineers of that day, were instructed to report on the relative cost of transportation on canals and railroads. In an introduction to their report by William C. Bouck and Michael Hoffman, Canal Commissioners, it is stated that it will not be difficult to show that the expense of transportation on railroads is materially greater than on canals. But in addition to this there were other important considerations in favor of canals:

1) A canal may be compared to a common highway on which every man can be the carrier of his own property, therefore creating the most active competition, and thus reducing the expense of transportation to the lowest rates. The farmer, merchant, and manufacturer can avail themselves of the advantages of carrying their own product to market in a manner best comporting with the interest of each individual.

2) Much of the property carried on the canals is carried by transportation companies, although the largest portion is carried by individuals and small associations. The individual who becomes the carrier of his own product has the advantage of paying nearly one-half of all the expense of transportation in the regular course of his business, and the cash disbursements do not often much exceed the payment of the tolls. To the farmer the profits on return freight, in many instances, give a full indemnity for the expense of taking his cargo to market. On railroads, on the other hand, the proprietors must necessarily be the carriers.

A fixed popular belief in the two principles laid down by Messrs. Bouck and Hoffman in their introduction to the transportation report of 1835 has been the cause of a great deal of mistaken policy in the State of New York. Nearly every year since the beginning of the railway era the newspapers of the State have teemed with the statement that the State must necessarily maintain the canal system in order to check the exorbitant tariff demands of competing railways. As we have seen, in 1830, just before the beginning of the railway era, the State was taxing every article transported upon the canals all that it would stand, and the system of excessive State tariffs was continued until a few years later, when the competition of the railways forced a reduction in the tariff for transportation on the canal.

Growth and decline of canal transportation. A number of reports bearing on transportation questions were submitted in 1835, and finally the fixed policy was adopted of enlarging the Erie canal, the act authorizing what is known as the Erie canal enlargement being passed in that year. The law authorizing the enlargement directed the construction of double locks and a prism with a width at water surface of 70 feet, and a depth of 7 feet, the locks to be 110 feet long and 18 feet wide. It was estimated that an enlargement to this extent would save 50 per cent in cost of transportation, exclusive of tolls. The enlargement to this standard width and depth was begun in 1836 and continued to 1842, when the Legislature directed the suspension of expenditures. In 1847 the work of enlargement was resumed, and substantially completed in 1862. Since that time to the work done under authority of chapter 79 of the laws of 1895 there had been no change in the standard of width at water line of 70 feet and depth of 7 feet. As an interesting fact it may be pointed out that while the enlargement authorized in 1835 led to a vast increase in the transportation business on the State canals, the cost of transportation gradually decreased, one chief cause of such decrease being the competition of railways, until in 1883 the competition from this source became too sharp to maintain longer transportation on the canals if any toll at all were charged. The canals were then made free by legislative enactment.

The popular notion, formerly prevalent in New York, that it has been necessary to maintain the State canals in order to regulate the railways, is seen to be far from true. The railways have regulated the canals quite as much or more than the canals have regulated the railways. Indeed, the railways must be considered as having the better of it, because the State has been obliged absolutely to do away with all tolls on the canals in order to insure their obtaining business at all.

In illustration of the value of the water resources afforded by the Great Lakes in conjunction with the New York State internal navigation system, the following statement of receipts of flour, wheat, corn, oats, barley, and rye at Buffalo for certain years, from 1836 to 1903, inclusive, is given.

TABLE NO. 92—NUMBER OF BUSHELS OF GRAIN CARRIED BY ERIE CANAL FROM 1836 TO 1903

YEAR	Flour	Wheat	Corn	Oats	Barley	Rye
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Barrels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1836....	139,178	304,990	204,355	28,640	4,876	1,500
1840....	597,142	1,004,561	71,337	....	....	....
1845....	746,750	1,770,740	54,200	23,300	....	....
1850....	1,103,039	3,681,347	2,593,378	357,580	3,627	....
1855....	937,761	8,022,126	9,711,430	2,693,222	62,304	299,591
1860....	1,122,335	18,502,615	386,217	1,209,594	262,158	80,822
1865....	1,788,393	13,437,888	19,840,901	8,494,799	820,563	877,676
1870....	1,470,391	20,556,722	9,410,128	6,846,983	1,821,154	626,154
1875....	1,810,402	32,987,656	22,593,891	8,494,124	916,889	222,126
1880....	1,317,911	40,510,229	62,214,417	649,351	335,925	743,451
1885....	2,993,280	27,130,400	21,028,230	767,580	577,230	309,370
1890....	6,245,580	14,868,630	44,136,660	13,860,780	5,165,700	1,281,030
1895....	8,971,740	46,848,510	38,244,960	21,943,680	10,253,440	787,340
1896....	10,384,184	54,411,207	47,811,010	40,107,499	16,697,744	4,404,354
1897....	12,440,617	56,565,610	56,932,625	64,140,618	14,548,100	7,213,650
1898....	10,371,653	83,872,837	67,950,073	45,501,233	11,391,332	6,821,694
1899....	9,088,873	48,008,014	53,843,327	26,469,401	15,110,672	2,260,865
1900....	11,463,079	47,826,458	63,192,660	28,422,256	9,868,196	1,314,743
1901....	11,053,439	61,294,248	30,539,848	21,438,545	7,687,239	1,256,284
1902....	12,026,616	62,452,696	22,487,454	15,891,387	8,969,865	3,716,628
1903....	11,243,027	40,455,328	43,364,579	30,976,088	10,681,655	3,216,983

A comparison of the statistics of railroad and canal traffic shows at once the vast preponderance of freight carried by the several railways centering at New York in comparison with that carried by Erie canal. In spite of the fact that the canal was made free in 1883, figures indicate that since that time there has been a continual decrease in the amount of freight carried on the canals. Probably no feature of this change is more significant than that of the internal movement in New York State. In 1889 the total movement within the State was 1,438,759 tons, while in 1896 it was only 565,482 tons. These statistics show at once the decreasing estimation in which the Erie canal as a means of transportation is held by the great body of shippers in the State of New York.

The following tabulation from the Report of the Buffalo Chamber of Commerce shows the receipts of grain, in bushels, at New York by canal, rail, river and coast routes during the season of navigation of 1903, compared with ten previous years:

RECEIPTS BY ROUTES, MAY 1 TO DECEMBER 1, 1903

	By canal, bushels	By rail, bushels	River and coast, bushels	Total bushels
(1)	(2)	(3)	(4)	(5)
Wheat	2,602,400	10,597,300	....	13,199,700
Corn	5,910,400	11,845,050	2,300	17,757,750
Oats	3,490,900	13,857,000	....	17,347,900
Barley	349,600	1,132,875	....	1,482,475
Rye	368,800	618,150	....	986,950
Malt	147,500	1,840,500	....	1,988,000
Peas	....	202,228	43,976	246,204
1903, total grain	12,869,600	40,093,103	46,276	53,008,979
Per cent	24.28	75.63	0.09	100
1902, total	11,509,050	43,093,569	13,804	54,616,423
Per cent	21.07	78.90	0.03	100
1901, total	14,350,600	52,577,750	602,300	67,530,650
Per cent	21.25	77.85	0.89	100
1900, total	11,351,100	72,033,225	2,454,115	85,838,440
Per cent	13.22	83.92	2.86	100
1899, total	16,299,400	89,688,623	7,630	105,995,655
Per cent	15.38	84.61	0.01	100
1898, total	18,686,000	88,809,259	18,243	107,514,393
Per cent	17.38	82.60	0.04	100
1897, total	20,934,400	97,078,000	41,456	118,053,856
Per cent	17.73	82.23	0.04	100
1896, total	31,404,650	62,314,800	224,172	93,943,622
Per cent	33.43	66.33	0.24	100
1895, total	14,612,700	54,289,835	63,831	68,966,366
Per cent	21.13	81.33	0.92	100
1894, total	42,608,700	19,772,420	166,320	62,547,440
Per cent	68.12	31.61	0.27	100

By way of illustrating the growth and decline of the business of the New York State canals from about 1835-36 to the present time, the following statement of the total tonnage of all freight on the canals, ascending and descending, and the value of the same for certain years from 1837 to 1902, inclusive, is presented:

TABLE NO. 93—TOTAL TONNAGE AND VALUE OF CANAL FREIGHT, 1837 TO 1902

	Tons	Value
1837	1,171,296	$55,809,288
1840	1,416,046	66,303,892
1845	1,977,565	100,629,859
1850	3,076,617	156,397,929
1855	4,022,617	204,390,147
1860	4,650,214	170,849,198
1865	4,729,654	256,237,104
1870	6,173,769	231,836,176
1875	4,859,958	145,008,575
1880	6,457,656	247,844,790
1885	4,731,784	119,536,189
1890	5,246,102	145,761,086
1895	3,500,314	97,453,021
1896	3,714,894	100,039,578
1897	3,617,804	96,063,338
1898	3,360,063	88,122,354
1899	3,686,051	92,786,712
1900	3,345,941	84,123,772
1901	3,420,613	83,478,880
1902	3,274,610	81,708,453

Without analyzing the figures in detail, it is sufficient to point out that if it is true, as popularly supposed, that the Erie canal ought to be maintained as a medium of competition with the railways, the figures derived from the annual statements of the chief competitor of the Erie canal must be taken as conclusive that the competition has, on the whole, been a failure. The railway, developed as a private enterprise, has not only been able to carry freight as cheaply as the canal, but has been able to charge for the same and do the work at a profit. In the year ending June 30, 1897, the New York Central & Hudson River Railway Company paid a dividend on its stock of $4,000,000, besides carrying $51,866.80 to the surplus account, whereas the canal, although all tolls were removed in 1883, has still been unable to compete. Among the chief reasons for this result, lack of organization of canal transportation must be placed first. The perpetuation of the idea that one advantage of the canals was that they were common highways on which each man could carry his own products to market has tended largely to produce this unsatisfactory result. Thus far there has never been any systematic organization for obtaining business for the canal. The boats are owned by small proprietors, each operating from one to three or four boats. When cargoes in hand are discharged at either terminus, each owner solicits another cargo. The results are delays, half cargoes, and consequent loss. During the last few years it has been only by the most rigid economy that the Erie canal boatmen could live. On the other hand, the business of soliciting freight for the railways is compactly organized and every possible advantage taken of the situation.

However unsatisfactory it may seem to the individual boatman, the future of effective transportation on the Erie canal depends on the organization of large transportation companies which conduct the business of carrying freight by canal on the same business basis as adopted by railways. As to the equity of the State furnishing and maintaining a waterway on which transportation may be conducted by such corporations at a profit the writer expresses no opinion further than to point out that the official discussion of such a proposition by the State Engineer and Surveyor in his annual report for the year ending September 30, 1896, may be taken to indicate that the day of the Erie canal as a State waterway has passed.

Cost and revenues of the New York State canal system. Table no. 94 exhibits the total cost of construction, maintenance and operation, and the total revenues from all sources of the several canals of New York from their original inception to September 30, 1892;

TABLE NO. 94—FIRST COST AND REVENUES FROM THE NEW YORK STATE CANALS

CANALS (1)	Cost of construction (2)	Cost of maintenance and operation (3)	Total cost (4)	Revenue from all sources (5)	Loss (6)	Gain (7)
Erie and Champlain	$57,688,676	$41,582,759	$99,271,435	$128,191,068		$28,919,633
Oswego	4,643,921	3,736,676	8,380,597	3,715,567	$4,665,030	
Cayuga and Seneca	1,886,662	1,157,754	3,044,416	1,055,016	1,989,400	
Black river	4,077,882	2,082,251	6,160,133	305,663	5,854.470	
Oneida river improvement	233,962	41,236	275,198	214,428	60,770	
Oneida lake	513,439	144,060	657,499	65,180	592,319	
Baldwinsville (so called)	31,000	18,039	49,039	1,261	47,778	
Seneca river towing path	1,602	20	1,622	7,782		6,160
Cayuga inlet	2,020	948	2,968	7,534		4,566
Crooked lake (abandoned)	395,092	424,658	819,750	45,490	774,260	
Chenango (abandoned)	4,807,952	2,105,217	6,913,169	744,027	6,169,142	
Chemung (abandoned)	1,512,041	2,022,259	3,534,300	525,565	3,008,735	
Genesee val. (abandoned)	6,741,839	2,814,809	9,556,648	860,165	8,696,483	
Total	$82,536,088	$56,130,686	$138,666,774	$135,738,746	$31,858,387	$28,930,359

The total cost of Crooked lake, Chenango, Chemung and Genesee Valley canals, which were abandoned under the provisions of the law of 1877, was $20,823,867, and the total revenue from all sources $2,175,247. The total loss on the abandoned canals was therefore $18,648,620. The following is the complete financial exhibit of all canals from their inception to September 30, 1892: Total loss on abandoned canals, $18,648,620; net gain on canals now in operation, $15,720,592; loss on the whole system, $2,928,028.

Improvement of Erie canal. The canal improvement of 1895 was formulated by State Engineer and Surveyor Horatio Seymour jr., in 1878. In his annual report for that year Mr Seymour discusses extensively transportation questions as related to the Erie canal, pointing out that transportation can be cheapened in two ways—by increasing the tonnage of boats or by increasing their speed. As to increasing the tonnage of boats, he states that two methods may be used—the locks may be lengthened or the depth of water may be increased. The width of the canal, Mr Seymour states, is substantially what it should be, but it lacks the necessary depth in order to conform to the law of relation of cross section of water to immerged section of boat, as determined by Mr Sweet. Reports were submitted showing that an additional depth of one foot could be obtained for about $1,100,000.

The matter of making the improvement, however, remained in abeyance until the passage of an act in 1895, which provided for submitting to the people at the State election in November of that year the question as to whether an improvement by deepening two feet should be undertaken at an expense of $9,000,000. Section 3 of chapter 79 of the laws of 1895 reads as follows:

Within three months after issuing of the said bonds the Superintendent of Public Works is hereby directed to proceed to enlarge and improve the Erie canal, the Champlain canal, and the Oswego canal; the said improvement to the Erie and Oswego canals shall consist of deepening the same to a depth of not less than 9 feet of water, except over and across aqueducts, miter sills, culverts, and other permanent structures, where the depth of water shall be at least 8 feet, but the deepening may be performed by raising the banks wherever the same may be practicable; also the lengthening or improving of the locks which now remain to be lengthened, and providing the necessary machinery for drawing boats into the improved locks, and for building vertical stone walls, where, in the opinion of the State Engineer and Surveyor and Superintendent of Public Works, it may be necessary. The improvement upon the Champlain canal shall consist in deepening the said canal to 7 feet of water, and the building of such vertical stone walls as, in the opinion of the State Engineer and Surveyor and Superintendent of Public Works, may be necessary.

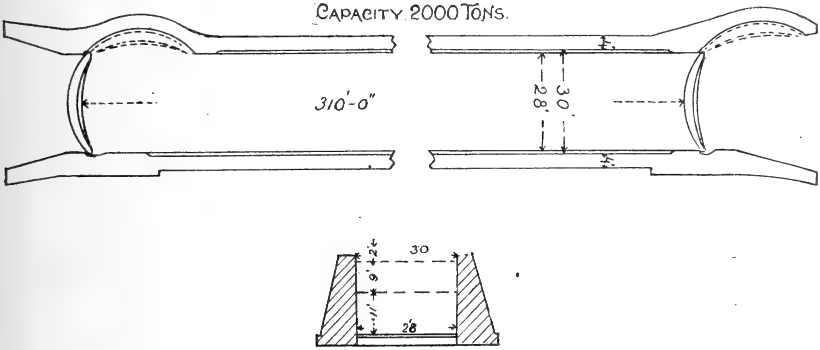

Fig. 48 Lock recommended by Canal Committee for Barge canal.

The necessary preliminary work was so far completed that bids for constructing the improvement were called for in October, 1896, and shortly thereafter contracts for work amounting to about $4,000,000 were awarded. The canal was closed December

1, 1896, and soon after work was begun and continued until May 5, 1897, when navigation was opened for the season of 1897, and all contractors not working with dredges discontinued operations until the winter of 1897–98. The act authorizing the 1895 improvement provided that the deepening of the canal prism might be accomplished either by excavation or by raising the side walls. Sometimes one method and sometimes the other has been followed, depending upon the conditions of each level. Usually a part of the increased depth has been obtained by raising the side walls, with the balance secured by excavation.

As is indicated in the extract from the act authorizing the improvement, the work included the lengthening of such locks as had not been previously lengthened. The original locks of the enlargement of 1836 to 1862 were 110 feet long by 18 feet wide. In 1885 work was begun lengthening these locks to 220 feet, or about 210 feet in the clear, thus permitting two boats to pass through at one lockage. Up to 1895, 42 of the 72 original locks had been lengthened. The 30 locks remaining to be dealt with were mostly bunched in groups or flights, as, for instance, at Cohoes, where 16 locks effect a change of level of 140 feet, and at Lockport, where 5 locks effect a change of 58 feet. In order to lengthen locks built in flights it would be necessary to entirely reconstruct them, and as the restricted space, specially at Lockport, would render this a very difficult thing to do in one winter season, it was therefore proposed to construct at Cohoes and Lockport, and possibly at Newark, vertical lift locks to take the place of the ordinary locks in use at these places. The State Engineer and Surveyor completed the plans for the proposed lift lock at Lockport, which was so located as not to interfere with the use of the locks now in place there during its construction.

It was announced late in 1897 that the $9,000,000 appropriated would fall about $7,000,000 short of completing the work of deepening and lengthening on the lines thus far carried out.[1]

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[1] For engineering and other details of the canal improvement of 1895 see Eng. News, Vol. XXXVIII (Sept. 2, 16, and 23, 1897). See also Effect of Depth upon Artificial Waterways, by Thomas C. Clark: Trans. Am. Soc. Civil Eng., Vol. XXXV, pp. 1-40. Also Eng. News, January 6, 1898, for discussion of the question, What Shall New York Do with Its Canals?

This announcement was followed by great excitement throughout New York State. Investigation showed that aside from the estimates made by commercial bodies, no estimate had ever been made as to the cost of the improvement, and that the commercial bodies making these estimates had not taken into account very many important items. Charges of criminal fraud were made against the State Engineer, Campbell W. Adams, as well as against George W. Aldridge, Superintendent of Public Works. The popular clamor was so great that the Legislature authorized the appointment of a commission to investigate and report in relation to the work done in enlarging and improving Erie, Champlain and Oswego canals, pursuant to chapter 79 of the laws of 1895 and the referendum.

The Canal Investigating Commission of 1898. The commissioners appointed under this act were George Clinton, Franklin Edson, Smith M. Weed, Darwin R. James, Frank Brainard, A. F. Higgins and William McEchron, who reported to the Governor under date of July 30, 1898. Edward P. North was consulting engineer to this commission and Lyman E. Cooley advisory engineer.

The commissioners considered there had been abuses, but that there was nothing criminal on the part of anybody. Governor Black referred the evidence taken before this commission and its conclusions to E. Countryman for an opinion as to whether there was an opportunity for criminal prosecution against either the State Engineer or the Superintendent of Public Works, or the employees of their departments. Mr Countryman reported to the Governor and Attorney-General under date of November 28, 1898, to the effect that several criminal prosecutions could be brought.

September 12, 1898, Campbell W. Adams, in his annual report, submitted a protest addressed to Governor Black in which he showed that at any rate there were two sides to the question of negligence, and under date of August 13, 1898, George W. Aldridge submitted a similar statement, likewise addressed to the Governor. In this statement there are some valuable figures as to the actual cost of improvements of a nature similar to that authorized by chapter 79 of the laws of 1895. They are as follows:

Erie canal, original estimate	$4,926,738 00
Actual cost	7,143,789 00
Erie canal, enlargement estimate	23,402,863 00
Actual cost	32,008,851 00
Oswego canal, estimates	227,000 00
Actual cost	565,437 00
Oswego canal, enlargement estimate	1,926,339 00
Actual cost	2,511,992 00
Champlain canal, engineers' estimates	871,000 00
Actual cost	1,746,062 00
Black river, engineers' estimates	1,068,437 00
Actual cost	3,157,296 00
Hoosic tunnel, engineers' estimates	1,948,557 00
Actual cost	20,241,842 31
Manchester ship canal, engineers' estimates	26,000,000 00
Actual cost	67,351,105 00
Chicago drainage canal, engineers' estimates	12,000,000 00
Already expended (1898)	27,303,216 00
Estimate to complete	10,358,436 94
Hudson river improvement, original estimate, United States army engineers	2,000,000 00
Estimate to complete after $2,000,000 had been expended	2,600,000 00
State capitol, Albany, estimate	4,000,000 00
State capital, Albany, cost	24,000,000 00

Theodore Roosevelt succeeded Frank S. Black as Governor January 1, 1899, and on January 25th of that year he appointed Austin G. Fox and Wallace McFarlane as special counsel to assist the Attorney-General in the prosecution and trial of any criminal proceedings which should be instituted against Campbell W. Adams or George W. Aldridge, or against any other person concerned, as a result of the Canal Investigating Commission, appointed under chapter 15 of the laws of 1898. The documents furnished to Messrs Fox and McFarlane were copies of the testimony taken before the commission in 1898, together with their report and with the report of E. Countryman to Governor Black, as well as the statements of Messrs Adams and Aldridge. Also the report of the consulting and advisory engineers and the large number of documents relating to the matters which had been made the subject of the inquiry.

The instructions were to examine this testimony, reports and documents and to make such further examinations as might be deemed advisable in order to determine whether or not the evidence warranted the institution of criminal proceedings, and in case it was decided to institute such proceedings, to take charge of the preparation and prosecution of them under the general direction of the Attorney-General.

In their report Messrs Fox and McFarlane say they have decided not to institute criminal proceedings, the evidence on the whole not justifying such action, an opinion directly opposed to that of Mr Countryman submitted a few months before.

On receipt of this report the whole matter was dropped and most of the people of the State hardly remember in 1904 that such an investigation was held.[1]

The New York Commerce Commission. It has been shown in the preceding pages that the commerce of New York has been relatively declining for a number of years. This decline is largely from natural causes which it would be very difficult to prevent, although the view is quite general throughout New York that the State's failure to keep the canals in a state of efficiency has

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[1] The following reports are referred to in the preceding: (1) Report of the Canal Investigating Commission, appointed by the Governor pursuant to chapter 15 of the laws of 1898 and amended by chapter 327 of the laws of 1898, transmitted to the legislature February 28, 1899; (2) Report of the special counsel, E. Countryman, designated to examine the report and testimony transmitted to the Governor by the Canal Investigating Commission; (3) Protest and Defense of Campbell W. Adams, State Engineer and Surveyor, to Frank S. Black, Governor, in Ap. No. 1, in An. Rept of State Engr. for the year 1898, p. 277-364, inclusive; (4) Statement made in reply to criticisms passed by the Canal Investigating Commission upon the Department of Public Works in connection with the improvement of the canals under the $9,000,000 improvement fund, by the Superintendent of Public Works, George W. Aldridge; (5) Report of counsel, Austin G. Fox and Wallace McFarlane, appointed by the Governor to prosecute certain State officials for alleged criminal practices in carrying out the canal improvement under chapter 79 of the laws of 1895 and 794, laws of 1896.

been the chief cause of the decline. Indeed, in summing up the whole matter, the Canal Improvement Committee of 1903 states that year after year the port of New York has been steadily losing its proper share of the export and import traffic of the country, and this committee further states that New York's growth in manufacturing and industrial enterprises has not kept pace with sister states in proportion to natural advantages.

In regard to this latter proposition, the statistics cited on the preceding pages of this report show that irrational and non-progressive laws are the chief causes of the failure of New York State to increase in manufacturing and industrial enterprises in the same ratio as sister states. Moreover, the proposition that the foreign commerce of New York is falling away may also be open to question, and the following from the Report of the Bureau of Statistics for 1903 may serve to show the contrary. In the fiscal year ended June 30, 1903, exports from New York amounted to $505,000,000, an increase of $158,000,000 over 1893. A comparison of seven Atlantic and Gulf seaports stands as follows:

	Exports in 1893	Exports in 1903	Increase
New York........	$347,000,000	$505,000,000	$158,000,000
Boston	85,000,000	88,000,000	3,000,000
Philadelphia	49,000,000	73,000,000	24,000,000
Baltimore	71,000,000	81,000,000	10,000,000
Savannah	20,000,000	54,000,000	34,000,000
New Orleans	77,000,000	149,000,000	72,000,000
Galveston	37,000,000	104,000,000	67,000,000

In regard to the increase of the two southern ports, New Orleans and Galveston, it is very largely due to the high price of cotton in 1903. It is evident that this staple, which is extensively grown in Texas and Louisiana, will naturally go to nearby ports and will not in any case come to New York.

Moreover, New York is ahead in imports. In 1903 her trade amounted to $618,000,000, while the imports at all the other Atlantic ports combined was only $203,000,000, an excess at New York of $415,000,000 over all the other ports.

This matter of the decline of New York's commerce having become the subject of considerable discussion, the Legislature passed an act, chapter 644 of the laws of 1898, authorizing the appointment of a commission to consider the whole question. The report of this commission, which is known as the New York Commerce Commission, was transmitted to the Legislature January 25, 1900, by Governor Roosevelt. In his letter accompanying the report he states that the thanks of the State are due to the commission for the marked ability and untiring industry shown throughout their labors.

The New York Commerce Commission was appointed to consider the whole problem of New York's loss of commerce, inquiring into the causes and seeking to discover remedies. In their report they state that the main cause of the damage to New York's commerce is the way in which the railroads of New York discriminate against her in the interests of competing ports.

The report submitted by the commission shows that this railroad discrimination, imposed by what is known as the differential agreement between the trunk line railroads to the Atlantic seaports, results in overcoming the advantage which New York would have under natural conditions as the cheapest route to foreign markets for the products of the west. It is claimed that this differential agreement gives preference in railroad rates not only to the cities of Philadelphia, Baltimore, Norfolk and Newport News, but Montreal and the Gulf ports are benefited by it to the injury of New York to as full an extent as if they were parties to the agreement. The differential agreement also provides the same rate for Boston as for New York, and permits the Boston roads to allow free insurance and free storage to such an extent as amounts to a substantial discrimination against New York.

The differential agreement was signed on April 5, 1877, by William H. Vanderbilt, H. J. Jewett, Thomas A. Scott and John W. Garrett, representing the New York Central, the Erie, the Pennsylvania and the Baltimore & Ohio railroad companies. It established a system of freight rates governing all traffic, both eastbound and westbound, bounded on the south by the Ohio river, on the west by the Mississippi river and on the east by an imaginary line, drawn through Toronto, Buffalo, Pittsburg and Parkersburg. Traffic destined to, or originating in, territory west of the Mississippi, was also subject to this agreement, and it has since been extended to other trunk lines and to seaports like Newport News and Norfolk, which have since become important. It has continued, with some modifications, substantially unchanged, until today. It governs the rate on all classes of freight and commodities, and regulates the movement of all grain and grain products in the United States, except those moving to the Gulf ports or the Pacific coast.[1]

In order to partially control the situation, the New York Commerce Commission considered that the canal question was really the central point around which hinged all other questions concerned with benefiting the commercial development of New York. Their report is very extensive, including 2200 octavo pages. It is accompanied by evidence taken by the commission at its several hearings. The following summary of the conclusions of this commission is taken from the report:

1) The decline in New York's commerce has been steady and continuous for many years; it has been more pronounced during recent years, and has now reached serious proportions in an actual loss of exports. This loss has been largely in exports of grain and flour. While New York has been steadily losing, Montreal, Boston, Baltimore, Newport News and the Gulf ports of New Orleans and Galveston have made substantial gains.

2) The loss to New York is due in great measure to a discrimination against New York in railroad rates imposed by an agreement, known as the differential agreement, between the trunk line railroads of the American Atlantic seaports, including the New York railroads.

3) While this differential agreement, by its terms, gives preference in railroad rates only to Philadelphia, Baltimore, Norfolk and Newport News, the port of Montreal and the Gulf ports are benefited to the injury of New York to as full an extent as if they were parties to the agreement, in view of the fact that in the competition with the Gulf ports and with Montreal the differential agreement alone prevents the New York roads from giving New York as low a rate as is recorded by the agreement to Baltimore and to Newport News; and the same differential agreement, while providing the same rate for Boston as for New York, permits the Boston road to allow free insurance and free storage to an extent that amounts to as substantial a discrimination against

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[1] From paper, Railway Discrimination Against New York and the Remedy, by Abel E. Blackmar. Trans. Am. Soc. C. E., Vol. XLVI, p. 182-250.

New York as is imposed by the discrimination in the rail rate in favor of Philadelphia, Baltimore and Newport News.

4) As a result of this situation, in which New York is prevented from receiving the benefit of her natural advantages in competition with these other ports, each of the ports named has made gains while New York has continued to lose.

5) While there are port charges in New York that can and should be reduced, it will be impracticable to assure to New York any benefit from such reductions so long as the railroads are permitted to offset the saving in expense thus secured by correspondingly increasing the differential against New York. That such is the principle of the differential agreement and the policy of the New York roads, as well as the roads to the southern Atlantic ports, was conceded by the officials of the New York roads when they appeared before the commission.

6) The theory of such discrimination is that, under natural competitive conditions, New York would maintain its preeminent position in the export as well as in the import trade of the country—New York under such natural conditions being the cheapest route to the foreign markets for the products of the west. To the extent that this differential agreement requires the New York roads to charge a higher rate than otherwise would be imposed upon the export products of the west it is, in effect, an export tax upon such products.

7) To abolish the differential, therefore, would not only result in New York regaining the commerce now diverted to other ports, but it would also benefit the producers and exporters of the west when competing in the foreign markets. This is explanatory of the fact that the western exporters express themselves as equally concerned with New York regarding this railroad discrimination against New York.

8) The principle of the differential agreement is inequitable and unjust in theory and in practice. New York has suffered much therefrom, and should use every means within her power not only to have it abolished, but also to render it impracticable of restoration. The differential rate applies not only on products destined for export, but also destined for local consumption by the people of New York city.

9) The fact that the New York Central & Hudson River Railway Company has received exceptional benefits from the State of New York makes that corporation exceptionally culpable for participating in the discrimination to the serious injury of New York.

10) This railroad discrimination against New York would be impossible without the participation of the New York Central and

Hudson River Railroad Company, and the demand that it withdraw irrevocably from the differential agreement is now made understandingly.

11) The State has it within its power, through an adequate improvement of the Erie canal, not only to apply the remedy that will secure it against further loss of its commerce, but that will secure to it as well the restoration of that which has already been diverted.

12) This result may be achieved through the completion of the improvement of the State canals contemplated by chapter 79 of the laws of 1895 at an expenditure not exceeding $15,000,000. To receive full benefit from the completion of such improvement canal terminals should be provided by the State, both at Buffalo and at New York, for the receipt, safeguarding and delivery of package freight transported or destined for transportation over the Erie canal.

13) While thus providing for competition with rail rates sufficient to render difficult if not impossible a discrimination against New York, certain high charges at the port of New York should be reduced, including the charge for elevating grain, and also including the excessive rentals imposed for the use of public docks.

* * * * * * * *

As stated in the eleventh conclusion, this commission was strongly of the opinion that the State has it within its power, by an adequate improvement of Erie canal, to remedy the deficiencies at present existing, and they accordingly recommended that an act should be passed providing for the earliest possible completion of the improvement of canals contemplated by chapter 79 of the laws of 1895, and providing for issuing bonds to the sum of $15,000,000 to pay for such improvement.

The commission also considered that there should be an amendment of chapter 494 of the laws of 1899 authorizing the designation for canal terminals of public piers in the City of New York, together with suitable locations upon the Erie canal lands at Buffalo, and providing that certain piers should be set apart exclusively for canal terminals.

The commission also considered that chapter 585 of the laws of 1888, entitled, An act to regulate the fees and charges for elevating, trimming, receiving and discharging grain by means of floating and stationary elevators and warehouses within this State, should be so amended as to make it more difficult of evasion and to provide for a maximum rate of one-half cent per bushel for such service.

They also considered that the Transportation Corporation Law should be amended in such manner as to allow companies to be organized with a capital stock exceeding $50,000.

The commission considered that the provision of the charter of New York city relating to the canal piers in that city should be so amended as to limit the use of canal piers to barges on the Hudson river north of Castleton.

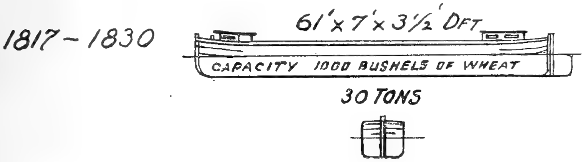

Fig. 49 Original boat used on Erie canal.

They also considered that an act should be passed prohibiting the conveyance in perpetuity of any land under water in New York now owned by the State or city and providing that leases of such land may be made.

They considered that the legislature should confer annually such authorization to the City of New York as would enable it to carry out plans for the construction of piers and the improvement of dock facilities whenever required.

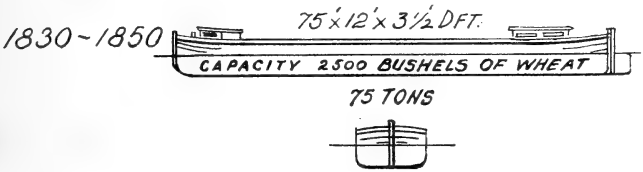

Fig. 50 Boat used at beginning of enlargement.

They finally considered that such additional authority should be conferred upon the City of New York within the constitutional limits as would enable the Dock Board to enter promptly into the possession of lands necessary to be acquired for the improvement between Gansevoort and Twenty-third streets.

The reasons for these several recommendations are included in the commission's personal report, pages 7-141, of volume I of their report.

The New York Commerce Commission consisted of Chas. A. Schieren, Andrew H. Green, C. C. Shayne, Hugh Kelly and Alexander R. Smith.

Description of the Canals Now in Operation and Their Water Supply

Following are some of the main facts in regard to the principal canals—Erie, Champlain, Oswego, and Black river—now in operation in the State of New York. Similar facts for Oneida lake canal, Oneida river improvement, the Cayuga and Seneca canal and others, may be obtained by reference to the annual reports of the Superintendent of Public Works. In order to save space, in a few cases, immaterial facts have been omitted.

LENGTH, CAPACITY, AND COST OF NEW YORK STATE CANALS

Erie canal

	Original canal	Enlarged canal
Length, in miles	363.00	351.78
Lockage, in feet	675.50	645.80
Average burden of boats, in tons	70.00	210.00
Maximum burden of boats, in tons	76.00	240.00
Construction authorized	Apr. 15, 1817	May 11, 1835
Construction completed	Oct., 1836	Sept., 1862
Actual cost of construction	$7,143,789	$44,465,414

Champlain canal

Length of canal, in miles	66
Length of feeder, in miles	7
Length of pond, in miles	5
Total, in miles	78
Average burden of boats, in tons	85
Construction authorized	Apr. 15, 1817
Glens Falls feeder authorized	Apr., 1822
Estimated cost of canal	$871,000
Total cost of canal and feeder to 1868	2,378,910
Total cost, including improvements and enlargements, to 1875	4,044,000

Oswego canal

	Original canal	Enlarged canal
Length, in miles	38.00	38.00
Lockage, in feet	154.85	154.85
Average burden of boats, in tons	62.00	210.00
Construction authorized	Apr., 1825	Apr., 1854
Construction completed	Dec., 1828	Sept., 1862
Actual cost of construction	$565,473	$4,427,589

Black River canal

Length of canal, Rome to Lyon Falls, in miles	35.00
Length of improved river to Carthage, in miles	42.00
Length of navigable feeder, in miles	10.50
Lockage, in feet	1,082.25
Average burden of boats, in tons	70.00
Construction authorized	Apr., 1836
Construction completed	1849
Actual cost of construction	$3,581,954

Eastern division of Erie canal. Erie canal is divided into three divisions, known as the eastern, the middle, and the western. The eastern division embraces the portion of the canal, with its feeders and side cuts, extending from the Hudson river at Albany to the dividing line between the counties of Herkimer and Oneida, and the whole of the Champlain canal, with its feeders, ponds, and side cuts. The entire mileage of canals, feeders, and river improvements on the eastern division is as follows:

	Miles
Erie canal, Albany to east line of Oneida county	106.24
Fort Schuyler and West Troy side cuts	0.35
Albany basin	0.77
Champlain canal, including Waterford side cut	66.00
Navigable river above Troy dam	3.00
Glens Falls feeder	7.00
Navigable river above Glens Falls feeder dam	5.00
Total	188.36

MILEAGE OF UNNAVIGABLE FEEDERS OF THE EASTERN DIVISION OF ERIE CANAL

	Miles
Mohawk river at Rexford Flats	0.39
Mohawk river at Rocky rift	3.92
Mohawk river at Little Falls	0.19
Schoharie creek	0.63
Total	5.13

To the west of Little Falls lies 19.2 miles of the eastern division, supplied from the reservoirs and streams of the middle division. East of Little Falls the supply is from Mohawk river, through Little Falls, Rocky rift, and Rexford Flats feeders, and from Schoharie creek through Schoharie creek feeder. As to the quantity of water used on that portion of Erie canal included in the eastern division very little is known. With the exception of a few thousand cubic feet per minute received from the middle division, the supply is, as just indicated, all derived from the Mohawk river and its tributary, Schoharie creek. Thus far no measurements of the actual quantity used have been made. Probably the total diversion amounts in dry weather to from 400 to 500 cubic feet per second. Some of this is returned to the Mohawk river by leakage and wastage, but just what proportion is returned, and what finally delivered either into the Hudson river at Albany or by the Troy and Fort Schuyler side cuts, is not known. In view of the magnitude of the power development on the Mohawk river at Cohoes it appears very desirable that such a determination be made.

The water supply of the Champlain canal is derived from Wood creek and several small streams to the north of Fort Edward, Glens Falls feeder, Hudson river feeder, from the Hudson river itself at Saratoga dam, and from the Mohawk river at the Cohoes dam.

As already stated, the Champlain canal is fed from the Hudson river by the Glens Falls feeder, which connects with the river about 2 miles above Glens Falls and from the Saratoga dam at Northumberland.

The length of the Glens Falls feeder, from the guard lock at its head to where it enters the Champlain canal, about 2 miles above Fort Edward, is 6.92 miles. From this point the water in the canal flows both north and south, the total length of the canal fed by the Glens Falls feeder being 31.81 miles. Fort Edward level, into which the Glens Falls feeder delivers water, is a summit level, and hence the water delivered into it, less the losses by percolation, evaporation, etc., is partly discharged into Lake Champlain and partly into the Hudson river at the Saratoga dam. The Champlain canal crosses through the pond formed by the Saratoga dam from the east side to the west of the Hudson and again passes out of the river, taking a full supply therefrom at the village of Northumberland, from which point to the Mohawk river at Cohoes the distance is 27.06 miles. The water from this section by passing into the Mohawk finally reaches the Hudson above the Troy dam. The canal crosses the Mohawk river at Cohoes, taking water therefrom to supply the section from Cohoes to near West Troy, a distance of 2.36 miles. A small amount of water also passes from the Champlain canal to the Hudson through the Waterford side cut.

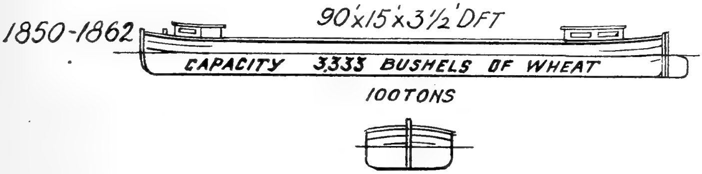

Fig. 51 Boat used during process of enlargement.

Since the construction of the Glens Falls feeder there have existed serious leaks through the seamy limestone rock in which the feeder is excavated at and below the village of Glens Falls. It is claimed that the losses through these seams have generally increased, until for several years past they have amounted to about 50 per cent of the total flow into the feeder at the guard lock.

This leakage has been repeatedly complained of by the owners of waterpower at Glens Falls and several attempts to check it have been made, but without much avail. The river falls 38 feet at Glens Falls, and the owners of the waterpower there claim that this leakage, which is practically all below the falls, is a detriment to their waterpower which ought not to exist. In order to determine the amount of this leakage, as well as the relation which it bears to the question of a material increase in the flow of the Hudson river by storage, a series of measurements of the flow of the feeder was undertaken early in October, 1895.

Arrangements having been made with the division superintendent to maintain a uniform feed for several days before the measurements began, as well as during the days when they were actually being made, and points established for verifying the uniformity of the flow during the time of the measurements, a series of accurate sections was then made at points both above and below the leakage, and a large number of current-meter readings taken from a footbridge thrown temporarily across the feeder at each section. The results so obtained are as follows:

1) On October 8, 1895, the flow in the feeder just below the guard lock at the feeder dam, above all serious leaks, was 383 cubic feet per second.

2) On the same day the flow at change bridge No. 13, about one-half mile from the feeder dam, above all serious leaks, was 364 cubic feet per second.

3) On October 9 and 10 the flow a short distance below all serious leaks was 213 cubic feet per second.

4) On October 10 the flow about half a mile farther down was 191 cubic feet per second.

5) On October 11 the flow just above the locks at Sandy Hill was 182 cubic feet per second.

6) A section, also taken October 11, in the Champlain canal, a short distance north of where the feeder enters, shows that the amount of water passing to the north at that time was 74 cubic feet per second.

These measurements show that the loss between sections 1 and 5, which may be taken as including about all the losses from the feeder, is 201 cubic feet per second. The water delivered into the Champlain canal is therefore only about 47 per cent of the quantity entering the feeder at the guard lock. The measurements also show that of the 182 cubic feet per second actually delivered to the Champlain canal 74 cubic feet per second is diverted to the north, and 108 cubic feet per second, less the loss from evaporation, etc., is returned to the river at the Saratoga dam.

Taking into account the losses from evaporation and absorption by vegetation during the summer months, we may place the demands for the Champlain canal during the months of canal navigation at the following approximate monthly means. These figures are roughly proportional to evaporation from a water surface:

	Cubic feet per second
May	553
June	600
July	600
August	600
September	553
October	510
November	495

With the leakage of the Glens Falls feeder done away with, the foregoing figures may be reduced about 200 cubic feet per second for each month. For the section of the Champlain canal from Northumberland to Cohoes we may assume the water supply of the enlarged canal at about 255 cubic feet per second in May, October, and November, and at about 280 to 290 cubic feet per second in June, July, August and September.

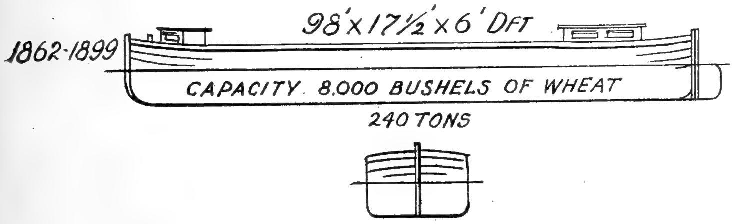

Fig. 52 Boat used after enlargement was completed in 1862.

Middle division of Erie canal. This division comprises that portion of the Erie canal lying between the east line of Oneida county and the east line of Wayne county, as well as the Oswego canal from Syracuse to Oswego, the Baldwinsville side cut, the Cayuga and Seneca canal, the Black River canal, and other short stretches as indicated in detail below. The following are the lengths in miles of the several sections:

	Miles
Erie canal from east line of Oneida county to east line of Wayne county	97.02
Oswego canal	37.78
Side cuts and slips at Salina	2.02
Slips at Liverpool	0.25
Baldwinsville side cut	0.59
Cayuga and Seneca canal	22.99
Black River canal	35.52
Old Oneida lake canal	1.05
Chenango slip	0.05
Chemung canal, original lake level	2.53
Total	199.80

MILEAGE OF RIVER IMPROVEMENTS PERTAINING TO THE MIDDLE DIVISION OF ERIE CANAL

	Miles
Black river	42.50
Onondaga outlet	0.75
Oneida river	20.00
Seneca river towing-path	5.83
Seneca river	Not used
Ithaca inlet	2.05
Seneca outlet	0.17
Total	71.30

MILEAGE OF NAVIGABLE FEEDERS OF THE MIDDLE DIVISION OF ERIE CANAL

	Miles
Limestone creek	0.83
Butternut creek	1.67
Camillus	1.04
Delta	1.40
Black river	11.29
Total	16.23

The total length of canal, river improvement, and navigable feeders on the middle division is thus found to be 287.33 miles. The following feeders of the middle division are not navigable:

	Miles
Chenango canal, summit level	5.31
Leland pond	0.31
Madison brook	2.99
West branch	5.83
Bradleys brook	0.67
Hatch lake	0.23
Kings brook	1.87
Oriskany creek	0.53
Mohawk feeder at Rome	0.03
Oneida creek	2.91
Cowaselon creek	0.40
Chittenango creek	0.28
Cazenovia lake outlet	0.51
Tioughnioga river	1.00
De Ruyter reservoir outlet	0.12
Orrville	0.55
Camillus (unnavigable portion)	0.65
Carpenter brook	0.18
Skaneateles creek	0.09
Putnam brook	0.20
Centerport	0.18
Owasco creek	2.10
Lansing kill	1.80
Sugar river	0.14
Canachagala lake outlet	0.16
Total	29.04

Rome level, which is a summit level, extends from lock No. 46 to lock No. 47, a distance of 55.96 miles. The following is the estimated water supply of this level before the beginning of the enlargement of 1895.

	Cubic feet per second
Leland pond, Madison Brook reservoir, Eaton Brook reservoir, Bradley Brook reservoir, Hatch lake, Kingsley Brook reservoir, and Oriskany creek feed through the Chenango canal, Oriskany creek, and Oriskany creek feeder into the Rome level, 6 miles west of lock No. 46	100
Mohawk river, Black river, Forestport pond, Forestport reservoir, White Lake reservoir, Chub lake, Sand lake, First, Second and Third Bisby lakes, Woodhull reservoir, Twin lakes, South Branch reservoir, North Branch reservoir and Canachagala lake feed through the Rome feeder and Black River canal into the Rome level at Rome, 14 miles west of lock No. 46	217
Oneida creek enters the canal through feeder 30 miles west of lock No. 46	17
Cowaselon creek enters the canal through feeder 31.5 miles west of lock No. 46	3
Cazenovia Lake reservoir, Erieville reservoir and Chittenango creek enter the canal through Chittenango creek feeder, 41.5 miles west of lock No. 46; average for navigation season about	47
De Ruyter reservoir enters the canal through Limestone creek (Fayetteville) feeder, 50 miles west of lock No. 46; average for the navigation season about	32
Limestone creek (natural flow) also enters the canal through Limestone creek (Fayetteville) feeder, 50 miles west of lock No. 46	8
Jamesville reservoir enters the canal through the Orrville feeder, 52 miles west of lock No. 46; average for navigation season	11
Butternut creek (natural flow) enters the canal through the Orrville feeder, 52 miles west of lock No. 46	8
Total	443

The following detail in regard to the preceding feeders and reservoirs is condensed from the Barge Canal Report.

Oriskany feeder. This feeder has a catchment area above the diversion dam at Oriskany of 234 square miles, which includes 87 square miles of the catchment of Chenango river, therefore leaving 147 square miles tributary to Oriskany creek. On the Chenango river catchment there are a number of reservoirs, a list of which has been given on page 417.

Mohawk feeder. A short distance east of the Black River canal a portion of the Mohawk river is diverted by the Mohawk feeder into the Erie canal. The catchment area of the river above the point of diversion is 156 square miles. It is thus without water storage. The minimum flow of the Mohawk river at Ridge Mills, as shown on a preceding page, is rather large, although it should not be overlooked that it receives the waste and leakage of twenty-five miles of the Black River canal. For the present it may be taken at 0.2 cubic foot per second per square mile.

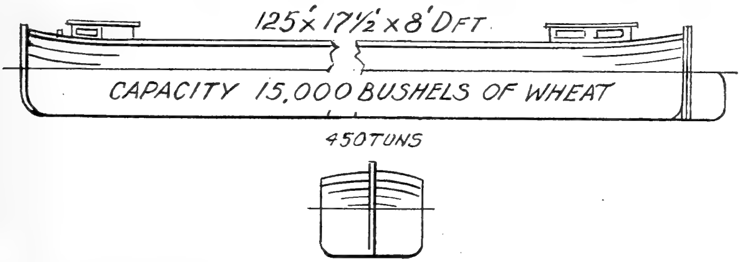

Fig. 53 Boat suggested by Canal Committee for Erie canal improvement.

Black river canal feeder. The Erie canal is supplied with 183 cubic feet per second of water from the Black river canal, which unites therewith at Rome. The summit level of the Black river canal is supplied from Black river at Forestport by means of a navigable feeder about 10.5 miles in length. The distance from Boonville to Rome is about twenty-five miles.

The pond at the head of the Forestport feeder is formed by a diversion dam across Black river, a short distance below Woodhull creek. The catchment area at the diversion dam is 267 square miles. The Forestport reservoir is on Black river about 1.5 miles above the diversion dam. This reservoir has an area of

793 acres and an average depth of 7 feet. Its storage capacity is 212,444,000 cubic feet. The catchment area is 147 square miles. There are also a number of lakes, ponds and reservoirs in the upper portion of the catchment area of Black river which are utilized but which are not specifically mentioned here because they are tabulated on page 544.

Wood creek feeder. This stream flows into Erie canal in the western part of Rome. Its catchment area is 7 square miles, and since the amount of water furnished by this catchment is so small as to be inappreciable, it is not taken into account in the preceding tabulation. The minimum flow amounts to about 0.3 cubic foot per second.

Oneida feeder. Oneida feeder enters Erie canal at Durhamville. A portion of the water of Oneida creek is diverted into Oneida feeder at Oneida. The catchment area of the creek above the diversion dam is 73 square miles. There are no storage reservoirs upon Oneida creek.

Cowaselon feeder. This feeder empties into the Erie canal 2.5 miles west of Durhamville. The catchment area above the feeder is 28 square miles. There are no storage reservoirs upon this stream.

Chittenango feeder. The Chittenango creek unites with the outlet of Cazenovia lake at Cazenovia and is diverted into the Chittenango feeder at Chittenango.

The Erieville reservoir is situated in the extreme southeastern portion of the catchment on one of the smaller branches of Chittenango creek. The tributary catchment is 5.4 square miles and its storage capacity 318,424,000 cubic feet. The water surface is 340 acres and the average depth is 21.5 feet.

The outlet of Cazenovia lake unites with Chittenango creek 9.4 miles above the feeder. The catchment area of the lake is 8.7 square miles, and according to recent determinations the water surface is 1.7 square miles, although in the reports of the Canal Department it is stated at 2.8 square miles. The outlet is also stated to be so controlled as to afford a storage of 348,523,000 cubic feet by drawing off a depth of 4.5 feet. This depth on an area of 1.7 square miles gives a storage of only 206,997,000 cubic feet. The area of the catchment above the diversion dam is 77.1 square miles. That of Erieville reservoir and Cazenovia lake combined is 14.1 square miles.

Fayetteville feeder. A portion of the water of Limestone creek is diverted into the Fayetteville feeder at Fayetteville. This feeder is 1.2 miles long and is navigable for 0.83 of a mile. Near Delphi, Limestone creek divides into two branches. De Ruyter reservoir is located at the head of the branch from the south. This reservoir is formed by an earth dam 70 feet high, and has a storage capacity of 504,468,000 cubic feet, with an average area of 626 acres and depth of 18.5 feet. It impounds water from 18.2 square miles of the catchment of Tioughnioga river. Its location is 15 miles southeasterly from the head of the diversion dam at Fayetteville, and the intermediate catchment is 77.1 square miles. The total catchment above Fayetteville is 95.2 square miles; below this village the feeder intercepts Bishops brook, with a catchment of 8.3 square miles. The total catchment area tributary to the Fayetteville feeder is therefore 103.5 square miles.

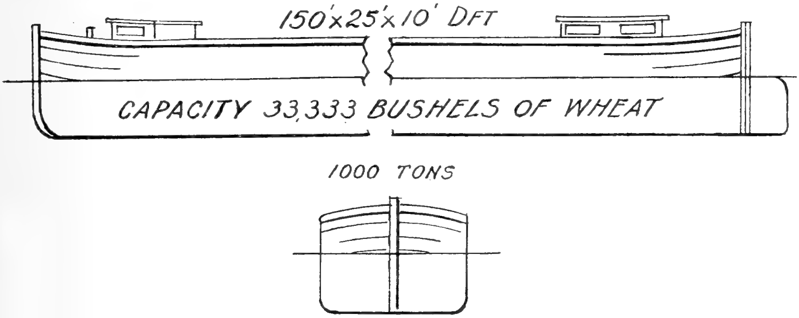

Fig. 54 Boat recommended by Canal Committee for Barge canal.

The storage capacity of De Ruyter reservoir is at the rate of 27,800,000 cubic feet per square mile of tributary catchment, as figured on the basis of 18.2 square miles of catchment area.

Orrville feeder. At a point 2.2 miles south of the canal at De Witt the water of Butternut creek is diverted through the Orrville feeder into the canal. Jamesville reservoir, 2.4 miles above the head of the feeder, is formed by a dam across the creek. The area of the reservoir formed is 252 acres; average depth, 16.5 feet, and storage capacity, 170,000,000 cubic feet. The catchment area of the creek above the head of the feeder is 52 square miles, and the catchment area above the reservoir is 46.2 square miles.

The storage of the Jamesville reservoir is at the rate of 3,680,000 cubic feet per square mile of catchment tributary to the reservoir. In order to make the entire yield of the area available, a much larger storage capacity than this is required.

Jordan level, which is also a summit level, extends from lock No. 50 to lock No. 51 and is 14,903 miles in length. The following feeders are tributary to this level:

	Cubic ft. per second
Otisco lake reservoir fed through Camillus feeder into the canal, 4 miles west of lock No. 50	86
Ninemile creek (natural flow) also fed into canal through Camillus feeder	13
Carpenter brook feeder	3
Skaneateles feeder[1]	146
Total	248

The following feeders deliver water into the Port Byron level, which extends from lock No. 51 to No. 52, a distance of 7.79 miles:

	Cubic ft. per second
Putnam brook feeder at Weedsport	3
Owasco feeder	69
Total	72

Oswego canal receives about 167 cubic feet per second from the Erie canal at Syracuse. The balance of its water supply is derived from the Seneca and Oneida rivers. The total amounts to about 1233 cubic feet per second. Seneca and Cayuga canal receives about 67 cubic feet per second from Erie canal at Mon-

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[1] See statement in regard to Skaneateles feeder on page 168.

tezuma, and 300 cubic feet per second from Seneca lake, making a total of 367 cubic feet per second.

The approximate water supply of the middle division of the Erie canal may therefore be summarized as follows:

	Cubic ft. per second
Frankfort and Rome level	443
Jordan level	249
Port Byron level	70
Total	762
Oswego canal:	
Supply from Seneca river	900
From Oneida river	333
Total	1,233
Seneca and Cayuga canal	300
Grand total	2,295

The total water supply of the middle division may thus be placed, approximately, at 2,295 cubic feet per second.[1]

The details of reservoirs on the Black river, as well as those of the other reservoirs for the water supply of the Erie canal, may be obtained from table No. 95.

Western division of Erie canal. The western division of the Erie canal includes the following:

	Miles
Erie canal from the east line of Wayne county to Hamburg street, in the city of Buffalo	148.92
Five slips in the city of Buffalo, aggregate length	1.60
Genesee river feeder in the city of Rochester	2.25
Total	152.77

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[1] This is a very general statement from the reports of the State Engineer and Surveyor, and to be taken in connection with a large amount of detailed information in the reports not specifically cited here.

The unnavigable feeders of this division are:

	Miles
Tonawanda and Oak Orchard creek	11.55
Prism of old Genesee Valley canal, Cuba reservoir to Rockville	7.65
Prism of old Genesee Valley canal, Scottsville to Rochester feeder dam	11.00
Total	30.20

The only reservoirs on the western division are the Oil creek and Rockville reservoirs, originally constructed to feed the summit level of the Genesee Valley canal, and still retained as subsidiary feeders to the Erie canal, their waters being finally discharged into the Genesee river and thence taken into the canal through the Genesee river at Rochester. The main characteristics of Oil creek and Rockville reservoirs may be obtained from table No. 95.

The sources of water supply for the western division are: Lake Erie, at Buffalo; Tonawanda creek, at Pendleton; Tonawanda and Oak Orchard creeks, at Medina; Allens creek, through the prism of the old Genesee Valley canal, from Scottsville to Rochester; the Genesee river at Rochester.[1]

Ship Canal Projects and their Water Supply

By virtue of the geographic position of New York, with the Great Lakes on its western boundary and the Atlantic ocean on its eastern, and with the commercial capital of the western continent as its chief city, all discussions of deep waterway projects from the upper Great Lakes to the seaboard are necessarily chiefly discussions of the water resources of New York. It is proper, therefore, that the several deep waterway projects should be briefly noticed in a report of this character.

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[1] The foregoing statements as to length, water supply, and reservoirs of the Erie canal, while covering only a small amount of the total data, are still as much as can be given at this time. Full information may be obtained by reference either to the annual reports of the State Engineer and Surveyor from 1850 to 1903, inclusive, or to those of the Superintendent of Public Works from 1878 to 1903, inclusive. Previous to 1878 reports of the Canal Commissioners may also be consulted for a large amount of information.

TABLE NO. 95—RESERVOIRS FOR THE WATER SUPPLY OF ERIE CANAL

RESERVOIR	Date of completion	Elevation	Distance to canal	Flow-line area	Hight of flow-line	Average area	Average depth	Capacity	Original cost	Cost per million cubic feet
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		Feet	*Miles*	*Acres*	*Feet*	*Acres*	*Feet*	*Cubic feet*		
Rome level—Erie canal	......	428	......	......	......	......	......	......	......	......
Woodhull	1859	1,854	25.0	1,236	16	1,118	18.0	876,550,000	$24,089	$27 47
Bisby lake, No. 1[1]	1881	2,018	27.8	156	4					
Bisby lake, No. 2	1881	2,018	27.0	204	4	......	3.5	40,000,000	......	......
Bisby lake, No. 3	1881	2,006	26.0	41	4					
Sand lake	1872	1,808	24.0	344	18	306	18.0	199,879,822	5,505	27 71
Chubb lake	1881	1,599	20.5	530	22	200	4.0	34,848,000	8,134	233 43
White lake[2]	1881	......	18.0	332	5	296	5.0	64,468,800	5,102	79 27
Canachagala lake	1881	......	32.0	347	4	320	10.0	55,756,800	1,456	26 11
North Branch lake	1857	1,821	25.5	423	28	277	25.0	337,851,360	34,637	102 22
South Branch lake	1859	2,019	26.0	518	26	372	26.0	421,312,320	20,168	47 87
Twin lakes	1881	......	22.0	212	6	175	9.0	60,984,000	......	......
Forestport pond	1853	1,124	10.5	160	......	......	2.0	13,921,920	......	......
Forestport reservoir	1894	1,139	12.5	793	21	700	7.0	212,444,000	......	......
Boonville level—Black river canal	......	1,121	25.0	......	......	......	......	......	......	......
Jordan level—Erie canal	......	408	......	......	......	......	......	......	......	......
Skaneateles lake	1844	864	9.0	8,320	......	......	9.0	2,174,512,000	14,928	6 87
Otisco lake	1869	......	12.0	2,200	......	......	10.0	784,000,000	43,753	55 81
Port Byron level—Erie canal	......	403	......	......	......	......	......	......	......	......
Owasco lake	1866	704	12.0	680	......	......	5.0	1,481,040,000	36,296	25 59
Rochester level—Erie canal	......	508	......	......	......	......	......	......	......	......
Cuba level—Genesee Valley canal	......	1,489	......	......	......	......	......	......	......	......
Oil creek	1858	......	91.0	605	65	525	15.0	435,738,000	69,216	158 85
Rockville	1842	......	8.3	......	......	72	20.0	18,200,000	7,711	423 68
Ischua	1858	......	3.0	......	......	......	......	......	......	......
Rome level—Erie canal	......	428	......	......	......	......	......	......	......	......
Erieville	1850	1,577	20.0	340	46	......	21.5	318,424,000	36,837	115 68
Cazenovia lake	1857	1,176	10.0	1,778	......	......	4.5	348,523,000	10,885	31 23
De Ruyter	1863	1,276	25.0	626	......	......	18.5	504,468,000	78,761	156 13
Jamesville	1874	585	6.0	252	......	240	16.0	170,000,000	150,000	882 35
Hatch lake[3]	1836	......	36.0	134	15	......	10.0	58,370,400	4,464	76 47
Eaton brook[3]	1836	......	38.0	254	60	244	50.0	553,212,000	28,059	50 72
Bradley brook[3]	1836	......	35.0	134	30	......	25.0	145,926,000	16,159	110 73
Leland pond[3]	1836	......	25.0	173	13	150	8.0	59,287,040	8,894	150 02
Madison brook	1836	1,127	29.0	345	55	235	45.0	460,647,000	36,301	78 80
Kingsley brook	1867	......	33.0	113	......	......	20.0	98,445,600	80,481	817 54

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[1] Supply to canal through Forestport pond and Black river canal.

[2] The Bisby lakes and White lake reservoir have been abandoned.

[3] Supply to canal through Oriskany creek feeder.

The Deep Waterways Commission of 1895. In February, 1895, Congress by a joint resolution authorized a preliminary inquiry concerning deep waterways between the Great Lakes and the ocean, and provided that the President should appoint three commissioners to make such inquiry. The President, under this resolution, appointed Prof. James B. Angell, of Ann Arbor, Michigan; John E. Russell, of Leicester, Massachusetts, and Lyman E. Cooley, of Chicago, Illinois. The report of the commission, published in 1897, includes a large amount of valuable information in regard to a deep waterway from the upper Great Lakes to the Atlantic seaboard. In regard to the State of New York, it has been pointed out by Mr Cooley that nature has indicated two feasible routes for such a canal. The first of these is the Oswego-Mohawk-Hudson route, extending from Oswego through the valley of the Oswego and Oneida rivers, and thence across the divide to the Mohawk, thence through the Mohawk valley to a point on the Hudson in the vicinity of Troy, and so on through the Hudson river to tidewater at New York. One objection to this route is the lockage over the summit between Lake Ontario and the Mohawk valley. Another objection is the absorption of a large quantity of water in central New York for the supply of the summit level of the canal, and which probably can be more effectively used in manufacturing; that is to say, the State of New York, by developing its manufacturing resources to their fullest extent, can realize more return from manufacturing than from the use of its inland waters for purposes of internal navigation of any kind whatever. The Oswego-Mohawk-Hudson route would utilize the great natural highway which has been an easy passage to commerce from the early days of settlement on the Atlantic coast.

The second natural route through the State of New York is by way of St Lawrence river to the head of Coteau rapids, where the low-water level of Lake St Francis is 153.5 feet above tide, or 68.5 feet above the low-water level of Lake Champlain. On this plan a canal would be constructed from Coteau Landing to the head of Lake Champlain, near Rouses Point, this section requiring cutting through a summit about 50 feet in hight. Lake Champlain would then be utilized to Whitehall, from which point a canal would be cut through the valley leading from Whitehall to the Hudson river at Fort Edward, the elevation of the water surface of the Hudson a few miles below Fort Edward being somewhat less than the low-water elevation of Lake Champlain. After reaching the Hudson the work would include the deepening of that stream to deep water, a few miles below Albany. Either of the foregoing projects would further include the construction of a ship canal connecting Lakes Erie and Ontario.

The advantage of the St Lawrence-Champlain-Hudson over the Oswego-Mohawk-Hudson route is that the lockage would be all in one direction; that is, eastward-bound vessels would lock down all the way from Lake Erie to New York. Its disadvantages are increased length and the location of the canal connecting the St Lawrence river with Lake Champlain in Canadian territory. In regard to increased length, it is claimed that not much more time would be required in traversing it than would be consumed in locking over the Oswego-Mohawk summit.

Fig. 55 Earth section of deep waterways for 21-foot channel.

As to the capacity of the proposed canal, the Deep Waterways Commission points out in its report that such a canal, if built, should be so carried out as to be adequate for vessels of the most economical type, not only for coasting or domestic trade but also for the foreign movement, so that commerce may be carried on directly between lake ports and other domestic and foreign ports without transshipment. Taking into account various other conditions, the commission believes that the requirements of the present demand a limiting draft in the proposed canal of 27 or 28 feet; hence, the commission recommends the securing of a channel of a navigable depth of not less than 28 feet.

The commission also says that, starting from the heads of Lakes Michigan and Superior, the most eligible route for a deep waterway is through the several Great Lakes and their intermediate channels and the proposed Niagara ship canal to Lake Ontario, and that the Canadian seaboard may then be reached from Lake Ontario by the way of the St Lawrence river, and the American seaboard reached from Lake Ontario by way of either the Oswego-Mohawk-Hudson route or the St Lawrence-Champlain-Hudson route. The Deep Waterways Commission was not authorized to make any considerable expenditure for surveys, and hence the conclusions announced are to some degree tentative. In view of the uncertainty as to final cost, it is recommended that the alternative routes from Lake Ontario to the Hudson be subject to complete survey in order to obtain a full development of the governing economic considerations, as well as to determine their relative availability.

The commission also recommends a moderate control of the level of Lake Erie and of Niagara river above Tonawanda by dam, but leaves the practical details undetermined in the absence of a full understanding of the physical conditions.

The credit for systematizing the information belongs almost entirely to Lyman E. Cooley. In his special report on the technical work of the Deep Waterways Commission he has defined clearly the main elements of the problem and produced a report which will be an important reference so long as deep waterways are a live topic in the United States.

The report of Major Thomas W. Symons. The river and harbor act of June 3, 1896, directs the Secretary of War to cause to be made accurate examinations and estimates of the cost of constructing a ship canal by the most practicable route, wholly within the United States, from the Great Lakes to the navigable waters of the Hudson river, of sufficient capacity to transport the tonnage of the lakes to the sea. Under the provisions of this act a report was submitted by Major Thomas W. Symons, of the Corps of Engineers, dated June 23, 1897.[1]

Major Symons states that there are three possible routes for the ship canal, entirely within the territory of the United States, from the Great Lakes to the navigable waters of the Hudson, as follows:

1) From Lake Erie via the upper Niagara river to the vicinity of Tonawanda or La Salle; thence by canal, with locks, either to the lower Niagara at or near Lewiston, or to some point on Lake

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[1] Report Chief of Engineers for the year ending June 30, 1897.

Ontario; thence through Lake Ontario to Oswego; thence up Oswego and Oneida rivers to Oneida lake, and through Oneida lake; thence across the divide to Mohawk river, and down that river to the Hudson at Troy; thence down the Hudson. This he designates as the Oswego route. From Oswego to Hudson river it is, in effect, the Oswego-Mohawk-Hudson route, already described.

2) To follow either the line of Erie canal from Lake Erie to the Hudson, or this line so modified as to provide for a continuously descending canal from Lake Erie to the Hudson. This he designates as the Erie canal route.

3) This route coincides with the first from Lake Erie to Lake Ontario, but runs thence through Lake Ontario to St Lawrence river and down said river to some point near Ogdensburg; it then crosses the State of New York to Lake Champlain and up that lake to Whitehall; and thence follows in general the route of the Champlain canal to Hudson river at Troy.

There is also discussed a fourth route—the St Lawrence-Champlain—all of which, except a small portion, is within the United States. This route would be via Niagara Falls, Lake Ontario, the St Lawrence, Caughnawaga, and Richelieu rivers, Lake Champlain, and the Hudson.

The opinion is expressed that the best route for the contemplated ship canal is that via Niagara river, Lake Ontario, Oswego and Oneida rivers, Oneida lake, and Mohawk and Hudson rivers, and that to build such a canal by any of the possible routes mentioned would, at a rough estimate, cost $200,000,000, the exact figure depending very largely upon the action of the State of New York in regard to the State canals, feeders, reservoirs, etc.; and that to maintain the canal and to keep it in repair, including the maintenance of river channels, reservoirs, and feeders, would cost, at a rough estimate, $2,000,000 a year. The statement is made that a ship canal would be of no special military value, and that its construction is not worthy of being undertaken by the general government because the probable benefits to be derived from it would not be commensurate with the cost.

Major Symons further expresses the opinion that Erie canal, when enlarged under the present plans of the State of New York, may give, if State restrictions are removed, commercial advantages practically equal to those to be derived from the proposed ship canal, and that if Erie canal be further improved by enlargement to a size sufficient for 1500-ton barges, making such alterations in alignment as to give a continuously descending canal all the way from Lake Erie to the Hudson, and canalizing Mohawk river, the improved canal, navigated by barges, would render practicable the transportation of freight between the east and the west at a lower rate than by a ship canal navigated by large lake or ocean vessels. The difficulty of navigating large vessels through long, shallow canals is the loss of time and the consequent great increase in the pro rata expense account, as compared with the actual amount transported between terminals. Major Symons is also of the opinion that the enlargement of the Erie canal on these lines is a project worthy of being undertaken by the general government, because the benefits to be derived would be commensurate with the cost, which he estimates at approximately one fourth that of a ship canal, or $50,000,000. The following is a summary of Major Symons's report:

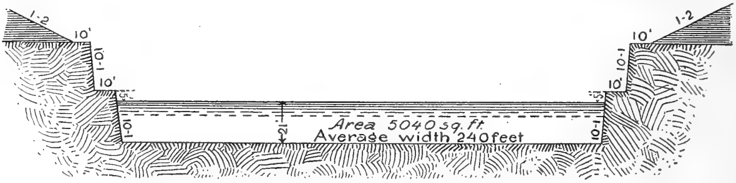

Fig. 56 Rock cross-section of deep waterways for 21-foot channel.

1) A ship canal which would permit lake vessels to reach tidewater and ocean vessels to reach lake ports would be valuable in reducing and regulating lake freights, transfer charges, etc. on such freight as might be tributary thereto.

2) To justify construction the benefits to be derived from such a canal should be clearly shown to be suitably commensurate with its cost and the cost of maintenance and necessary improvements.

3) The present and prospective conditions of lake and interlake channels and harbors limit the reasonable depth of a ship canal to that required for vessels of 20-foot draft.

4) Any ship canal built should be entirely within the territory of the United States, and should terminate at a first-class American seaport and commercial and manufacturing center in order that western products for domestic consumption, as well as those

designed for exportation, may be transported at minimum cost, and that return freight of the greatest possible magnitude may be secured and the canal benefit alike the people of the west and of the east.

5) Any ship canal built should not only subserve the interests of foreign-bound commerce, but as well the domestic commerce between the centers of population in the east and the producing regions of the west.

6) The domestic commerce is of more importance to consider than the commerce destined to or from foreign countries.

7) A ship canal by the St Lawrence route to Montreal, or by the St Lawrence-Champlain route to New York, does not fulfill these conditions, and should not be considered by the United States.

8) The route considered best for a ship canal is by the Niagara river, Lake Ontario, Oswego, Oneida lake and the Mohawk and Hudson rivers.

9) For the highest economy in transportation special types of vessels are needed for use on the ocean, on the lakes and on the canals, and neither can replace the other in its proper waters without suffering loss of efficiency. Ocean vessels could not, as a general rule, engage in the business of passing through a ship canal and the lakes to upper lake ports, and lake vessels are not fitted for use upon the ocean, and if they made use of a canal they would have to transfer their cargoes at the seaboard. For economical transportation through a canal from the Great Lakes to the sea, special vessels, differing from and far less costly than ocean or lake vessels, are required.

10) Important and serviceable canals already exist between the Great Lakes and the Hudson, the Erie canal connecting Lake Erie with the Hudson, and the Oswego-Erie canal connecting Lake Ontario with the Hudson. By these canals low rates of freight are attained.

11) These canals are being improved by the State of New York to the extent that when completed the capacity of the boats navigating them will be increased about 70 per cent, the time of transit will be materially reduced, and it will be possible and practicable to move freight between Lake Erie and New York for about 60 per cent of the present cost.

12) Under existing conditions and methods these canals require, and will when improved require, the transference of freight from lake vessels to canal boats, and vice versa, at lower lake ports.

13) This transference is an important and expensive item in the cost of through freight, and its avoidance or material reduction is very desirable.

14) Transference at lower lake ports is necessary for economical distribution of a very large part of the freight shipped in lake vessels, and this would be the case regardless of any canal.

15) The present cost of transference at lower lake ports can be materially reduced and business still be done at a profit.

16) Any canal which will enable this transference to be avoided will cause its reduction to a minimum.

17) The amount of tonnage which it is estimated may be possibly tributary to a ship canal is 24,000,000 annually, 18,000,000 tons transported eastward and 6,000,000 tons transported westward.

18) The cost of a ship canal suitable for use by the largest vessels of the lakes from Lake Erie to New York, and necessary work in connection therewith, would be approximately $200,000,000, and the cost of operation and maintenance would be approximately $2,000,000 per year. The cost would depend largely upon the arrangement which could be made with New York State for the possession of its canals, feeders, reservoirs, etc. which would necessarily be absorbed in the greater canal.

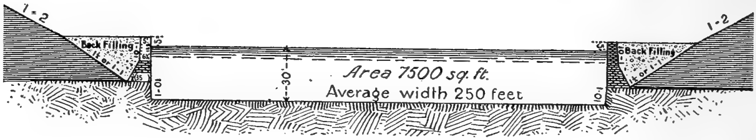

Fig. 57 Cross-section of deep waterways, partly in rock and partly in earth, for 30-foot channel.

19) The Erie canal, as it is being enlarged by the State of New York, will, if all restrictions upon its use be removed, give commercial advantages practically equal to the commercial advantages which would be given by a ship canal.

20) If the Erie canal be further improved by enlarging it to a size sufficient for 1500-ton barges, making necessary alterations in its alignment so as to give a continuously descending canal all the way from Lake Erie to the Hudson, and canalizing the Mohawk river, such improved canal, navigated by barges, will enable freight to be transported between the east and west at a lower rate than could a ship canal navigated by the large lake or ocean vessels. The cost of such enlargement would be approximately one quarter the cost of a ship canal.

21) If a ship canal were built, the business thereon would not be done in large lake or ocean vessels, but in barges and boats which could be equally well accommodated in a canal of much less size.

22) A ship canal between the Great Lakes and the ocean would have no military value.

23) The construction of a ship canal from the Great Lakes to the sea is not a project worthy of being undertaken by the general government, as the benefits to be derived therefrom would not be properly commensurate with the cost.

24) The enlargement of the Erie canal, as suggested, with everything adapted to transport the tonnage of the lakes, is a project worthy of being undertaken by the general government, as the benefits to be derived therefrom would be properly commensurate with the cost.

25) The cost of the necessary surveys for a ship canal by the Niagara-Oswego route is estimated at $190,000.

26) The cost of an entirely independent survey for the enlargement of the Erie canal and canalization of the Mohawk river is estimated at $125,000.

27) The cost of a combined survey of the Niagara-Oswego ship canal and for the enlargement of the Erie canal is estimated at $250,000.

28) A thorough understanding with the State of New York with reference to its canals should, if possible, precede action of any kind.

Report on the Oswego-Mohawk-Hudson route. The Oswego-Mohawk-Hudson route is discussed in a report by Albert J. Himes appearing in the Report of the State Engineer and Surveyor for 1895.[1]

In this report Mr Himes expresses the opinion that a sufficient water supply could not be obtained for a high summit level across the divide, and hence the canal must be cut from the level of Oneida lake through to the corresponding level in the Mohawk valley. In this way he proposes to use Oneida lake as a storage reservoir from which to discharge water both ways to the Oswego and Mohawk rivers. By this plan the surface of Oneida lake would be raised 10 feet, furnishing 1100 cubic feet per second continuously for seven months. If such a canal is constructed, the experience gained in the last seventy-five years teaches the danger of small economies in water supply. Experi-

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[1] Report on the Enlarged Canal via the Oswego Route, by Albert J. Himes. Report State Engineer and Surveyor for the year ending September 30, 1895.

ence shows that canal water supplies must be made ample, as otherwise a shortage will result sooner or later.

In a paper on An Enlarged Waterway Between the Great Lakes and the Atlantic Seaboard, by William Pierson Judson, the water supply of the summit level of the Oswego-Mohawk-Hudson route is discussed at length. Mr Judson considers that it would be entirely proper to take whatever deficiency there might be from the headwaters of the Black river, reservoirs in addition to those now existing being constructed on the Beaver and Moose rivers, tributary to the Black, for the purpose of furnishing this water. He recognizes that the item of adequate water supply for such a canal is vital, and states that if surveys and thorough investigations were to show that the demand for water for such a canal is beyond the capacity of the sources of supply, then the Oswego-Mohawk-Hudson route would be shown to be impracticable, although as an alternative proposition he states that it would be entirely practicable to supply the summit level of such a canal from Lake Erie. This, it is pointed out, can be accomplished by a feeder branch taken from the present Erie canal near Macedon, 12 miles west of Newark, where the Erie canal is now 35 feet above the Rome level. The proposed feeder, instead of stepping down, as does the Erie canal, can be swung off to the south on higher ground at the necessary elevation, passing along the south side of the Clyde river and crossing the Seneca river near the Cayuga Lake outlet. Seneca river is narrowest here, and the feeder could be carried across it in an open trunk on a 40 to 50 foot trestle about 2 miles long.

Fig. 58 Earth section of deep waterways for 30-foot channel.

A canal on the Oswego-Mohawk-Hudson route 28 to 30 feet in depth, with corresponding surface and bottom dimensions, will probably absorb all available water of central New York, as well as a considerable portion of Black river. The waterpowers on

Mohawk river at Cohoes will necessarily be made subservient to the exigencies of such a canal, although Mr Judson, in the paper already referred to, has pointed out how valuable these water powers would be for seven or eight months of the year to the manufacturing cities of the Mohawk valley. Under this head we may, however, inquire as to how the waterpower for only seven months of the year would be of any special value to the city of Cohoes, where, owing to the kind of manufacturing, continuous power three hundred and ten days in the year is required. This development is a result of wise management of the waterpower, without which there is no reason to suppose that the area on which the city stands would have any greater value than that of the surrounding farming region. A proposition to interfere seriously with the waterpower at Cohoes can only be looked on by the writer as most extraordinary. Indeed, not the least extraordinary feature of the present agitation for ship canals across the State of New York is the entire lack of appreciation—so far as the discussion indicates—of the value to the State of New York of its inland waters.

Aside from the report of Major Symons, the discussion has thus far apparently proceeded on the supposition that the taking of inland waters for navigation purposes was a matter on a par with the taking of agricultural lands for right of way, the economic value of the water for power purposes and the resulting effect on the internal development of the State having thus far been almost entirely ignored.

What the people of the State of New York need to consider first of all is whether the inland waters are not now worth more for manufacturing than they can possibly be worth for navigation purposes. If after investigation it is shown that the water will produce greater income to the people of the State in manufacturing than it will in operating such a canal, then from mere commercial considerations the people ought not to consent to the construction of such a canal. The State of New York can not afford to forego the possibility of developing its manufacturing interest in order to furnish water for the summit level of the proposed Oswego-Mohawk-Hudson deep-water canal. At any rate we should know just what results may be expected before embarking in the enterprise. If, however, after full investigation it appears that the canal water supply can be obtained and the manufacturing interests protected, no reasonable objection can be urged.

The foregoing was written in 1897. In 1898–99 the writer investigated this question for the United States Board of Engineers on Deep Waterways, arriving at the conclusion that water enough to supply the deep waterways could be obtained without interfering with the development of manufacturing. How this may be accomplished is detailed in the present report.

In order to justify the construction of the ship canal as a commercial proposition, the saving on the transportation of an estimated annual tonnage of 24,000,000 tons over the cost of its transportation by existing means and methods must at least, equal the interest on the cost of the canal plus the annual cost of maintenance and operation. The first cost is taken at $200,000,000, with the maintenance at $2,000,000 per year. Assuming an interest charge of 3 per cent, the annual interest plus the maintenance becomes $8,000,000, which sum represents the annual expense of the proposed ship canal connecting the Great Lakes with the Atlantic seaboard. As regards the State of New York, there should be added to this amount a sum representing the decrease in wealth in central New York due to the absorption of the inland waters of the State away from manufacturing interests in favor of navigation interests. As a rough estimate the writer places such decrease at not less than $5,000,000 per year, although the decrease would probably be much greater than this, but in the absence of data for full discussion he places it at a conservative figure, which can not well be gainsaid. On the other hand, if the International St Lawrence-Champlain-Hudson route were to be constructed, not only would this source of loss be entirely eliminated, but since that plan proposes to deliver water from the St Lawrence river into Lake Champlain, and thence by a through cut from Lake Champlain to the Hudson river, there would be delivered into the Hudson river a considerable quantity of water which would be available for power at Saratoga dam, Mechanicville and Troy. This ship-canal project thus increases rather than decreases the productive capacity of the State.

Without wishing to present the foregoing as in any degree a final conclusion, it is the broad view to take of the question.

Report of the Board of Engineers on Deep Waterways. Under the provisions of the Sundry Civil Act, passed June 4, 1897, the President appointed Major Chas. W. Raymond of the Corps of Army Engineers, Alfred Noble and George Y. Wisner to make surveys and examinations of deep waterways between the Great Lakes and the Atlantic tidewaters, as recommended by the Report of the Deep Waterways Commission. The sundry civil act of July 1, 1898, provided that this board should submit in their report the probable and relative cost of canals 21 and 30 feet in depth, with a statement of the relative advantages.

This board examined the project for a ship canal in all its phases, making the most elaborate report thus far made on an engineering project anywhere; $485,000 was spent and the report includes over 1000 pages, illustrated by maps and diagrams, showing every possible phase of the subject. Its length precludes anything like a complete review of it here, and the writer will confine himself to such references as are necessary to understand its relation to water supply in the State of New York.

Attention may be again called to the fact that the Board of Engineers was limited in its investigations to the recommendations made by the Deep Waterways Commission. These recommendations included the following:

1) That complete surveys and examinations be made and all needful data to mature projects be procured for—

a) Controlling the level of Lake Erie and projecting the Niagara ship-canal.

b) Developing the Oswego-Oneida-Mohawk route.

c) Developing the St Lawrence-Champlain route.

d) Improving the tidal Hudson river.

e) Improving intermediate channels of the lakes.

2) That the collecting and reducing of existing information, supplemented by reconnaissance and special investigations, be continued until the general questions have been fully covered.

3) That a systematic measurement of the outflow of the several lakes and a final determination of their levels shall be undertaken.

Since the principal canal to be constructed in connecting the Great Lakes with the Atlantic tidewaters passes through the State of New York, the following outline of the work of the Board of Engineers is herewith given:

Dimensions of prism. This board made a study of the dimensions of St Clair, Suez, Manchester, Amsterdam and Kiel canals, together with the speed which steamships can maintain in these waterways, arriving at the conclusion that the cross-section of the canal prism should be made such as to permit a speed of 8 miles per hour on tangents without danger to either passing ships or damage to the banks. On this basis the cross-section best adapted for economic transportation of the lake traffic and permitting a speed of 8 miles per hour is about 5500 square feet for a 21-foot waterway and 8000 square feet for a 30-foot waterway.

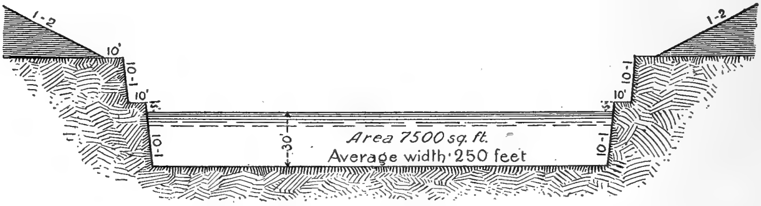

Fig. 59 Rock cross-section of deep waterways for 30-foot channel.

On open rivers a bottom width of 600 feet was adopted as necessary for safe navigation. On the Hudson and Mohawk rivers the cross-section of the waterway was designed with reference to carrying flood discharges with current velocities not exceeding 4 linear feet per second. On the Mohawk river the economic cross-section for carrying the flood discharge at not exceeding 4 linear feet per second required a depth of considerably over 21 feet.

Dimensions of structures. The dimensions of lock structures were designed with reference to the type carrier likely to use the waterway and to the importance of the amount of time required to pass a ship through the waterway relative to the number of ships which can be passed through a lock in a given time, and in view of the fact that the increase of detention at high locks only increases the detention for additional time required to fill the lock chamber, it was concluded that the advantages to be derived from quick time and from developing shipbuilding industries was of more importance than a small decrease in traffic capacity.

The dimensions of lock structures which will best subserve the foregoing conditions were investigated with the following results:

Single locks for a 30-foot waterway are to be 740 feet long and 80 feet wide and to have lifts conforming to the present development of waterpower on the routes. That is, the hight of lift will be whatever the present power dams are.

For a 21-foot waterway the locks are to be 600 feet long, 60 feet wide and with the same hight of lift as in the foregoing. At Lewiston, Long Sault rapids on the St Lawrence river and at Champlain, the natural conditions require lifts of from 40 to 50 feet.

Dams and sluices. Dams on the Mohawk and Hudson rivers were designed with as great a length as the natural conditions would permit in order to keep the range between stages of high and low water as little as possible. This range can be further reduced by making the crests movable. Sluice gates of the Stoney type are provided where long dams are not desirable. With four exceptions the dams can be constructed on rock foundations, and at the locations where rock is not available the heads on the dams will be small.

Breakwaters. At Olcott and Oswego, terminals of the Niagara ship canal and of the Oswego-Mohawk route, artificial harbors protected by breakwaters will be necessary. A study was made of the type best adapted to the conditions at these harbors and the results are given.

Cornell experiments. Uncertainty as to the value of the coefficients in the ordinary weir formula rendered it desirable that additional investigations should be made before estimates could be made either of the value of waterpower rights or of the amount of slope wall and bank protection to be used between the limits of high water and low water stages of the proposed waterway. Previous to the Cornell investigations there was very little certain information as to the flow over weirs when the depth was greater than 2 feet. A series of experiments was accordingly made at Cornell University, extending the results up to 6 feet.

Bridges. The railway and highway bridges were designed for 250 feet clear span on the 30-foot channel and 240 feet on the 21-foot. In a few cases of highway crossings steam ferries were provided for instead of bridges.

Unit prices. In establishing unit prices for the estimates the prices paid on large works throughout the country, involving similar constructions, were considered and the advice and opinion of most of the experienced contracting engineers was secured.

Control of Lake Erie. Under the influence of varying supply, evaporation and discharge, the monthly mean level of Lake Erie has varied 4.6 feet during the past seventy years. The low level occurs from September to November, when navigation is the most active. In order to maintain the level the discharge must be so controlled that it will always be approximately equal to the difference between the water supply and the evaporation of Lake Erie. This can be accomplished by establishing regulating works at Buffalo. They must be so arranged that they will not only maintain the level of the lake at or near the fixed stage adopted, but will also produce no injurious effect upon the lakes and waterways from which the supply is derived, or upon those receiving the discharge. This problem was investigated by the Board of Engineers, and they concluded that the best location for the regulating works would be at the foot of the lake, just below Buffalo harbor. The board also concluded that the level of the lake could be maintained during the season of navigation within about 0.6 foot below the level adopted for regulation, under all the conditions of supply. Variations of level, due to violent winds, will

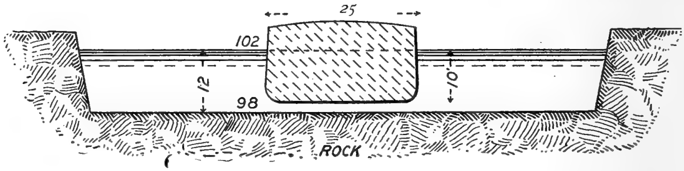

Fig. 60 Rock cross-section of proposed Barge canal.

occasionally happen, but it was not considered that they would seriously interfere with the regulation of the lake level.

The effect on the Niagara river, Lake Ontario and the St Lawrence river will not be objectionable, while the depth of water will be increased about 3 feet in Lake Erie, 2 feet in Lake St Clair and 1 foot in Lake Huron.

Niagara ship canal. The project for a waterway from the Great Lakes to the Atlantic tidewaters suitable for transporting the commerce of the upper lakes has attracted public attention for nearly a century, during which time the people of New York have maintained that such a canal must be built directly across the State in order to aid in building up the financial and commercial supremacy of New York city, while the people of the western states have considered that the canal should be constructed on the route best adapted for transporting the commerce of the country tributary to the Great Lakes; that is to say, everybody except the people of New York have considered that the preferable route was by a Niagara ship canal into Lake Ontario at the most convenient point, and from thence through Lake Ontario to Oswego. Even in 1812, before the construction of the Erie canal, the authorities of the territory of Michigan resolved unanimously that in their opinion the canal contemplated by the Commissioners of Internal Navigation of the State of New York would not be so desirable as a canal around Niagara. To this the New York Commissioners replied that they had too much respect for the authorities of Michigan to suppose they had given such opinion without information and consideration, and therefore the New York Commissioners inferred that the information received was either not founded in fact, or that not having turned their attention to the subject of canals, the authorities of Michigan were not well qualified to judge.[1]

It is certain that the St Lawrence river is the natural outlet and the line of least resistance for a waterway from the Great Lakes to tidewater.

A waterway large enough to transport the tonnage of the lakes can be constructed by way of Lake Ontario for less cost than by any other route. Moreover, a steamer will traverse it in about

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[1] New York Canals, Vol. 1, p. 74.

three quarters of the time required on a direct waterway from Lake Erie to the Mohawk. The matter therefore takes this form: If it is desired to develop a waterway best subserving the interests of the lake commerce, the route should be through Lake Ontario and a ship canal from Lake Erie to Lake Ontario would be an essential part of it.

Five surveys have been made for a canal on the American side from Lake Erie to Ontario, in most of which only two routes have been considered—one from Niagara river above the falls at Lasalle to below the falls at Lewiston, thence by the Niagara river to Lake Ontario; and the other from Tonawanda to Lake Ontario at Olcott. These surveys contemplated the use of the Niagara river from Lake Erie to the entrance of the canal as part of the route.

The Board of Engineers on Deep Waterways studied two routes for the Niagara ship canal. Both of these begin at deep water in Lake Erie and, running through Black Rock harbor to near the head of Squaw island, lock down to the river level and then follow the general course of the river to Tonawanda and Cayuga island, just off the village of Lasalle, at which points the two waterways leave the river.

Lasalle-Lewiston route. The Lasalle-Lewiston route continues from Lasalle to within half a mile of the foot of lock No. 2, above Lewiston. The route then passes down the bluff to the Niagara below the falls half a mile below Lewiston, with six double locks, each of 40 feet lift and two locks each of 39.4 feet lift. The estimated cost of the 30-foot channel, with Lake Erie regulated, is $73,435,000. Estimating with reference to standard low water, the estimated cost for a 30-foot channel is $75,084,000. The estimate for a 21-foot channel with Lake Erie regulated is $42,393,000 and for a 21-foot channel with standard low water the estimated cost is $43,214,000.

Tonawanda-Olcott route. This route leaves the Niagara river at Tonawanda and continues at the level of the river to just west of Lockport, from which point it descends to Eighteenmile creek, one mile from Lake Ontario, following the valley of that creek to Lake Ontario. The descent is accomplished by two single and three double locks of 40 feet lift each; one single lock of 30.5 feet lift, and three double locks, of 30 feet lift, each. The proposed harbor at Olcott is a widening of Eighteenmile creek to the width of 400 feet from the last lock to the lake, the entrance being protected by breakwaters. The estimated cost of the Tonawanda-Olcott route for a 30-foot channel, with Lake Erie regulated, is $75,572,000, and with standard low water the estimated cost of a 30-foot channel is $77,221,000. The estimate for a 21-foot channel, with Lake Erie regulated, is $48,454,000, and with standard low water the estimated cost for a 21-foot channel is $49,275,000.

As to the relative value of these two routes, it is stated that a steamship of 19 feet draft in the 21-foot channel would consume one hour and nine minutes more time between Buffalo and a point common to the two routes in Lake Ontario in traversing the Tonawanda-Olcott route than in Lasalle-Lewiston route, and that in a 30-foot channel a steamship of 27 feet draft would be one hour and forty-three minutes longer by the Tonawanda-Olcott route. The cost of maintenance of the Lasalle-Lewiston route would be less than for the Tonawanda-Olcott route. It is therefore evident that economy in original construction, transportation and time of passage for ships determine the Lasalle-Lewiston route as preferable.

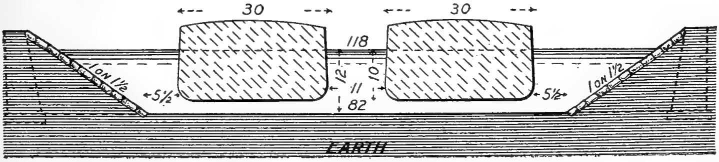


Fig. 61 Earth section of proposed 1500-ton Barge canal.

Oswego-Mohawk route. From Lewiston vessels pass through the deep lower Niagara river to the mouth at Queenstown, from whence the route is by open water of Lake Ontario to Oswego, 112 miles, at which place the line leaves Lake Ontario from an artificial harbor to be constructed about one mile west of Oswego river. It then passes through the westerly limits of the city of Oswego to a dam above Minetto, where the deep waterway joins the river, 85.6 feet above Lake Ontario. This difference in level will be overcome by four locks of 21.4 feet lift each. From Minetto the line follows the river to the northern edge of the village of Fulton, where it enters the valley of a small creek, and continues across swamp and sand reaches to Oneida lake.

Two different projects for connecting waterways from Oswego river to the Mohawk have been examined—the first of these with the summit level 416 feet above tide, with a water supply to be furnished through a feeder from reservoirs on the Black and Salmon rivers, and the second, with a summit level the same as that of Oneida lake, 379 feet above tide. For a waterway having a high summit level across the divide between Oneida lake and the Mohawk river, it is proposed to establish the low-water level of the lake at 376 + T. W., while for the project having the lake for the summit level, low water will be established at 379 feet + T. W. For the project having a high summit level it is proposed to overcome the 45-foot rise from the Oswego river at Fulton to Oneida lake by two locks with 22.5 feet lift each, while for the latter project there will be two locks of 18 feet lift each, and one with varying lift from 12 to 19 feet, according to the stage of Oneida lake.

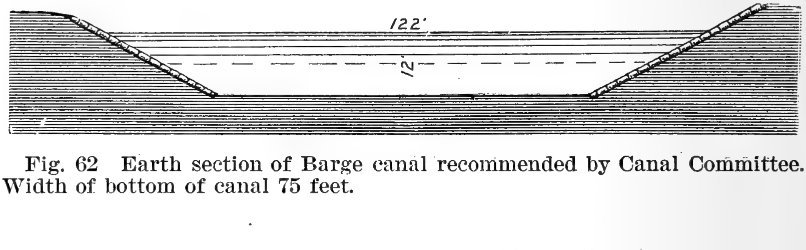


Fig. 62 Earth section of Barge canal recommended by Canal Committee. Width of bottom of canal 75 feet.

In regard to the high-level project, the summit of the divide near Rome is about 430 feet + T. W. The deep waterway would cross this summit with a water surface elevation of 416 feet. The summit level would be nearly 14 miles long and receive a water supply from the Black river feeder at or near its western end, three miles west of Rome, from which point the line would follow in a direct course to Oneida lake, at the mouth of Fish creek. The eastern end of the summit level is about one mile east of the mouth of Oriskany creek.

In the low level project it is proposed to convert Oneida lake into a storage reservoir, and by cutting a channel through the Rome divide, navigation at lake level could be extended to the Mohawk river at Frankfort, a distance of seventy-two miles from the lock at the western end of the level, 2.5 miles east of Fulton. From Frankfort to the Hudson the route is practically a rectification of the Mohawk river to Rotterdam Junction, thence for three miles along the south side of the Mohawk valley and across the divide to the head of the Normans kill, which stream enters the Hudson a short distance below Albany.

The water supply of the high level project, including evaporation, leakage, waterpower, waste, etc. is taken at 1600 cubic feet per second for a 30-foot channel and at 1400 cubic feet per second for a 21-foot channel. In order to provide this quantity, a reservoir was located in the valley of Black river, with surface area, when full, of 73 square miles and an impounding capacity of 57,000,000,000 cubic feet, and one in Salmon river valley of 8.5 square miles area and a storage capacity of over 7,000,000,000 cubic feet. The storage of the Black river reservoir would be sufficient to maintain a supply except in periods of low precipitation, when additional supply might be needed from the Salmon river reservoir. The Black river reservoir also provided for maintaining the waterpower on Black river below the reservoir.

A study was also made of an alternative tunnel project as a substitute for the feeder line, which has sufficient merit to warrant further investigation. This tunnel would leave the south end of the Black river reservoir at Lyon Falls and open into the upper Mohawk at the village of North Western, a distance of 20.5 miles from the reservoir, and thence discharge from the channel of the Mohawk into the waterway near Rome. It is considered that the tunnel plan would be preferable because the amount of waste and cost of maintenance would be much less than for the open feeder. The danger of accident would be reduced to a minimum. The costs of the two systems, as estimated, are approximately the same.

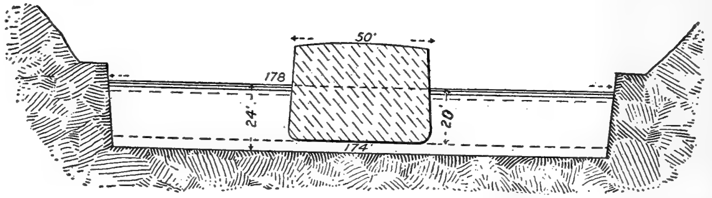
The estimated cost for a 30-foot channel on the high level project is $195,870,000.

For the low level project, the estimated cost of a 30-foot channel is $199,926,000.

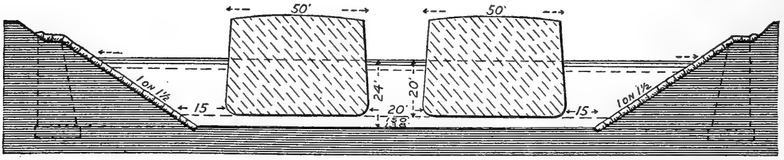
For the high level project, the estimated cost of a 21-foot channel is $151,165,000.

For the low level project, the estimated cost for a 21-foot channel is $152,843,000.

St Lawrence-Champlain route. This route extends from the foot of Lake Ontario to the lower end of the Oswego-Mohawk route, at the mouth of the Normans kill, following the St Lawrence river from Lake Ontario to Lake St Francis; from Lake St Francis to Lake Champlain; from Lake Champlain across the divide between that lake and the Hudson river, and along the Hudson river to the junction with the Oswego-Mohawk route below Albany.



Rock section.



Earth section.

Fig. 63 Major Symons's proposed Ship canal, Lake Erie to Hudson river.

The estimated cost for a 30-foot channel is $208,448,000, while for a 21-foot channel the estimated cost is $142,075,000.

The tidal portion of the Hudson river from the mouth of the Normans kill to tidewater at New York would require some work to be done, although for a 21-foot channel the river is mostly deep enough. The work on this section below the Normans kill, for a 30-foot channel, is estimated at $10,383,000 and for a 21-foot channel at $4,160,000.

The Board of Engineers also considered the intermediate channels of the lakes, as at the head of Lake Erie, at Lake St Clair and the St Clair flats, between Lakes Huron and Michigan, etc.

These several improvements, while necessary for a complete system of navigation of the Great lakes do not otherwise specially apply to the State of New York, and are therefore not given here. They may be found in detail in the report of the board.

The utilization of natural waterways. Probably the particular feature which most deserves attention in the deep waterways surveys is that they are a utilization of natural waterways and not in any sense artificial channels. Of the total distance from Buffalo to New York (477 miles) only 102 miles are in standard canal section, and 98 miles are in canalized rivers from 250 to 1000 feet in width. The remaining 277 miles are in open lakes and rivers, where a vessel can make nearly or quite as good time as she can on the open waters of Lake Erie or Lake Huron. On the Barge canal about 200 miles, or nearly double the distance, is in artificial channel.

This, taken in connection with the liberal size adopted for the canal section, will enable vessels to make a very high speed on this route. The estimates have been worked out with care, from the known time occupied by vessels in passing the Sault lock and the St Clair canal, checking them by the most thorough investigation of all available data of the speed of vessels in existing ship canals. The result shows that a vessel of 11,700 tons displacement and 8600 tons of cargo capacity would take 64 hours to make the passage from Buffalo to New York city, 477 miles. About 7 hours are required for the passage from Buffalo through the Niagara river and down the flight of locks to Lake Ontario; 11 hours more through the open waters of Lake Ontario bring the vessel to Oswego. About 17 hours are then required for the passage up the Oswego valley and through the long canal section to the pools of the Mohawk river (of which about two hours are spent in traversing the open waters of Lake Oneida). Then 9½ hours are required for the passage down the Mohawk valley; 8 hours for the passage from there to the Hudson, and 12 hours for the run down the Hudson to New York.[1]

The preferable route. The following in regard to comparison of the waterways is taken from the Report of the Board of Engineers:

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[1] Abstract from editorial in Engineering News.

The investigation of the routes for a waterway between Lake Erie and Lake Ontario indicates that the Lasalle-Lewiston line can be constructed at less cost than the others, and can be traversed by a type carrier between points common to all the routes in less time than by the other routes.

The natural harbor at the mouth of the Niagara river and the comparatively small amount of restricted channel on the Lewiston line make it a better location on which to construct a waterway than the route from Tonawanda to Olcott.

The route from Lake Ontario to New York is 208 miles farther by the St Lawrence, Lake Champlain and the Hudson river than by the Oswego, Mohawk and Hudson rivers, but has 292 feet less lockage than the Mohawk low level and 366 feet less lockage than the Mohawk high level routes.

The length of standard canal prism is practically the same by each route, the difference in distance being almost entirely in the open lake and river portions of the waterway.

The sailing time for a type carrier is twelve hours longer by the Champlain route than by the Mohawk route, which difference is due to the greater time required to sail 208 miles farther by the former than to make eighteen more lockages on the latter.

The comparative values of the two routes depend largely upon the cost to construct and maintain the respective channels, the annual traffic capacity of each, and the time required for type carriers to make round trips.

The estimated cost of the 21-foot waterway and the sailing times between terminals are based on locks 600 feet long and 60 feet wide. If the locks should be made 80 feet wide for the purpose of passing large ships from the lake shipyards to the Atlantic, the estimated cost of the Mohawk route would be increased $4,221,000 and the Champlain route $2,560,000, the annual capacity of the routes slightly diminished, and the time required for making round trips increased.

Summit level water supply. The following in regard to summit level water supply for a 30-foot channel is from the report to the Board of Engineers:

The proposed summit level of the Oswego-Mohawk route, with water-surface elevation of 416 feet above tide, extends a distance of 71,900 feet (13.62 miles). The water surface for a 30-foot channel in earth is 334 feet wide, and for a 21-foot channel 310 feet. The area of cross-section of a 30-foot channel is 8000 square feet and for a 21-foot channel 5500 square feet.

The tributary streams may be relied upon to keep the main channel full during the winter season, even under the most adverse conditions of winter drought. Filling in the spring may be therefore left out of the account, and the problem is accordingly simplified to a determination of the quantity required to supply lockages, evaporation, percolation, gate-and-sluice-leakage losses and wastage. The locks at the ends of the summit level are to be 740 feet in length by 80 feet wide, with lifts of 20 feet. Also, at Little Falls, 129,460 feet (24.52 miles) east of the east end of the summit level, there are to be duplicate sets of tandem locks, with total lift of 43 feet, the lock chambers being 740 feet long by 60 feet in width.

West Canada creek, which has a catchment area above its mouth of 569 square miles, flows into the Mohawk river at Herkimer. The several small streams known as Crane creek, Reels creek, Knapp brook, Budlong creek, Sterling creek, Bridenbacker creek and adjacent territory lying on the north side of the Mohawk river and between Herkimer and the east boundary of Ninemile creek area have a catchment area of 86 square miles. To the east of Herkimer, on the north side of the Mohawk river, Beaver brook and adjacent territory have 15 square miles, while on the south side, between Utica and Little Falls, Ballou creek, Factory creek, Ferguson creek, Meyer creek, Steele creek, Fulmer creek and adjacent territory have a catchment area of 139 square miles. The total catchment area tributary to the main deep waterway between Little Falls and the east end of the summit level is therefore $(569 + 86 + 15 + 139) = 809$ square miles. This area may be expected to yield from 150 to 200 cubic feet of water per second in a dry time, which will, it is believed, be ample for the various losses and small additional lockage requirement on the reach of canal between the east end of the summit level and the double locks at Little Falls.

According to data furnished by the Board of Engineers, the annual traffic is assumed at 25,000,000 tons, with an assumed tonnage per lockage for a 30-foot channel of 3000 tons and for a 21-foot channel a tonnage per lockage of 2500 tons.

The question of water supply of canals has been so fully discussed elsewhere as to make it impossible to add very much thereto at this time. So far as the United States is concerned, experience on the Erie canal in New York State is the most extensive of any.[1]

From the foregoing data of annual traffic and tonnage per lockage we have a total lockage per year of 8333, and adding the usual 50 per cent for two ends of summit level, 4167, we have a total number of lockfuls of water of 12,500.

Assuming 222 days of navigation, we have the following:
Volume of one lockful $=(740 \times 80 \times 20)=1{,}184{,}000$ cubic feet.

For mean water supply per second, we have:

$$\frac{12{,}500 \times 1{,}184{,}000}{222 \times 24 \times 3{,}600} = 772 \text{ cubic feet,}$$

or, for even figures, we may place the lockage requirement at 800 cubic feet per second. The foregoing quantity of 800 cubic feet per second expenditure of water for lockage is based upon absolutely uniform distribution of vessels, both as to direction and season. As a modifying factor we should take into account these elements:

1) Since the feeder has no storage in the vicinity of the main canal a draft in excess of the mean quantity must be drawn from the main channel itself.

2) There will be a tendency to more lockage in daylight than at night.

3) In the spring of the year, on account of the preponderance of the grain trade, the larger proportion of movement will probably be, for a time, from west to east. At other seasons there are likely to be times when the traffic will be in excess in one direction. The estimate of one and one half lockfuls of water for each vessel passing the summit is based on uniform distribution of the traffic, otherwise two lockfuls per vessel passing is required. The proper addition to the lockage requirement on account of such irregularity can not be definitely determined until one has statistics of the actual movement covering a series of years. In the absence of such the foregoing may be pointed out as a reason why the lockage requirement should be properly placed somewhat larger than the theoretical figure.

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[1] For these data reference may be made to the section on Loss of Water from Artificial Channels in this report. There are a number of other references, as Water Supply of Western Division of Erie Canal, etc. The Barge Canal Report contains a resumé of the preceding, together with the European data, etc.

The table of evaporation from a water surface, as observed at the Mount Hope reservoir of the Rochester Waterworks, shows that for the navigation months, April to November inclusive, evaporation ranges from 1.33 inches in November 1897, to 6.85 inches in July 1898. The water surface of the proposed summit level is so small as to make evaporation, even in the maximum month, hardly worth taking into account. At 6.85 inches for the month the evaporation on the summit level becomes, roundly, 5 cubic feet per second. In order to give evaporation some value in the estimate of total water supply we will take it at from 5 to 10 cubic feet per second.

There is no rational method of estimating percolation loss for a canal under the conditions which exist in the Mohawk valley. The drainage is all towards the valley, and at first thought it might appear that percolation was a negligible quantity. However, if we consider that the total water supply, as estimated for the summit level, takes into account the entire yield of the catchment area tributary to the main channel, and further consider that the channel, as located, has its water surface for a considerable distance several feet above the ordinary water plane of the Mohawk river and Wood creek in their natural condition, we may conclude that percolation ought not to be entirely neglected, more specially because the soils in the Mohawk bottom are open and porous, and without some method of consolidation of the natural soils, which does not now occur to the writer, can be devised, there is likely to be considerable loss from percolation. By way of showing the relation of water surface of the summit level to ordinary water levels in the Mohawk river and Wood creek the following data are cited:

At a distance of 17,000 feet east of Rome the ordinary water surface of the Mohawk river is at an elevation of 415, or the same as water surface of the summit level; 24,000 feet east of Rome it is 413; 32,000 feet east it is 408; 41,000 feet east, 404, and 47,000 feet east, 401.

At 17,500 feet west of Rome the ordinary water surface of Wood creek is at 414, or one foot lower than the summit level; at 21,500 feet west of Rome it is 408, and at 25,500 feet west, 398.

The writer has no way of demonstrating the proposition, although it seems clear enough to him that with an open, porous soil the percolation from the canal at points where the summit level is raised somewhat above the ordinary water level of the Mohawk river and Wood creek will be considerable. The porous soils of these valleys will take up water like a sponge, making considerable areas from which, due to a luxuriant vegetation, the summer evaporation may be as much as 60 inches over the actual ground area affected. The land damage on these areas will be considerable and should be taken into account in the estimate. In dry years, with a total rainfall from June to November inclusive of from 8 to 12 inches, the amount required to keep up this great evaporation must come by percolation from a deep waterway channel. If we assume an area of 10 square miles as affected, the amount of water required to keep up constant evaporation on the basis of 60 inches for the navigation season would be nearly 80 cubic feet per second, or, even if we consider the area affected as not exceeding 5 square miles and take into account the loss into the old-water channels, it seems rational to allow percolation from summit level of 75 to 100 cubic feet per second.

Leakage at gates and structures is a very uncertain element. Under ordinary conditions the gates ought to be worked without very much leakage. The data furnished indicate a probable loss from this source of perhaps 60 to 80 cubic feet per second.

A considerable amount of power will be required at each lock for operating gates and for electric light at night. A conservative allowance for this purpose seems to be from 20 to 25 cubic feet per second at each end of summit level, or a total of 40 to 50 cubic feet per second.

On the Erie canal considerable time is saved by flushing boats out of the locks on to the lower levels by letting water through the gates from above. The writer does not understand, however, that this practice is specially applicable to locks passing boats carrying their own power. In order to accommodate local traffic it is probable, even though deep waterways should be constructed on substantially the line under consideration, that the Erie canal would be maintained on its present line from near Rome to Buffalo. Independent of other considerations, this would lead to considerable traffic on deep waterways in the way of barges, timber rafts and fleets of canal boats, the handling of which will probably be more or less expedited by a reasonable use of water for flushing out on to the lower levels. As a matter of judgment purely, this item has been placed at from 50 to 60 cubic feet per second, although by the use of mechanical arrangements for doing this work the quantity of water could be materially reduced, flushing being in any case an uneconomical method of applying power.

In order to pass the large flood flows of the upper Mohawk without great fluctuation of the water surface, it will be necessary to provide from 2000 to 2500 linear feet of spillway at each end of the summit level, and over which, whenever there is any interruption of uniform distribution of lockages, there must necessarily be considerable waste. Taking into account the actual water-surface area of the summit level of (71,900 × 334) = 24,014,600 square feet, and assuming an inflow of 1300 cubic feet per second, without any outflow, the increase in depth per hour becomes 0.19 foot, or in three hours the increase in depth would become 0.58 foot. However, if there were no lockages for three hours, the depth would not increase as rapidly as this because of the leakage at gates and sluices and wastage on the spillways. In order to illustrate this matter we may consider the following tabulation, in which the heads are given in inches and feet. The coefficient used for the computation, as derived from Bazin's experiments, is applicable to a flat-crested, or nearly flat-crested, weir from 6 to 7 feet wide. The quantity of discharge, Q, in cubic feet per second, is given per linear foot of crest and also for 2500 feet of crest.

HEAD			Q per linear foot of crest, in cubic feet per second	Q for 2500 feet of crest, in cubic feet per second
Inches	Feet	Coefficient		
1	0.083	2.20	0.053	133
2	0.167	2.20	0.150	375
3	0.250	2.35	0.294	735
4	0.330	2.42	0.459	1,148
5	0.417	2.47	0.665	1,663

It appears from the foregoing that when the water rises to a depth of only one inch on such a crest, the discharge over 2500 linear feet would become 133 cubic feet per second, while for two inches depth it becomes 375 cubic feet per second, and for three inches depth, 735 cubic feet per second, and so on up to 1663 cubic feet per second for a depth of five inches. However, the wastage would be less than these figures indicate, because of the outflow from leakage and the wastage over the crest. Under the existing conditions of the proposed deep waterways summit level, whenever there is an interval of two or three hours without lockages the wastage over the long spillways at the ends of the level will amount to several hundred cubic feet per second. This quantity may probably be reduced somewhat by the use of flashboards, to be set in place and taken off as necessary, although, in view of the sudden flood rises of the Mohawk river and consequent necessity for removing the flashboards frequently, the writer considers that such remedy would be somewhat unsatisfactory. The safer way, without doubt, is to provide a liberal wastage requirement. On this basis, from 150 to 250 cubic feet per second has been assumed. Bringing these several items of summit water supply together we have the following:

	Cubic feet per second		
1) Lockages	800		800
2) Evaporation	5	to	10
3) Percolation	75	to	100
4) Leakage at gates, etc	60	to	80
5) Power and electric lights	40	to	50
6) Flushing out canal boats, barges and timber rafts	50	to	60
7) Wastage at spillways	150	to	250
Total	1,180	to	1,350
8) Feeder losses	300	to	600
Final total	1,480	to	1,950

Proceeding on similar lines of discussion for water supply of summit level for a 21-foot channel, it is concluded that from 1215 to 1600 cubic feet per second would be required—or as a mean, the quantity may be fixed upon as 1400 cubic feet per second, including feeder losses.

The water supply for a low-level ship canal may be fixed at from 1000 to 1100 cubic feet per second, which could be furnished from storage of Oneida lake.

The deep waterways surveys were executed in 1898-99.

The Canadian canals. In discussing canal projects as applying to the State of New York it ought not to be overlooked that there is now a waterway 14 feet in depth through Canada, by way of the Welland canal, connecting Lake Erie with Lake Ontario and the several canals around the rapids of the St Lawrence river, to tidewater at Quebec. These canals have been in existence a number of years, but they have never been in any sense competitors of the New York canals, largely because the river and Gulf of St Lawrence are a region of fogs, which necessarily will always make the St Lawrence route an objectionable one. The river St Lawrence must be thoroughly marked by lighthouses and buoys, and even after this is done there will remain a thousand miles of difficult navigation from Montreal to the open ocean.

The present Canadian canals are, as stated, only 14 feet in depth, although two projects for 21-foot canals are considerably talked of at the present time.

The first of these is the Georgian bay canal through Lake Simcoe to Lake Ontario near Toronto. This proposed canal is only about one hundred miles in length, from Georgian bay to Lake Ontario, of which fifteen miles are in Lake Simcoe, leaving about eighty-five miles of actual canal construction. The elevation of Lake Simcoe is 714 feet above tide, or 134 feet above Georgian bay. The mean elevation of Lake Ontario may be taken at 247 feet, or it is 467 feet below Lake Simcoe. The total lockage on this canal, therefore, is roundly 600 feet. There is a very heavy cut through ridges both at the west and east of Lake Simcoe. The cut to the west is ninety feet in depth and seven miles long. The cut to the east is 200 feet in depth, and about eleven miles long. The quantities in these two cuts are about double those of the Culebra cut on the Panama canal. The difficulties of taking out this cut are known to everybody, although it is conceded that difficulties due to climate would not tend to delay the work in Canada, as they have on the Isthmus of Panama. The flight of locks from Lake Simcoe to Lake Ontario would be perhaps twelve in number, with a lift at each lock of a little less than forty feet, while from Lake Simcoe to Georgian bay there would be four locks, or sixteen in all. So far as known, no estimate of the cost of this canal has been made, but it can not fail to be exceedingly expensive.

The second Canadian project to which attention is directed is that known as the Montreal, Ottawa and Georgian bay canal, by way of French river, Lake Nipissing, Matawan and Ottawa rivers, connecting Georgian bay with the St Lawrence, near Montreal. It is proposed to canalize these streams. The distance from Georgian bay to the St Lawrence, at Montreal, is 425 miles, and there would be twenty-nine locks, as proposed. Lake Nipissing, the summit level, is forty-six feet above Georgian bay and 640 feet above the St Lawrence river, at Montreal. The estimated cost of this canal is $80,000,000. A company has been formed to construct it, and it is stated that they have been merely waiting to see what turn the barge canal project would take in the State of New York. It is understood now that they are preparing to build this canal.

When the Welland canal was opened it would accommodate most of the lake vessels of that day, but since then the size of lake vessels has greatly increased—the cost of running larger vessels being less in proportion—so that there is now a considerable fleet shut in between Buffalo and Port Colborne. The barge canal having carried in New York, the Canadians are now contemplating a radical improvement to the Welland canal, and preliminary thereto are spending $2,000,000 at Port Colborne, the Lake Erie end of Welland canal, in harbor improvements, the intention being to deepen the harbor to accommodate boats drawing 20 feet of water.

The project is also being actively agitated to reconstruct Welland canal, making it deep enough to take boats of 20 feet draft. The fall from Lake Erie to Lake Ontario is 326 feet, which is now made by twenty-five locks. It is proposed to reconstruct these, making seven or eight locks instead, each lock to be 650 feet by 65 feet and 22 feet on the sills. It is estimated that such an enlargement can be completed in four years at a cost not exceeding about $25,000,000.

This project is advocated by the Dominion Marine Association and by the St Catherine and Thorold Boards of Trade. In case the Welland canal is enlarged as proposed, the deepening of the St Lawrence route to 20 feet would then be a comparatively small matter.

Recent Canal Projects in New York.

Report of the Committee on Canals of New York. On March 8, 1899, Governor Roosevelt appointed Francis V. Greene, George E. Green, John W. Scatcherd, Thomas W. Symons, Frank S. Witherbee, Edward A. Bond and John N. Partridge a committee on canals to consider the whole question and to advise the State of New York as to what policy should be followed with reference to the canals. In the letter of appointment it is stated that the opinion of a body of experts was required who should include not merely high-class engineers, but men of business, who knew the relative advantages and disadvantages of ship canals, barge canals and ordinary shallow canals and who were acquainted with the history of canal transportation as affected by the competition of railways and who had the knowledge that would enable us to profit by the experience of other countries in these matters.

This committee, which was known as the Canal Committee, reported, under date of January 15, 1900, in favor of enlarging the canal enough to take a barge of 1000 tons capacity. In order to accomplish this, a canal 12 feet deep is required, 75 feet wide at the bottom and 123 feet wide at water surface.

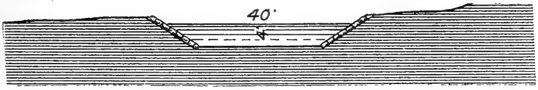

Fig. 64 Earth section of original Erie canal. Width of bottom of canal 26 feet.

Seymour plan for enlargement of Erie canal. The canal improvement of 1895 was formulated by State Engineer and Surveyor, Horatio Seymour, Jr., in 1878.

The Canal Committee considered the Seymour plan and reported that the cost of completing it would be $12,923,639. This estimate includes the work required to deepen the prism of the canal to 9 feet and to give not less than 8 feet across aqueducts, mitre sills, culverts and other permanent structures, and for lengthening and improving locks remaining to be lengthened. The estimates are considered large enough to cover the increased cost due to the eight-hour law and the increase in cost of labor and materials and for engineering and inspection.

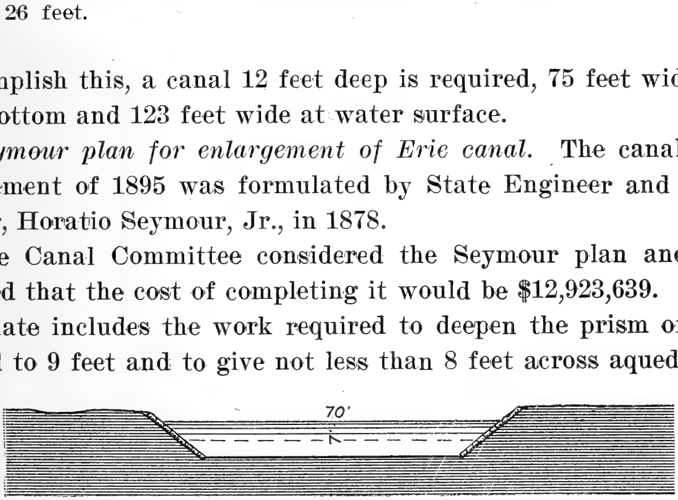

Fig. 65 Earth section of enlargement of Erie canal of 1862. Width of bottom of canal 52 feet.

The Seymour–Adams plan. In his report for 1896 State Engineer Adams proposed an extension or modification of the original project authorized for the Erie canal under the "$9,000,000 act." His proposition was to obtain a depth of 9 feet throughout the canal, over aqueducts, structures, etc., as well as in the canal reaches, and to lengthen the locks by changing the gates so as to allow their use by boats 115 feet long, of the present width, and drawing 8 feet of water. This follows the present route of the canal.

This would enable ordinary boats to carry 400 tons of freight, and a four-boat steam fleet would carry 1500 tons of freight, or about 50,000 bushels of wheat. So far as known no definite estimate was made by Mr Adams of the cost of the additional work proposed. The estimated cost, however, of this plan, as made by the Canal Committee, was $15,068,048. This includes new quadrant buffer steel gates, with the necessary masonry at each lengthened lock, and the unlengthened locks to be improved to correspond, and all structures to be given such depth as will admit their use by boats drawing 8 feet of water.

According to an estimate given in the Report of the Canal Committee the cost per ton for carrying freight on this canal from Buffalo to New York would be 50⅓ cents; the cost per bushel would be 1.51 cents, and the cost per ton mile would be 1 mill.

New Erie canal proposed by Canal Committee. In considering the enlargement of the Erie canal to 9 feet, the Canal Committee proposed that the principal features of the Erie canal should be as follows:

1) The prism of the canal to be left at its present width generally, but to be deepened to 9 feet throughout, at aqueducts and structures as well as in the canal levels, and to be put into condition for use by boats of the present width and drawing 8 feet.

2) Three important changes in the route of the canal to be adopted. The first and greatest change is to deflect the canal from a point just east of Clyde into the Seneca river, follow down the river to its junction with the Oneida river, thence follow up the Oneida river to Oneida lake, through Oneida lake, and thence by canal up the valley of Wood creek and to the present Erie canal near New London, making several river cut-offs to shorten distance and give better alignment.

The second change is to do away with the two aqueducts across the Mohawk river and the portion of the canal in Saratoga county. This is to be done by throwing the canal into the Mohawk at Rexford Flats, and following down the river to the vicinity of the great falls of the Mohawk at Cohoes.

The third change is at the West Troy side-cut where, instead of the awkward right angle turn requiring even small boats to uncouple, a diagonal deflection is made which will enable fleets to pass directly and conveniently into the Hudson without breaking up.

3) Pneumatic or other mechanical locks or appliances for the passage of boats to be provided at Cohoes and Lockport, and possibly at Newark. All other locks (one of each pair) to be lengthened and enlarged to take in two boats of 125 feet length, 8 feet draft, and of the present width. The locks to be provided with water-power generating apparatus wherever necessary, with steel quick-acting quadrant gates, equipped with spring buffers, or other gates equally good, with power capstans at each end of the lock for pulling the boats in and out, and generally with everything of the most modern and up-to-date character. The other small lock of each pair of locks to be lengthened to take in one boat 125 feet long.

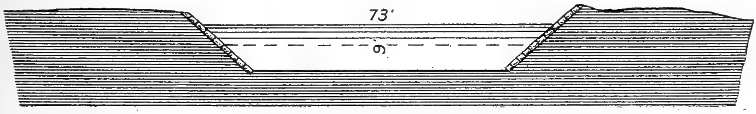

Fig. 66 Earth section of improvement of Erie canal suggested by Canal Committee. Width of bottom of canal 49 feet.

On a canal by this plan the cost per ton for carrying freight from Buffalo to New York would be 44 cents; the cost per bushel, 1.32 cents, and the cost per ton mile, 0.88 mill.

The enlarged canal. After giving due consideration to the various features of the problem, the Canal Committee decided that if the canal were to be materially enlarged its new dimensions should be such as would fit it for use by barges of 150 feet length, 25 feet width, and 10 feet draft of water, with all locks arranged to take in two boats coupled together tandem.

The route deemed most desirable for such a canal from Lake Erie to the Hudson river is to follow the present line of the Erie canal with minor diversions from Buffalo to just east of Clyde, then to deflect into the Seneca river, and follow down this river and up Oneida river through Oneida lake, and by the valley of Wood creek to the line of the Erie canal near New London. The two aqueducts across the Mohawk would also be done away with and the canal thrown into the river, and at West Troy side-cut the location would be changed to better the debouchment into the Hudson. This canal would require the rebuilding of all the locks on the portion of the Erie canal retained, substituting at Cohoes, Lockport and possibly at Newark, pneumatic or other mechanical locks for those now existing, building new locks on the Seneca-Oneida and lower Mohawk portions of the route, and deepening and widening the prism of the canal to give a waterway of not less than 1000 square feet cross-section.

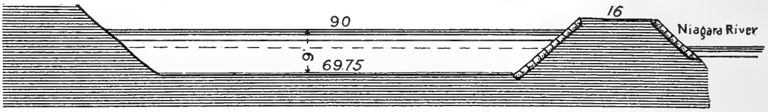

Fig. 67 Earth section of Erie canal from Black Rock to Tonawanda.

By such a canal the cost per ton of carrying freight from Buffalo to New York would be 26 cents; the cost per bushel, 0.8 cent, and the cost per ton mile, 0.52 mill.

The number of trips which can be made annually is estimated at nine for the Seymour-Adams plan, and at ten for the new Erie canal as well as for the enlarged canal.

The Canal Committee also reported that the work on the Oswego canal at Phœnix and Oswego, undertaken in 1896, should be completed. The cost of completing the Oswego canal was estimated at $818,000.

The Canal Committee recommended that the Champlain canal should be improved to the full extent authorized by chapter 79 of the laws of 1895, at an estimated expense of $1,824,000.

The estimated cost of enlarging the Erie canal to a barge canal was $58,895,000, or making a total for the Erie, Oswego and Champlain canals of $61,537,000.

Study of continuously descending canal from Lake Erie to the Hudson river. Ever since the publication of the paper by the late Elnathan Sweet in 1884 in regard to a radical enlargement of the artificial waterway between the lakes and the Hudson river, the opinion has extensively prevailed that it was preferable to relocate the Erie canal in such manner as to eliminate the depression between Newark and Syracuse, thus making a canal with a continuous fall all the way from Lake Erie to the Hudson.

In his report for 1883 State Engineer and Surveyor Silas Seymour remarks that an examination of the Erie canal profile will show that by raising Montezuma level 36.4 feet and the intervening portions of the canal to the same elevation, Rome level would be extended to a corresponding level west of the valley of the Seneca river, and the lockage discharges of the entire Erie canal would all be to the eastward, thus making Lake Erie the principal source of water supply for the whole canal. He concludes his discussion by suggesting that if a ship canal should ever be seriously contemplated, the practicability of this improvement should be carefully considered.[1]

So far as known, the foregoing is the first reference in canal literature of this State to a continuously descending high level canal from Newark to the west end of Rome level.

In the early days of inland navigation in the State of New York effort was entirely directed towards the improvement of the natural watercourses, artificial channels being only considered when necessary to connect such.[2] There were no engineers in the State at that time, and the difficulties of meeting flood conditions seemed to our ancestors insuperable. The result was that when the Erie canal was finally projected from about 1808 to 1817, as a waterway independent of the streams, it was made an artificial channel, although for the greater portion of its distance it paralleled waterways which could easily have been canalized, producing much greater depth of water than was contemplated in the canal. There is little doubt but that the mistake of making the artificial channel has retarded the development of New York State in many ways; and it is accordingly in-

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[1] Report State Engineer and Surveyor for 1883, p. 16-17.

[2] Refer to description of works of Western Inland Lock Navigation Company on page 724.

teresting to note that the recent projects have returned to the canalization of streams.

Among the changes proposed by Mr Sweet, in his paper in 1884, were the following:

> One essential change in profile consists in extending the Rome level westward to lock 57, between Newark and Lyons, in Wayne county, throwing out the locks 47 to 56, inclusive. This change in profile can be effected by swinging the route to the southward, near Newark, crossing the Canandaigua outlet and occupying ground of the proper elevation along the south side of the Clyde river, and crossing the Seneca river at the narrowest part of its valley, which is near its junction with the outlet of Cayuga lake, from whence it should gradually approach the present route of the canal and connect with or cross it just east of the city of Syracuse.

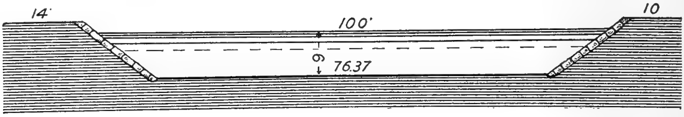

Fig. 68 Cross-section of Erie canal below Lockport.

Mr Sweet states that the only serious difficulty encountered on this route is the crossing of the Seneca river, where the water surface of the canal must be nearly 50 feet above that of the river, and for nearly two miles over 40 feet above the surface upon which its embankment must be built.

This change of route, to secure a continuously descending profile from the lake to the Hudson river, is the only deviation from the route of the old canal that is absolutely necessary, but it is believed that the construction would be simplified and cheapened, and the best possible waterway secured by the adoption of an entirely new route from Syracuse eastward.

Lower ground can be obtained for the Rome level, except at the summit itself, by moving the line northward; thus by lowering the elevation of this level throughout, lessening the difficulties of the Seneca river crossing, and from a point a little west of Utica eastward to the Hudson, the Mohawk river should be canalized by the erection of locks and movable dams at suitable points in its course, and the deepening and rectification of its channel.

From the mouth of the Mohawk, at Troy, to the deep water of the Hudson river, below Coxsackie, the latter river must be improved by narrowing and deepening its channel, or a canal must be constructed along its shore. The former method of construction affords the simplest and most useful means of securing the desired result.

The plan may therefore be summarized as the widening, deepening and necessary rectification of the worst curvatures of the present canal, from Buffalo to Newark (about 130 miles); the construction of a new canal from Newark to Utica (about 115 miles); the canalization of the Mohawk river from Utica to Troy (about 100 miles), and the improvement of the Hudson river from Troy to Four Mile Point, in Coxsackie (a distance of about 30 miles).

The elevation of the western level of the canal being governed by the surface of Lake Erie, it must secure the required depth wholly by deepening, while the profiles of the levels from Lockport east can be adjusted to meet the economical requirements that will be disclosed by detailed surveys.

The first level from Buffalo to Lockport will be 32 miles long. Descending from this level at Lockport, by two locks, each of about 25 feet lift, the second level of the canal will be reached. This level, 64 miles in length, will extend to Brighton, where, descending by two locks of about 24 feet lift, we reach the third level of the canal, extending from Brighton to Macedon, 20 miles, there descending by a lock of about 20 feet lift we reach the fourth level, extending from Macedon to Newark, 12 miles; where, by a lock of about 20 feet lift, is reached the level of the proposed new canal, to extend from Newark to Utica, about 115 miles, which will be the fifth and longest level of the new canal. From that point the Mohawk river (except at Little Falls and Cohoes, where combined locks will be required) can best be canalized through locks of 10 or 12 feet lift, making pools having an average length of about 5 miles each.

The change in profile between Newark and the west end of the Rome level, in the eastern suburbs of Syracuse, was considered a very important one by the Canal Committee, and they accordingly early arranged to have this matter thoroughly examined. The writer examined the several routes in detail.

The following are the elevations and distances on the levels from Rome level westward to the upper level at Newark:

Designation of level	Length of level, miles	Elevation above tide water, feet
Rome level	......	429.7
Short level, from lock 47 to lock 48	0.19	419.5
Level, lock 48 to lock 49	0.71	409.0
Syracuse level, lock 49 to lock 50	5.01	402.0
Jordan level, lock 50 to lock 51	14.90	409.9
Port Byron level, lock 51 to lock 52	7.79	404.3
Montezuma level, lock 52 to lock 53	17.69	392.9
Level, lock 53 to lock 54	3.15	397.6
Level, lock 54 to lock 55	3.35	405.0
Level, lock 55 to lock 56	1.71	411.2
Level, lock 56 to lock 57	3.22	421.1
Level, lock 57 to lock 58	0.18	429.1
Level, lock 58 to lock 59	0.16	437.1
Total distance	58.06	
Level above lock 59 (Newark-Palmyra level)		445.6*

The southern route. In view of the persistency with which the proposed high level continuously descending rectification from Newark to the west end of the Rome level has gotten into the Erie canal improvement literature, it seems proper, by way of clarifying the matter, to discuss it at length, even though the studies made in 1899 have shown that this proposed high-level rectification is not applicable to present conditions.

The objections to the southern route are three in number: (1) Seneca river crossing; (2) right of way in Syracuse; and (3) difficult construction of canal on sand and gravel areas. The Seneca river crossing would be about 1.9 miles in length, with the

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*The foregoing elevations refer to mean tide at New York and differ somewhat from the Erie canal datum which is mean tide at Albany. The difference is about 1.3 feet.

water level 48 feet above the level of Montezuma marsh. Hard bottom is found at a depth of 20 to 60 feet below the marsh level—probably 30 feet is a fair average for the whole distance across. For the first twenty feet in depth the marsh is in many places composed of nearly pure marl, below which is found either firm soil, gravel or hardpan. No rock indications have ever been determined in this portion of Montezuma marsh.

The next objectionable feature of the southern high-level route is found in the city of Syracuse, where the effect of changing the present location would be merely to take the canal out of the business part of the town, where dockage and business arrangements are now established, placing it instead in a residence district, where new arrangements for transacting canal business would have to be made. Aside from an expensive right of way, this change would be exceedingly undesirable.

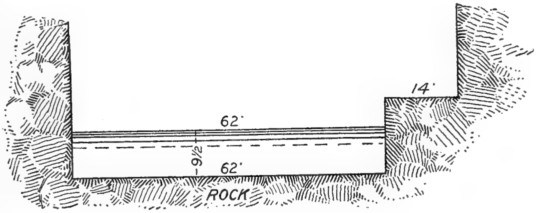

Fig. 69 Cross-section of Erie canal, 2½ miles above Lockport.

As to the third difficulty, the region through which the southern line would be laid is largely sand and gravel, requiring expensive puddling in order to insure water-tightness. The location is largely on a side hill, where the conditions for water-tight work are unfavorable. The estimated cost of right of way on this route was $4,666,000 and the total cost $29,000,000, or for 57.8 miles, the average cost per mile was $501,730.

The northern route. The southern high-level route having turned out to be so expensive, a route on the north side of the Seneca river was then examined between Newark and the west end of the Rome level. The chief difficulties of this route are: (1) Seneca river crossing, and (2) difficult construction on account of lack of water on surface, as well as extensive sand and gravel areas.

As to the crossing of the Seneca river, while the river is only about 400 feet in width, the depth is 30 feet with soft bottom. A few hundred feet north soundings indicate a depth of water of 46 feet. Probably foundations of the aqueduct would have to be carried considerably deeper than this.

The most serious objection to the northern high-level route was found in the considerable areas of sand and gravel which, on the north side of the Seneca river, are even more extensive than on the south side. For the whole distance there is very little water upon the surface, and during the fall of 1899 the farmers of the region were hauling water for domestic use several miles. Not only this region, but that along the proposed southern route, is entirely destitute of stone—for miles only an occasional bowlder is seen.

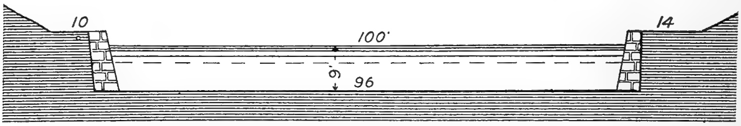

Fig. 70 Earth section of Erie canal from Pendleton to 2½ miles above Lockport.

The length of the canal by this route is the same as by the southern route. The estimated cost was $22,400,000, which for a total length of 57.8 miles is $387,540 per mile.

Extension of Syracuse level. It has also been proposed that a rectification could be made more cheaply and safely by extending the Syracuse level westward near the present canal location and eastward through the flat country south of Oneida lake, cutting down the Rome summit to correspond. In order to understand this possible change, it may be mentioned that the Syracuse level locks up at both ends. To the east it rises by three locks to the Rome level, and to the west by one lock to the Jordan level. The elevation of the Syracuse level is 402 + T. W.; of the Rome level, 430 + T. W., and of the Jordan level, 410 + T. W. There are also long stretches of marl near Jordan. This rectification was examined into with the result that it is shown to present great difficulties. The estimated cost for 113 miles amounts to $32,500,000.

The Seneca-Oneida route. The southern and northern routes from Newark to the west line of Syracuse having turned out so unsatisfactory, the writer then proposed to the Canal Committee to entirely modify their plan. Instead of building the continuously descending canal, it was suggested that a canal dropping down to the level of the Seneca river be constructed, thence through that river to Three Rivers Point, thence through the Oneida river to and through Oneida lake, with an artificial channel from Oneida lake, finally joining the Rome level of the Erie canal at a point about halfway between Stacey Basin and New London, a few miles west of Rome.

One main object of the proposed high level continuously descending canal is to deliver Lake Erie water to the Rome level and thence into the Mohawk river, thereby obviating difficulties of water supplies from reservoirs along the line of the canal. Another point to be gained by the high-level route was to eliminate lockages, thereby saving time. If, however, as much time can be gained by a broad, deep river and lake navigation as by eliminating lockages, then lockage objection is not very important. Taking everything into account, the writer reported to the Canal Committee that under the existing conditions a route by Seneca-Oneida rivers would, due to breadth and depth of channel, permit of navigation in less time than by a proposed high-level canal. The argument is therefore in favor of the Seneca-Oneida route, specially since it can be built at much less cost.

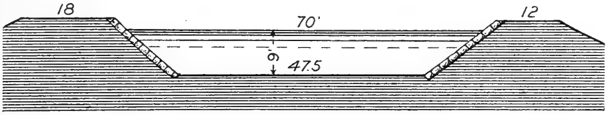

Fig. 71 Earth section of Erie canal east of Rochester.

It seems to the writer an extraordinary fact that the possibilities of the Seneca-Oneida route, extending as it does for over ninety miles through the center of the State, have not long since been thoroughly exploited. Considering the relatively small cost of making effective navigation on this line, and looking at the question from the point of view of today, one would suppose that this route would have long ago received careful attention. Probably there are two reasons for this neglect:

1) The early reclamation projects, through which it was expected to reclaim Seneca river marshes.

2) Difficulty of constructing a towpath along a marshy river.

The estimated cost of the Seneca-Oneida route was $6,000,000, which, for a total length, by way of certain cutoffs on Oneida river which reduce the length somewhat, of 81.6 miles, gives an average cost per mile of, roundly, $73,530.

The following correspondence explains in detail why this change was made. In his letter of August 3, 1899, to the writer, Gen. F. V. Greene says:

GEORGE W. RAFTER, Esq., *Rochester, N. Y.:*

Dear Sir.—In accordance with a resolution of this committee authorizing the chairman to employ an engineer for the purpose of giving technical advice upon certain points connected with our investigation and report on the canal question, I desire to obtain your services to such an extent as may be necessary during the next four months for the purpose of reporting to us on the following questions:

First. What will be the approximate cost of constructing a new canal from the vicinity of Newark to the Rome level, joining the latter at a point just east of the city of Syracuse, the said canal to have a continuous descent to the eastward and to have a prism sufficient to carry a boat 25 feet in width and 10 feet draft, with a waterway not less than four times the immersed section of the boat?

* * * * * * * *

Very respectfully, for the Committee,
(Signed) F. V. GREENE,
Chairman.

The foregoing instructions apparently limit the investigation to a canal continuously descending, but after making an examination the writer, under date of September 16, 1899, wrote to John A. Fairley, Secretary of the Commission, as follows:

MR JOHN A. FAIRLEY, *Secretary, New York, N. Y.:*

Dear Sir.—

* * * * * * * *

In regard to the proposed rectification between Newark and Syracuse, two lines have been examined—one to south of present canal and one to north. The line to north appears to be the better, although both are very expensive and violate the modern view that canals should be located in the thread of valleys rather than along side hills and on high ground. One result of my study of this matter so far as it has proceeded is to indicate another solution, which, however, is apparently barred out by the committee's instructions to investigate a canal with a continuous descent from Newark to west end of Rome level.

The solution referred to will take about the following form: Leave the present canal where it crosses under the New York Central and Hudson River railway a few miles east of Clyde and continue to Seneca river just north of where New York Central railway crosses that stream. Thence along Seneca and Oneida rivers and through Oneida lake, building a new stretch of canal from east end of Oneida lake to Rome. This does not avoid the lockage but gives the advantage of a broad, deep navigation for about sixty-five to seventy miles. My studies on deep waterways project indicate that an ample water supply for the Rome summit can be obtained from the two Fish creeks and Salmon river.

As regards carrying a water supply from Lake Erie east of Seneca river, I may state that the high level, with continuous descent from Newark to Rome level, will necessarily be laid on open porous soils from which the percolation losses will be large; and while I am not prepared to give a final opinion at this time, the indications are that Seneca river is about the eastern limit of effective feeding from Lake Erie. If this view is right, then the alternative line for an enlarged canal via Seneca and Oneida rivers and Oneida lake is the only solution. In making this latter statement I take into account that there are extensive marl deposits along line of present canal between Ninemile creek and Seneca river, which make a radical enlargement along the present canal a very serious proposition. I mention these various points in order that you may appreciate the broad scope of the study on which I am engaged.

In view of the possible outcome of the study of a continuously descending high-level canal from Newark to Rome level, I would be glad to know whether the committee's instructions were intended to exclude study of such an alternative line as I have here outlined. If so, then I will not devote any time to it. Otherwise, I should feel impelled to give it attention. There are one or two other alternative propositions which should be looked into, but explanations of which I can not well go into in a letter for lack of space.

In regard to lines other than a continuously descending high-level canal from Newark to Rome level, I may point out that the advantages to be gained are not necessarily to eliminate lockages *per se,* but to gain time. If, then, the time can be gained and lockages retained, there could apparently be no objection to the Seneca-Oneida-rivers-Oneida-lake-line, where by reason of broad, deep channel greater speed can be obtained. Especially would this be true if the river line can be built at less cost.

* * * * * * * *

Very truly yours,
(Signed) Geo. W. Rafter.

In the meantime the proposed change of plan was suggested in a conversation with Major Symons on September 18, 1899. September 22 General Greene answered the letter of September 16, in the following terms:

George W. Rafter, Esq., *Consulting Engineer, Rochester, N. Y.:*

Dear Sir.—Yours of September 16 arrived a few days since, but owing to my absence in Philadelphia I have not until now had an opportunity to answer it. I am also in receipt of a letter from Major Symons telling me of his conversation with you, and that he said the committee would undoubtedly like to have you make the study of the northern route through the Oneida river and lake, and I write to confirm Major Symons' statement.

* * * * * * * *

Yours very truly,
(Signed) F. V. Greene.

Conclusions of Canal Committee. The Canal Committee, as the result of its examination, states:

The committee is unanimously of the opinion that there are only three projects for consideration. The first of these is the completion of the project authorized by the law of 1895, with the following modifications:

The deepening of the prism to 9 feet throughout, and the lengthening of the locks on one tier, so as to pass two boats, each 125 feet in length, 17½ feet in width and 8 feet draft, with a cargo capacity of 450 tons; and the lengthening of the locks on the other tier so as to pass a single boat of the same size.

The use of pneumatic locks, or other mechanical lifts, at Cohoes, Lockport, and possibly Newark and Little Falls.

The construction of a new canal from near Clyde to near New London, about 81 miles in length, giving a wide waterway through the Seneca and Oneida rivers and Oneida lake, and avoiding Montezuma marshes.

The abolition of the two aqueducts across the Mohawk river, and the substitution of the river for the canal from Rexford Flats to Cohoes.

The construction of a new canal from the foot of the falls of the Mohawk, near Cohoes, to the Hudson river, near the West Troy side-cut.

The second project is for a canal to accommodate boats of the same dimensions as above given, but which shall follow the route of the present Erie canal, except from Albany to lock 18, in place of which the diversion by a mechanical lift over the Cohoes falls and a canal from the foot of the falls to the Hudson river at West Troy side-cut shall be substituted.

The third project is for a canal following the same route as the first project, but of sufficient size to carry boats 150 feet in length, 25 feet in width and 10 feet draft, with a cargo capacity of approximately 1000 tons each, with locks capable of passing two boats at one time.

The estimated cost of the barge canal, including the improving of Oswego and Champlain canals, was, in round figures, $62,000,000. In regard to this estimate of the Canal Committee, it may be stated that they made no surveys, although the writer in estimating upon the southern and northern routes between Newark and just east of Syracuse, as well as on the estimate for the Syracuse level extended, and on the Seneca-Oneida route, availed himself of the field sheets of the United States Geological Survey at a scale of $\frac{1}{45,000}$. With these sheets in hand the several routes were traversed, a distance of about 320 miles in all. Subsequently, profiles were platted from the locations decided upon in this way, quantities taken out and an estimate made. These estimates, therefore, may be considered as in the nature of preliminary—they could hardly be classified as final estimates. On other portions of the canal the maps prepared in connection with the improvement of 1895 were used.

Attention may be called to the maps which were prepared of these surveys in 1899. They present the topography for a considerable distance each side of the proposed lines and enable anybody with the requisite training to determine whether or not the best lines have been selected. They accompany the Report of the State Engineer for 1900.

The Barge canal survey. The report of the Canal Committee was presented to Governor Roosevelt under date of January 15, 1900, and chapter 411 of the laws of 1900 directed the State Engineer and Surveyor to cause surveys, plans and estimates to be made for improving the Erie canal, the Champlain canal and the Oswego canal, appropriating $200,000 therefor. The route to be surveyed is defined in this act, and follows the recommendations of the Canal Committee already given. It is also provided in section 3 of this act that the surveys, plans and estimates for the construction and improvement of the Erie canal shall be of such dimensions as will allow said canal to carry and lock through boats 150 feet in length, 25 feet in width and of 10 feet draft, with a cargo capacity of 1000 tons each. The prism of Erie canal was to have a depth of water of not less than 12 feet, with 11 feet in the locks and over structures. The locks were to be 310 feet long and 28 feet wide and 11 feet deep. The State Engineer was required by the act to complete the survey and hand his report to the Governor on or before January 1, 1901. The Governor was to submit the same, with his own recommendations relating thereto, to the Legislature on or before January 15, 1901. Chapter 411, became a law April 12, 1900.

This act required the completion of the survey in about eight months, and while there was a large amount of data available, which had been gathered two years previously by the Board of Engineers on Deep Waterways, nevertheless it is difficult to suppose that very complete surveys could have been made in so short a time as this. The State Engineer conducted the survey ably, and it is intended to merely point out that from limitation of time alone the survey was necessarily somewhat approximative.

The estimates are, generally speaking, as reliable as could be expected for the amount of time put upon them. The total cost of the improvement on the present line of the Erie canal throughout the whole extent, and including the Oswego and Champlain canals, is estimated at about $87,000,000, while the total cost on the most desirable route, via Mohawk and Seneca rivers, is about $77,000,000. There are certain additions to this which will increase it to about $82,000,000. This estimate provides for a canal 12 feet deep via the Mohawk and Seneca rivers, as well as by the interior route, through Syracuse, Clyde, Lyons, Newark, Palmyra, Rochester and Lockport to Buffalo.

During the legislative session of 1903, some question having arisen as to the adequacy of the estimates made, they were again gone over and finally revised. In a communication to the Legislature under date of March 2, 1903, the State Engineer says:

> I have no hesitation, therefore, in asserting that the estimates of cost given in the barge canal report were as complete and accurate as any estimates ever prepared within the time allotted for a work of such magnitude, and that they were reliable estimates of the cost at that time for the improvement covered by the report, with the one possible exception of the allowance for unforeseen contingencies and expenses.
>
> It is an undisputed fact that during the past few years the prosperity of our country has resulted in an increase in the construction of public works of all descriptions, and in the development of native resources by private capital, creating such a demand for labor and materials that both have advanced in price within the past two years; furthermore, the fact of the State enlisting in an enterprise of this magnitude would have a tendency to increase the price of labor and materials entering into its construction.

The State Engineer then answers several questions in detail, finally ending with the conclusion that in 1903 the barge canal would cost roundly $101,000,000. He states that water supply is based on a business of 10,000,000 tons of freight per canal season, and that if the business of the enlarged canals should increase to double this quantity, or to 20,000,000 tons per canal season, there should be added to the estimate $1,330,000.

The original water supply included a feeder from Fish creek to near Fort Bull, together with the construction of the Salmon river reservoir, already described. The water from this reservoir may be turned into Mad river, a tributary of Fish creek, without serious expense. On this plan the total cost of the water supply for a traffic of 10,000,000 tons per year would not exceed $3,000,000. Aside from the supply to the present Erie canal from Butternut, Limestone, Chittenango, Cowaselon creeks, etc. the additional supply was to be obtained from a single large reservoir, advantage being taken of the fact that a large reservoir can be constructed for less cost per unit of volume than a number of small reservoirs. In the barge canal report it was assumed that it was important to construct a number of small reservoirs along the line of the canal with the result that the cost of a water supply for the canal route, with traffic of 10,000,000 tons per year, is estimated at $5,555,000. For the river route, with traffic of 10,000,000 tons per year, the estimated cost is $4,469,000.

Origin of barge canal. The question has arisen in the State of New York as to who originated the barge canal idea. The following statement is given as bearing on this point:

We have already seen that Silas Seymour, in his report for 1883, referred to a continuously descending high-level canal from Newark to the west end of the Rome level.[1]

The next detailed reference appears in the report of Martin Schenck, State Engineer and Surveyor, for the year 1893. Mr Schenck says:

> In my report of last year I briefly outlined a proposed enlarged canal capable of bearing barges 250 feet in length by 25 feet breadth of beam, with 10 feet draft of water and of the lowest possible hight above water so that the greater part of the bridges crossing it could be fixed structures instead of movable ones.
>
> This canal would have a general width of 100 feet at the water line, a depth of 12 feet (except at such points as over aqueducts or other expensive structures where economy would suggest the reduction of a foot in depth) and have vertical or battered side walls except in localities of existing wide waters where economy of width would be a minor consideration. The general width proposed might be materially reduced for short distances through the cities and towns along its route, over aqueducts, through expensive rock cuts, etc., and since no towing-path would be required, there are many miles of cuttings where the removal of that alone would give nearly the entire width required. The route proposed for this canal would generally follow the present alignment of Erie canal except for short distances, where it would be wise to make detours in order to obtain economy of construction and better alignment. The vessels designed for use might be built, for convenience in handling, in two sections and be towed in fleets by means of similar boats fitted with twin screws and

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[1] Refer to page 801.

propelled by steam or electric power. Vessels of such size as those described could navigate the proposed canal with the greatest degree of economy, would have a carrying capacity of at least 50,000 bushels, and could carry wheat at a profit from Buffalo to New York for two cents per bushel. When grain can be carried through our canals at a profit from Lake Erie to the metropolis at the foregoing rate, all questions relative to the commercial supremacy of the Empire State will be set at rest. Without a careful survey it is impossible to determine the exact route of the proposed canal, but it may be approximately stated to be as follows: Beginning at the port of Buffalo, the alignment would follow very closely the present line of the canal, the depth to be secured to Lockport by excavating from the bottom of the canal. Through the deep rock cut near Lockport the only widening required for the present would be that obtained by cutting out the present towing-path. At Lockport a pair of hydraulic lifts or two pairs of high-lift locks would be substituted for the five combined locks now there. From Lockport eastward to Rochester the present alignment would be quite closely followed except that considerable detours would probably be made to avoid those rather bold but unnecessary bits of engineering known as the high banks at several points west of this last-named place and that east of it at Irondequoit. Continuing eastward from Rochester, making a slight change of alignment near Newark, substituting two locks for the three now there, no special engineering difficulties would be encountered until the Montezuma aqueduct over the Seneca river is reached, where one of two plans must be adopted, viz, either to construct at a very large expense an enlarged aqueduct or drop down by means of a single lock to the level of the Seneca river, crossing at the river level and locking up to the proper elevation on the opposite side, meanwhile retaining the present aqueduct as a feeder to carry water to the remainder of the level eastward.

As the present aqueduct was constructed over a bed of peat upon sunken cribs of only sufficient bearing capacity to sustain with safety its present weight, it is exceedingly doubtful if any great increase of weight such as would be necessary in making the required enlargement could be had without endangering the stability of the whole structure. The waste of water caused by locking boats down to the river level and up again while considerable, would not be a serious matter since this is the last level fed from the westward. The cost of the two locks required would be a trifle compared to that of a new aqueduct, but it goes without saying that the building of a new aqueduct is by far the better plan and the one that would eventually be adopted.

From Port Byron to Jordan the present line of the canal would be followed quite closely, but it is probable that it would be better to make a detour at the Jordan level so as to drop it down to the elevation of that at Port Byron. The rather limited water supply on the Jordan level makes it extremely desirable that the proposed change be made so that the reliable water supply of the western slopes of the Adirondacks can pass unimpeded to meet the waters of Lake Erie on the Montezuma level. From Syracuse eastward to Rotterdam the present alignment would be quite closely adhered to, with the probable substitution of a hydraulic lift or one lock for the three upper locks at Little Falls. From Rotterdam eastward we have presented to us the choice of two routes, the one following the present line of canal, the other crossing the Mohawk on a new aqueduct to be built at that place and making a short cut across country, striking the present canal line at the eastern terminus of the upper Mohawk aqueduct.

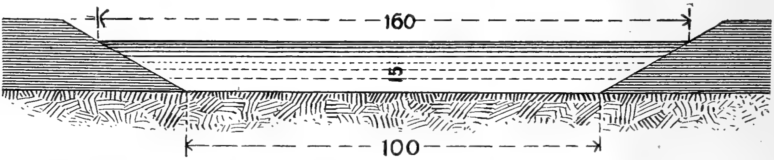

Fig. 72 Earth section of Welland and Soulanges canals.

This report was followed by that of Major Symons, dated June 23, 1897, who proposed a boat of a capacity of 1500 tons burden, the same as proposed by Mr Schenck. Neither made any estimate, although Mr Schenck considered that his canal could be built for $25,000,000, while Major Symons considered that $50,000,000 would be sufficient. The Committee on Canals considered that $63,000,000 was sufficient to build the canal; the barge canal survey of 1900 placed the cost at from $77,000,000 to $87,000,000, depending upon the route, while in 1903 the State Engineer placed it at $101,000,000.

Increase in size of boat in comparison with cross-section of canal. In order to show the progressive changes which have taken place in our ideas of canals, the cross-section of the original Erie canal and of the various enlargements, together with the cross-section of the recent proposed canals, will be cited in comparison with the size of boat for navigating each section.

The original Erie canal, completed in 1825, carried 4 feet in depth of water and was 26 feet wide on the bottom and 40 feet at the surface. The sectional area was 132 square feet. The boats navigating the original Erie canal were 61 feet long, 7 feet wide by 3½ feet draft, and with a capacity of 30 tons. An enlargement of the Erie canal was authorized in 1835, which, however, was not fully completed until 1862. The size of boats in the meantime had increased during this enlargement to 75 and 100 tons.

The enlargement completed in 1862 made the canal 7 feet deep, 52 feet wide on the bottom, 70 feet water surface, and gave a sectional area of 427 square feet. After the completion of this enlargement the boats were 98 feet long, 17½ feet wide and with 6 feet draft. Their capacity was 240 tons, which size boat is still used on the Erie canal.

The improvement suggested by State Engineer Adams and seconded by the Canal Committee is 9 feet deep, 49 feet wide on the bottom, with 73 feet width of water surface. The sectional area is 549 square feet. For this improvement, the boats would be 125 feet long, 17½ feet wide, with 8 feet draft. Their capacity would be 450 tons.

The barge canal recommended by the Canal Committee has 12 feet in depth of water, is 75 feet wide on the bottom and 122 feet water surface. The sectional area is 1182 square feet. For the barge canal recommended by the Canal Committee boats are proposed 150 feet long, 25 feet wide and 10 feet draft. Their capacity is to be 1000 tons.

The canal suggested by Mr Schenck in his report as State Engineer for 1893 was to have 12 feet in depth of water, carrying a boat 25 feet wide and 250 feet long, with capacity of 1500 tons. Major Symons proposed a canal carrying boats with width of 30 feet, length of about 190 feet and a draft of 10 feet, the capacity to be 1500 tons. Major Symons also proposed a ship canal from Lake Erie to the Hudson on the line of the present Erie canal, 24 feet in depth, bottom width of 138 feet and water surface of 210 feet. The sectional area of such a canal would be 4176 square feet. The boat was to be 50 feet in width and with draft of 20 feet. As we have seen, the Committee on Canals adopted a boat 25 feet wide, 150 feet long and drawing 10 feet of water.

The 21-foot channel proposed by the Board of Engineers on Deep Waterways would have a bottom width of 215 feet and a sectional area of 5497 square feet. The section proposed for a 30-foot canal would have a bottom width of 203 feet and a sectional area of 7990 square feet. The foregoing widths are for channels in earth cutting—in rock sections, widths are somewhat different. The Board of Engineers proposed for a 21-foot canal a boat 52 feet wide, 480 feet long, with 19 feet draft and a net carrying capacity of 8600 tons.

We see, therefore, that from 1825 to 1904—seventy-nine years—the capacity of boats has increased from 30 tons to a proposed capacity of over 8000 tons. This fact is cited as showing that inasmuch as there is actually still in use a boat carrying 240 tons, canal development is not yet commensurate with the developments of commerce.

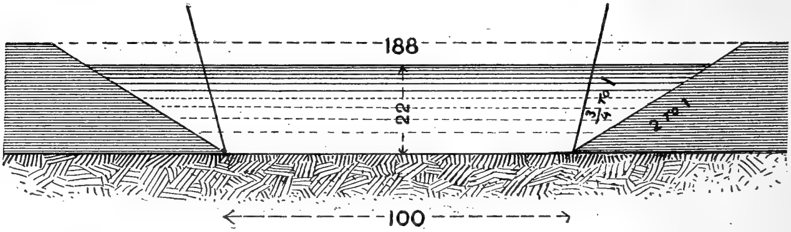

Fig. 73 Earth section of Montreal, Ottawa and Georgian Bay canal.

Chapter 147 of the laws of 1903. Chapter 147 of the laws of 1903, an act making provision for issuing bonds to the amount of $101,000,000 for the improvement of Erie canal, Oswego canal and Champlain canal, and providing for submitting the same to the approval of the people, became a law April 7, 1903, with the approval of the Governor. This act was voted upon at the general election held November 3, 1903, and was approved by a majority of over 245,000. New York county gave 253,000 for and 29,000 against; Kings county gave 62,000 for and 21,000 against; Erie county, 39,000 for and 8000 against. The balance of the State, with few exceptions, was against. It appears, therefore, that the support which this project received was from the two terminals of the canal.

This act provides that the route of the Erie, Oswego and Champlain canals, as improved, shall be as follows:

Beginning at Congress street, Troy, and passing up the Hudson river to Waterford; thence to the westward through the branch north of Peoble's island and by a new canal and locks reach the Mohawk river above Cohoes falls; thence in the Mohawk river canalized to Little Falls; thence generally by the existing line of the Erie canal to Herkimer; thence in the valley of Mohawk river, following the thread of the stream as much as practicable to a point about six miles east of Rome; thence over to and down the valley of Wood creek to Oneida lake; thence through Oneida lake to Oneida river; thence down Oneida river, cutting out the bends thereof, where desirable, to Three Rivers Point; thence up to Seneca river, to the outlet of Onondaga lake; thence still up Seneca river to and through the State ditch at Jack's Reefs; thence westerly generally following said river to the mouth of Crusoe creek; thence substantially paralleling the New York Central railroad and to the north of it to a junction with the present Erie canal about 1.8 miles east of Clyde; thence following substantially the present route of the canal with necessary changes near Lyons and Newark to Fairport; thence curving to the south and west on a new location, joining the present canal about one-half mile west of the crossing of Irondequoit; thence following the old canal to a point about one and one-fourth miles west of Pittsford; thence following the existing line of the canal for nearly a mile; thence running across the country south of Rochester to the Genesee river near South park, here crossing the river in a pool formed by a dam; thence running to the west of the outskirts of Rochester and joining the present canal about one mile east of South Greece; thence following substantially the route of the present Erie canal, with the necessary change in

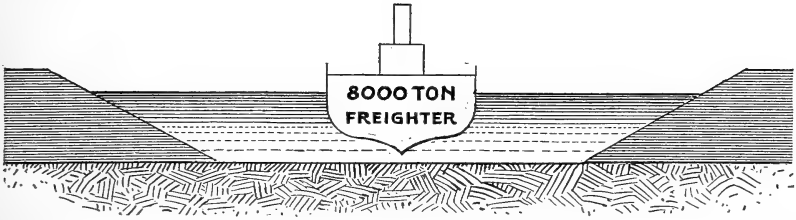

Fig. 74 Earth section of 22-foot canal carrying vessel of 8,000 tons capacity.

alignment near Medina to a junction with Niagara river at Tonawanda; thence by Niagara river and Black Rock harbor to Buffalo and Lake Erie. The existing Erie canal from Tonawanda creek to Main street, Buffalo, shall be retained for feeder and harbor purposes. The route of the Oswego canal as improved shall be as follows: Beginning at the junction of the Oswego, Seneca and Oneida rivers, it shall run northward to a junction with Lake Ontario at Oswego, following Oswego river, canalized, and present Oswego canal. The route of the Champlain canal as improved shall be as follows: Beginning in the Hudson river at Waterford; thence up Hudson river canalized to near Fort Edward; thence via the present route of Champlain canal to Lake Champlain near Whitehall.

This act also provides for the appointment of an advisory board of five engineers, whose duties shall be to advise the State Engineer and Superintendent of Public Works, to follow the progress of the work, and from time to time to report to the Governor, State Engineer and Superintendent as they may require, or as the board may deem proper and advisable. A special deputy and special resident engineers are also provided for by the act. The following have been appointed members of the advisory board: Edward A. Bond, Thomas W. Symons, Elmer L. Corthell, Wm. A. Brackenridge and Alfred B. Frye.

Power canal along line of Erie canal. In a discussion before the American Society of Civil Engineers several years ago, Edward P. North of New York City proposed a power canal along the line of the Erie canal, and J. Y. McClintock of Rochester has also extensively advocated such a canal.

Mr McClintock proposes that deep waterways be constructed along this line of sufficient dimensions to carry water enough to develop 800,000 horsepower. This water would be taken from Niagara river and the power developed at Lockport, Gasport, Middleport, Medina, Albion, Holley, Brockport, Spencerport, Rochester, Pittsford, Macedon, Palmyra, Newark, Lyons and at points on the Seneca river, as well as at other points where intersecting streams furnish convenient points for developing power. There is no objection to such a project and possibly it may be ultimately carried out, although at present there is no probability because the streams of New York will furnish several hundred thousand horsepower at less cost per unit than can be furnished by this power canal.

Mr John Patten, in a paper read before the National Irrigation Congress held at Ogden, Utah, in 1902 proposed a canal along this line which very much exceeds in size that proposed by either Mr North or Mr McClintock. The name of the canal proposed by Mr Patten is to be "The Great Eastern Canal." The water supply will be taken from Niagara river at Tonawanda and conveyed through a canal to Rochester, where a dam 54 feet high across the Genesee river will continue it to the hills south of Rochester, effecting a natural embankment. The Great Eastern canal will continue in an easterly direction near the line of the Erie canal and the Seneca river to Syracuse, passing through the edge of Syracuse and continuing on to the Mohawk valley near Utica. After entering the Mohawk valley, the canal continues along the river as far as Schenectady, at which point there will be a dam across the Mohawk diverting the waters southeast along the slope of the Catskill mountains to the valleys of Esopus and Rondout creeks, where there is to be a large dam intercepting the flow of these creeks. This dam is high enough to flood the Wallkill valley, so that the course of the canal is up the Wallkill river into New Jersey, where it empties into Walnut valley and from thence into the Delaware as far as Easton, forming a natural waterway from Kingston to Easton over a hundred miles in length.

After damming the Delaware at Easton the course of the canal will continue up the Lehigh river, and southerly to within about five miles of Reading, where a dam across the Schuylkill river continues the water in the depression of the valley southerly. The canal is to be continued south from this point, embracing the Susquehanna, Potomac and James rivers. The plan calls for submerging Ellentown, Bethlehem and a few other towns, which Mr Patten states will make it a very expensive project.

There will be waterways from New York, Washington, Baltimore, Richmond, Philadelphia, Trenton and other cities extending to the canal. New York has exceptional advantages, inasmuch as fully 500 feet fall is obtained, with a natural outlet to the

Hudson. Power-houses along the banks of the Hudson will furnish New York, Brooklyn, Hoboken, Jersey City, Passaic, Paterson, Newark, Elizabethtown, the Oranges and other cities within a radius of fifty to one hundred miles with electricity, heat, power for manufacturing, etc.

The construction of the Great Eastern waterpower canal is estimated to develop 15,000,000 twenty-four-hour horsepower or 30,000,000 twelve-hour horsepower, the value of which, the author states, would be when fully utilized $750,000,000 per year. If only one-half the power is utilized, the saving to the country in one hundred years would amount, according to the author, to more than the value of all the property in the United States. The construction involves such items as embankments 1000 feet high and from ten to twenty miles in length. The estimated cost is not given, but can hardly be less than $15,000,000,000 or $20,000,000,000, or about as much as the present total value of property in the United States. The writer concludes, therefore, that this scheme, while involving magnificent possibilities, is not likely to be carried out at once.

PRIVATE COMPANIES ORGANIZED TO BUILD CANALS

In order to show how far the people of the State of New York became possessed with the idea that canal navigation was essential to their commercial prosperity, the following list of private companies which had been organized before 1860, for constructing canals and extending navigation in the State, is herewith included. The last of these was the Allegheny River Slack Water Navigation Company, organized in April, 1857, to improve Allegheny river below Olean.[1]

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[1] Gazetteer of the State of New York, by J. H. French.

LIST OF PRIVATE COMPANIES

Name of canal (1)	Date of organization (2)	Capital (3)	Connections (4)	Remarks (5)
Allegheny River Slackwater Navigation Co	April 7, 1857	$30,000	....	To improve Allegheny river below Olean
Auburn Canal and R. R. Co	April 24, 1832	150,000	Auburn and Erie canal	Nothing done
Auburn and Owasco Canal Co	April 28, 1828	100,000	Auburn and Owasco lake	Charter renewed in 1834. Not finished
Binghamton, Owego and Penn. Slackwater Nav. Co	April 9, 1855	100,000	....	Act amended in 1857
Black River Canal Co	March 28, 1828	400,000	Erie canal and Black river	Nothing done
Black River Navigation Co	April 5, 1810	10,000	Brownville and Lake Ontario	Not constructed
Cassadaga Navigation Co	April 16, 1827	20,000	....	To improve Cassadaga creek. Not completed
Catatunk Dock Navigation Co	March 3, 1815	70,000	....	To improve Catatunk creek from its mouth to northwest branch. Nothing done
Cayuga and Seneca Canal Co	April 20, 1815	....	Montezuma and Seneca lake	Rights purchased by State
Chenango Junction Canal Co	May 12, 1846	....	Binghamton to State line	Nothing done
Chittenango Canal Co	March 1, 1818	....	Chittenango village and Erie canal.	Assumed by State and used as navigable feeder to Erie canal
Delaware and Susquehanna Navigation Co	April 20, 1825	....	Delaware and Susquehanna river	Nothing done
Ellicotts Creek Slackwater Navigation Co	April 23, 1829	5,000	....	Nothing done
Gowanus Bay and East River	April 24, 1837	....	City of Brooklyn may cause to be constructed	Partially improved
Great Chazy Navigation Co	May 11, 1836	5,000	Lake and lower bridge at Champlain	
Granville Canal Co	April 18, 1825	....	Champlain canal and Bishops Corners	Nothing done
Harlem Canal Co	April 18, 1826	550,000	East river and Manhattanville	Partly done and abandoned
Harlem River Canal Co	April 16, 1828	500,000	Spuyten Duyvil creek and Harlem river	Surveyed but not constructed
Hudson River and Channel Co	April 4, 1806	3,500	For raft navigation on upper water	Nothing done
Jefferson County Canal Co	April 15, 1828	300,000	Carthage and Sacketts harbor	Nothing done
Junction Canal Co	April 21, 1828	100,000	From Erie canal near Champlain junction to Hudson river	Nothing done
Junction Canal Co	May 11, 1845	....	From Chemung canal at Elmira to State line to connect with North Branch canal	Completed in 1858
Long Island Canal Co	April 15, 1828	200,000	To connect bays on south side and cross Canoe Place to Peconic Bay	Nothing done but survey
Long Island Canal and Navigation Co	April 8, 1848	300,000	The same	Nothing done
Manlius Canal Co	April 15, 1828	50,000	Erie canal and Manlius Slackwater Navigation	State canal feeder
Mohawk and Hudson Lock Navigation Co	April 17, 1816	500,000	Cohoes Falls and Schenectady	Nothing done

LIST OF PRIVATE COMPANIES (*concluded*)

Name of canal	Date of organization	Capital	Connections	Remarks
(1)	(2)	(3)	(4)	(5)
Neversink Navigation Co	April 16, 1816	50,000	....	Project failed. State loaned credit for $10,000 and lost whole sum
New York and Sharon	April 19, 1823	....	Sharon, Conn., to tide water at any point on Hudson or in New York city	Surveyed nearly on present line of Harlem railroad
Niagara Canal Co	April 5, 1798	....	Lakes Erie and Ontario	Nothing done
Northern Inland Lock Navigation Co	March 30, 1792	....	Hudson river and Lake Champlain	Begun but not completed
Northern Slackwater and Railway Co	May 13, 1846	....	Port Kent and Saranac	Nothing done
Oneida Lake Canal Co	March 22, 1832	40,000	....	Finished in 1835. Purchased by State in 1841
Onondaga Canal Co	Nov. 25, 1824	....	Erie canal and Onondaga Hollow	Not constructed
Ontario Canal Co	March 31, 1821	100,000	Canandaigua lake and Erie canal	Nothing done
Orange and Sussex Canal Co	April 11, 1825	....	Columbia, on Delaware, through Orange county to the Hudson	Right granted in 1828 to build a railroad on the line. Nothing done on either
Oswegatchie Navigation Co	April 25, 1831	....	From St Lawrence to Black lake and Canton	Nothing done
Owasco and Erie Canal Co	May 1, 1829	150,000	Owasco lake and Erie canal	Nothing done
Peconia River Lock Navigation Co	April 8, 1808	....	To construct locks and dams in Peconic river	Nothing done
Rochester Canal and Railroad Co	March 26, 1831	30,000	Rochester and Lake Ontario	Railroad only constructed
St Lawrence Lock Co	April 1, 1808	....	For building locks at Isle au Rapid	Locks completed but too small for general use
Salmon River Harbor Canal Co	May 16, 1837	350,000	Lake Ontario and Port Ontario	Never completed
Scottsville Canal Co	April 30, 1829	15,000	Scottsville and Genesee river	
Seneca Lock Navigation Co	April 6, 1813	50,000	For improving navigation between Seneca and Cayuga lakes	Merged in Cayuga and Seneca canal
Seneca and Susquehanna Lock Navigation Co	March 31, 1815	300,000	From Seneca lake to Chemung river, near Elmira	Nothing done
Sodus Canal Co	March 19, 1829	200,000	From Seneca river or Canandaigua outlet to Great Sodus bay	Partly constructed but never used
Susquehanna and Chenango	May 20, 1836	....	From river to Chenango creek	
Wallabout Canal Co	April 9, 1828	20,000	Wallabout bay and Tillory street, Brooklyn	Not constructed
Wallabout Canal Co	April 18, 1838	25,000	Wallabout bay to Kent avenue, Brooklyn	
Western Inland Lock Navigation Co	March 30, 1792	....	To open navigation on the Mohawk, Wood creek, Oneida and Oswego rivers to Lake Ontario	Completed to Oneida lake in 1797. Rights were afterwards vested in State, and such as were available used for Erie canal

LOSS OF WATER FROM ARTIFICIAL CHANNELS

In order to provide ample water supplies, the large amount of canal construction in New York State has necessitated the collection of considerable information as to the various sources of loss of water to which artificial channels are subject.

The original Erie canal was constructed with the water surface 40 feet wide, the bottom width 28 feet, and the depth 4 feet. In 1824 measurements of the loss from filtration and evaporation were made by John B. Jervis on the eastern division and by David S. Bates on the western division. Mr Jervis states that his measurements were made in the original Erie canal, between the first locks below the village of Amsterdam and the aqueduct below Schenectady, a distance of 18 miles. This section was constructed mainly through an alluvial soil, containing a large portion of vegetable matter. In some places this soil was very leaky, owing probably to the decay of roots, although the greater portion retained water very well. There was a considerable quantity of gravel and slaty soils. He states that the quantity of water lost in this 18-mile section was very uniform, and averaged 2.10 cubic feet per second per mile.[1]

Mr Bates states that his measurements in 1824 showed that a mile of new canal, such as the Erie canal then was between Brockport and Ninemile creek, would require 1.7 cubic feet of water per second per mile in order to supply the losses from filtration, leakage and evaporation.[2] The following are some of the details of Mr Bates's measurements in 1824:

On 79 miles of the canal and feeder, comprising 20 miles of canal from Rochester to Brockport, 57 miles from Rochester to Cayuga, and 2 miles of feeder, the supply was 133 cubic feet per second, or 1.69 cubic feet per second per mile. The months are not stated, although it may be inferred that these observations are averages of the navigation season.

Mr Bates further states that in August, 1824, he found a total use for the 20 miles from Rochester to Brockport of 35 cubic

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[1] Report of John B. Jervis to the Canal Commissioners, on the Chenango canal. An. Rept Canal Com. (1834). Ass. Doc. No. 55, p. 54.

[2] Report of David S. Bates to the Canal Commissioners, on the Chenango canal (1830). Ass. Doc. No. 47, p. 31.

feet per second, equal to 1.75 cubic feet per second per mile. This section of the original Erie canal was considered to be entirely free from leakage at the structures, and the measured losses are therefore taken as those due only to percolation, absorption and evaporation.[1]

In August, 1839, Henry Tracy and S. Talcott, acting under instructions from W. H. Talcott, Resident Engineer of the Fourth Division of the Genesee valley canal, made a series of observations along the line of Chenango canal, with a view of determining the evaporation, filtration and leakage at the mechanical structures, and whatever else might be useful in the designing of the water supply of the summit level of the Genesee valley canal.

For the purposes of the measurements they selected a portion of the canal extending from the north end of the summit level to Erie canal, 22 miles in length, on which the total supply on August 31 was found to be 39 cubic feet per second. The leakage and waste at aqueducts, waste-weirs, and at lock No. 1 at the northern end were found to be 15 cubic feet per second, thus leaving the evaporation and filtration on 22 miles at 24 cubic feet per second, equivalent to 1.09 cubic feet per second per mile. It may be observed, however, that a measurement made at the end of August would probably not show a maximum of either evaporation or absorption by vegetation. Estimating these elements at the maximum, we may assume from 1.33 to 1.67 cubic feet per second per mile as a more reliable quantity than the 1.09 cubic feet per second per mile here actually observed.

Messrs Tracy and Talcott also measured the leakage and waste at the various mechanical structures, etc. which were as follows: Leakage at structures, 3.67 cubic feet per second; waste at waste-weirs, 3.40 cubic feet per second; leakage at lock No. 1, at the north end of the section, 7.98 cubic feet per second. This amount, Mr Talcott remarks, was so much greater than at any

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[1] See report of F. C. Mills in relation to the Genesee Valley canal (1840). Ass. Doc. No. 26, p. 26. See also report of W. H. Talcott in the same document. These two reports contain a summary of all that had been done in the way of measurements of the various losses now under discussion up to that time, as well as a number of references to foreign data.

other lock on the canal as to induce the belief that the gates were not properly closed at the time of measurement. At lock No. 69 on the same canal, the leakage was 6.37 cubic feet per second from an 8-foot lift.

Mr Talcott's report is very able, and presents forcibly all the data at hand at that time. It may be said that the data which he gave fixed the following quantities as fairly covering the various losses to which artificial waterways of the dimensions of the original canals of this State are subject.[1]

1) Loss by filtration, absorption and evaporation, 1.67 cubic feet per second per mile. With retentive soils this could be reduced to from 1.00 to 1.20 cubic feet per second per mile. Mr Talcott fixed on 1.10 cubic feet per second per mile for the Genesee valley canal, which was largely built through heavy soils, but this was subsequently found too small.

2) Leakage at mechanical structures; for locks of 11 feet lift, 8.33 cubic feet per second; for leakage and waste at each waste-weir, 0.50 cubic foot per second; for a wooden-trunk aqueduct, an amount depending on the length of the structure, but as an average, 0.058 of a cubic foot per second for each linear foot of trunk may be taken.

In response to a resolution of the Canal Commissioners of April 12, 1841, O. W. Childs, then Chief Engineer of the Erie canal, prepared a report on the water supply of the western division with reference to the enlargement then in progress.[2] In this paper Mr Childs gives the results of measurements made by himself in 1841 of losses from filtration, absorption, evaporation, and leakage on the original Erie canal between Wayneport, in Wayne county, and Pit lock, which corresponded to lock 53, near Clyde, of the present canal. He also gave the result of measurements made by Alfred Barrett between Pittsford and Lockport.

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[1] The quantities here given apply to canals 40 feet by 28 and 4 feet deep, and with locks 90 feet in length and 15 feet in width and 8 to 10 feet lift.

[2] See Supply of Water Required for the Canal Between Lockport and the Seneca River, by O. W. Childs: An. Rept Canal Com. (1848). Ass. Doc. No. 16, p. 141-175.

Mr Child's measurements were for a section of the canal 36.02 miles in length. On the Palmyra level, for a distance of 8.34 miles, where the soil is open and porous, the measurements showed a loss of 1.81 cubic feet per second per mile. On the Clyde level with a more retentive soil the losses from filtration, absorption, and evaporation were, for a distance of 27.68 miles, only 0.59 cubic foot per second per mile. The entire loss, including leakage, was, for the whole distance, 1.40 cubic feet per second per mile. These measurements were made for a term of thirty-three days, from July 30 to August 31, inclusive. Measurements were also made in June, early in July, and in the following October, from which the conclusion was derived that demands were greater and the supply less for the time during which the foregoing observations were taken than during any other portion of the season.

Mr Barrett's measurements were made at various points on the original canal between Pittsford and Lockport, and repeated each day from July 17 to September 30, inclusive. They showed an average loss for the whole period of 1.22 cubic feet per second per mile. Assuming the same ratio of loss between Pittsford and Wayneport, there resulted, for the entire distance of 122 miles from Lockport to Pit lock, an average loss of 1.12 cubic feet per second per mile. Mr Childs states that an addition to the foregoing quantity should be made as an allowance for springs and several small streams entering the canal which could not be measured. Making such additions he concludes that 1.42 cubic feet per second per mile should be taken as the total quantity consumed on the 122 miles of canal under consideration, which is equivalent to a total of 173 cubic feet per second. It is stated in the original reports that the supply of water was ample for all the purposes of navigation during these measurements.

Comparing Mr Childs's measurements of 1841 with those made by Messrs Jervis and Bates in 1824, one point of great practical utility is strongly brought out, namely, as to the excess of loss of water in new canals over those some time in use; thus Mr Bates found in 1824, on the same reach of canal as was measured by Mr Childs in 1841, a total loss of from 1.68 to 1.75 cubic feet per second per mile. It may be assumed that the springs and streams allowed for by Mr Childs were delivering into the canal in 1824 the same as in 1841, at least 0.17 to 0.25 cubic foot per second per mile. We have, then, as the total supply in 1824 from 1.92 to 2.00 cubic feet per second per mile. Adopting the latter figure as a maximum to compare with Mr Childs's figure of 1.42 cubic feet per second per mile, as found in 1841, the conclusion is reached that the decrease in the loss by filtration—due presumably to the gradual silting up of the bottom—is something like 0.58 cubic foot per second per mile.

This conclusion could be applied to the conditions of the Erie canal improvement of 1895 in which it was proposed to excavate one foot from the bottom of many of the levels. The effect of this would be to remove the silt accumulations of many years, thus placing the bottom of the canal, as regards porousness and consequent percolation and filtration loss, in the same condition as when first constructed. This consideration alone indicated the necessity of making the water supply of the enlarged canal liberal in order to answer the demands of the first few years while the bottom was again attaining a fixed condition.

The experience of over eighty years in the operation of the New York State canals has thoroughly shown the futility of any attempt at excessive economy in water supply. In the absence of systematic information as to yield of streams, the general tendency has been to overrate the summer flow, with the result of shortage frequently at points where the supply was believed to be ample. The chief sources of such shortage may be enumerated as follows:

1) The great variation in the yield of catchment areas from year to year, by reason of differences in the rainfall, humidity, and temperature.

2) The cutting off of forests, which has increased somewhat the spring-flood flows and decreased the summer flow.

3) The systematic drainage of large areas, which has also tended to increase the flood flows and decrease the summer flows.

4) The growth of aquatic plants on long levels and the formation of sand bars in the canal, which have tended to decrease the amount passing.

Among minor sources of loss, evaporation and absorption by growing plants may be mentioned, both of which vary somewhat in different years, although neither can be considered a serious source of loss.

A study of all the measurements in detail shows that in an artificial channel of the dimensions of the original Erie canal, there should be provided at least 1.33 to 1.67 cubic feet per second per mile, exclusive of water for filling and for lockages.

Using the data of the measurements of 1841, Mr Childs arrived at the water supply of the enlarged canal of that day in the following manner: It was assumed that the loss by filtration through the bottom and sides of the canal would be as the square root of the pressure or depth of the water, and as the area of the surface pressed. Proceeding on this assumption, he computed the quantity required to supply the losses from filtration, leakage, and evaporation (in the enlarged canal, 1840 to 1860), at 3.17 cubic feet per second per mile. This figure was subsequently substantially adopted for the entire enlarged canal, and, with the exception of a few special cases is still in use.

Adding the amount required for lockages at lock 53, Mr Childs placed the entire supply for the western division, from Lockport to the east end, at 3.48 cubic feet per second per mile, or at a total of 424 cubic feet per second for 122 miles of canal.

The canal enlargement of 1895 contemplated an increase in depth from 7 to 9 feet. Taking into account the results of the measurements on the original Erie canal, as well as those made by Mr Childs on the enlarged canal of 1840 to 1860, it has been concluded that the proper figure for water supply on the western division, to which the studies thus far specially refer, should be taken at from 4.17 to 4.50 cubic feet per second per mile.[1]

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[1] The foregoing statements in regard to measurements of water supply of Erie canal are abstracted from Report on the Water Supply of the Western Division of the Erie Canal, by the writer, and are to be found in Appenidx I to the An. Rept of the State Engineer and Surveyor for the fiscal year ending September 30, 1896.

The consumption of water from a navigable canal may be taken to include the following items:

1) For filling the prism, in case it is emptied for any reason.

2) Quantity required for lockages.

3) The supply for replacing water lost by evaporation. This head may be also taken to include the loss by percolation and absorption by subsoil and aquatic plants.

4) Loss by leakage as at aqueducts, culverts, lock gates, valves, etc.

5) Loss by wastage at spillways.

6) Water required for power to operate lock gates and for flushing out boats, barges and timber rafts, as well as for power to operate electric lights at the locks during the nights.

7) Quantity required for industrial and agricultural use.

8) Losses by evaporation, percolation, etc. along the feeder. This latter quantity, if the feeder is of considerable length, may be large and can not be safely neglected in an estimate as to water supply.

There is no specific rule for determining water supplies for canals. One chief source of loss is percolation, the determination of which, in any particular case, is a matter of judgment, based on experience. In any case we may assume much less loss with good construction than with poor. The safest way to proceed is to apply information derived from well attested experiments.

Table No. 96 gives measurements and estimates of loss of water from canals in New York State by evaporation, percolation, waste, etc. Many of these measurements have been referred to in the preceding.

In connection with the barge canal work, a number of gagings were made at various points along the Erie canal, as at Lockport, Boonville, Glens Falls and Rochester. Current meter and rod observations were also made at Cornell University. It is stated in the barge canal report:

> Much time was spent in attempting to find a number of fair comparisons in the results of the canal gagings made last summer (1900), but unfortunately the geological and topographical conditions of the levels, or sections, were not sufficiently similar to justify the acceptance of any expressions deduced therefrom.

TABLE NO. 96.—MEASUREMENTS AND ESTIMATES OF THE LOSS OF WATER FROM NEW YORK CANALS BY EVAPORATION, PERCOLATION, WASTE, ETC.

(From Barge Canal Report)

Serial number	Canal and locality	Year	DIMENSIONS OF CANAL IN FEET			Length of section observed. In miles	COMBINED LOSS BY EVAPORATION AND PERCOLATION IN—		By whom reported
			Surface width	Bottom width	Depth		Cubic feet per second per mile	Inches in depth per day	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	Original Erie canal, Brockport to Ninemile creek.	1824	40	28	4	....	1.67	8.18	David S. Bates
2	Original Erie canal, Brockport to Cayuga........	1824	40	28	4	75	1.69	8.28	David S. Bates
3	Original Erie canal, Brockport to Rochester......	1824	40	28	4	20	1.75	8.58	David S. Bates
4	Original Erie canal, Amsterdam to Schenectady..	1824	40	28	4	18	2.08	10.22	John B. Jervis
5	Original Erie canal, general......................	1838	40	28	4	....	1.67	8.18	John B. Jervis
6	Chenango canal, summit level..................	1838	40	28	4	22	1.09	5.35	W. H. Talcott
7	Original Erie canal, Lodi to Little Falls..........	1841	40	28	4	61.8	0.97	4.74	O. W. Childs
8	Enlarged Erie canal, Lodi to Little Falls.........	1841	70	52.5	7	20.7	1.60	4.48	O. W. Childs
9	Entire section of Erie canal, Lodi to Little Falls.	....	....	.....	....	82.5	1.13	9.22	O. W. Childs
10	Original Erie canal, Palmyra level...	1841	40	28	4	8.3	1.81	8.89	O. W. Childs
11	Original Erie canal, Clyde level.................	1841	40	28	4	27.7	0.59	2.89	O. W. Childs
12	Original Erie canal, both levels.................	1841	40	28	4	36.0	1.40	6.88	O. W. Childs
13	Original Erie canal, Lockport to Pittsford	1841	 40	 28	6 4	69	1.22	5.97	Alfred Barrett
14	Original Erie canal, Lockport to Pitlock..........	1841	....	.....	....	122	1.42	.....	O. W. Childs
15	Enlarged Erie canal, Lockport to Pitlock........	1847	88 70	56 38	8 8	122	3.17	19.02	O. W. Childs
16	Genesee valley canal............................	1846	40	28	4	.....	0.32	1.55	Daniel Marsh
17	Genesee valley canal............................	1846	40	28	4	.....	0.42	2.04	Daniel Marsh
18	Genesee valley canal............................	1846	40	28	4	.....	0.50	2.45	Daniel Marsh
19	Genesee valley canal, Rochester to Mt. Morris...	1854	40	28	4	36	0.62	3.03	Daniel Marsh
20	Genesee valley canal, Mt. Morris to Oromal......	1854	40	28	4	42	2.55	12.51	Daniel Marsh
21	Genesee valley canal, Rochester to Mt. Morris....	1855	40	28	4	36	0.37	1.79	L. L. Nichols
22	Genesee valley canal, Mt. Morris to Dansville....	1855	40	28	4	16	0.40	1.95	L. L. Nichols

TABLE NO. 96—MEASUREMENTS AND ESTIMATES OF THE LOSS OF WATER FROM NEW YORK CANALS BY EVAPORATION, PERCOLATION, WASTE, ETC. (*concluded*)

(From Barge Canal Report)

Serial number	Canal and locality	Year	Dimensions of canal in feet			Length of section observed. In miles	Combined loss by evaporation and percolation in—		By whom reported
			Surface width	Bottom width	Depth		Cubic feet per second per mile	Inches in depth per day	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
23	Genesee valley canal, Sonyea to Portage	1855	40	28	4	15	0.43	2.09	L. L. Nichols
24	Genesee valley canal, Portage to Oromal	1855	40	28	4	22	0.72	3.51	L. L. Nichols
25	Chenango canal	1855	40	28	4	.....	1.67	8.18	L. L. Nichols
26	Black River canal	1855	40	28	4	.....	1.67	8.18	L. L. Nichols
27	Enlarged Erie canal	1855	70	52.5	7	.....	3.33	9.34	L. L. Nichols
28	Enlarged Erie canal, Tonawanda to Montezuma	1849	70	52.5	7	120	3.33	9.34	Henry Tracy
29	Enlarged Erie canal, Tonawanda to Montezuma	1850	70	52.5	7	120	3.67	10.28	Unknown
30	Enlarged Erie canal, Tonawanda to Montezuma	1860	70	52.5	7	120	3.87	10.57	S. H. Sweet
31	Enlarged Erie canal, Tonawanda to Clyde	1858	70	52.5	7	126	3.33	9.34	John D. Fay
32	Chemung canal	1860	40	28	4	.....	1.11	5.44	S. H. Sweet
33	Original Erie canal	1860	40	28	4	.....	1.11	5.44	S. H. Sweet
34	Enlarged Erie canal	1860	70	52.5	7	.....	2.83	7.93	S. H. Sweet
35	Enlarged Erie canal, Lockport to Rochester	1877	85	62	7.6	62.5	3.17	7.31	W. H. Searles
36	Enlarged Erie canal, Spencerport to Rochester	1877	72.5	53.7	7.5	12.0	3.17	8.57	W. H. Searles
37	Enlarged Erie canal	1885	70	52.5	7	.....	2.67	7.47	E. Sweet, Jr.
38	Proposed Erie canal	1885	180	100	18	.....	10.67	11.63	E. Sweet, Jr.
39	Enlarged Erie canal, Lockport to Rochester	1896	72.5	49	9	62.5	4.17	11.28	Geo. W. Rafter
40	Original Erie canal, western division	1841	40	28	4	122	1.24	6.09	C. H. McKinstry
41	Enlarged Erie canal, western division	1889	70	52.5	7	.....	3.82	10.71	C. H. McKinstry
42	Proposed Albany-New Baltimore ship canal	1853	120	50	20	.....	6.78	11.09	W. J. McAlpine
43	Glens Falls feeder, near Sandy Hill	1887	53	38	6	3.0	66.67	.....	Ellis B. Noyes

SELLING PRICE OF WATERPOWER

The original places in New York State at which hydraulic developments have been made for the purpose of selling power are Oswego, Cohoes, Lockport and Niagara Falls. At Oswego the power on the east side of the river is owned by the Oswego Canal Company, the development being by a canal 4000 feet long, with an average surface width of 60 feet and a depth of 6 feet. The water from this canal is dropped into the Oswego river at the level of Lake Ontario. The working head is from 18 to 20 feet, although with high water in the canal and low water in Lake Ontario, the working head becomes somewhat greater.

The State controls the first right to the flow of the Oswego river in order to maintain slack-water navigation in the pool above the dam at the head of the Oswego Canal Company's raceway; all water not needed for canal purposes being equally divided between the Oswego Canal Company's race on the east side and the Varick canal on the west side. The Oswego Canal Company gives a 999-year lease of water, but without land for location of buildings. A water right on this canal is called a run, meaning, probably, the amount of water required to drive a run of stone, a run of water being taken at 11.75 cubic feet per second which, under the ordinary working head of 20 feet, will, at 75 per cent efficiency, produce 20 horsepower. There are assumed to be 32 first-class runs, the rental for which is $350 a year for each run. At this price the cost of a horsepower a year, with 75 per cent efficiency, becomes $17.48, or the cost of a gross horsepower a year becomes $13.11. There are also 32 second-class runs, of which the rental varies from $250 to $300 a year for each run. Further, there are surplus runs which are rented at a little over one-half of the rental charged for first-class runs. In case of a shortage of water the surplus runs are shut down successively, beginning with the most recent leases; after this the second-class runs share equally with one another in reduction; and finally, in case of extreme shortage, the first-class runs are similarly cut down.

The Varick canal on the west side of the river controls one-half of all the water not needed for navigation purposes, the same as the Oswego Canal Company's canal on the east side. In order that the water may be divided equally between these two canals both have the same aggregate waterway at the head gates, and by gages on both sides, which are examined whenever necessary, it can be seen whether one canal is drawn below the other, and the gates changed accordingly. On this canal there are recognized 50 first-class runs, 17 second-class, and an unlimited number of third-class. For first-class runs the rental is from $250 to $300 per annum; for second and third class it ranges from $125 to $150. By a decree of the Supreme Court, dated August 21, 1875, a run of water on the Varick canal ranges between 28 cubic feet per second, under a head of 12 feet, and 25 cubic feet per second, under a head of 13 feet. The actual working head is, however, ordinarily only about 10 feet, so that on the foregoing basis a run of water may be taken as 33.3 cubic feet per second. At the price of first-class runs of from $250 to $300, and with 75 per cent efficiency, the cost per horsepower per annum varies from $8.80 to $10.56, a run on the Varick canal being equal to 33.3 cubic feet per second on 10 feet head, an amount of water which yields 37.9 horsepower under that head.

As to the difference in cost of water on these two canals at Oswego, it may be pointed out that the Oswego Canal Company's race has a substantial advantage over the Varick race, in that it extends to the harbor, enabling vessels to come directly alongside of the mills. Moreover, the division of water rights is such that a first-class run of water can always be depended on along the Oswego Canal Company's race, but can not on Varick canal.[1]

At Cohoes we have the great power development built up by the Cohoes Company, which has, by careful management of the waterpower, built up at this place a fine manufacturing city of 24,000 inhabitants.

The Cohoes Company not only owns all of the hydraulic canals, but also the land adjoining the canals. It gives to manufacturers a perpetual lease of land and water, the entire property leased remaining subject to a rental of $200 per year per mill power. On this basis the land is regarded as donated and the rental applies only to the waterpower. Formerly, the standard

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[1] For additional detail of the water power at Oswego, see Report of Water Power of the United States, Tenth Census, Vol. I, p. 24-27.

for measuring water was 100 square inches, to be measured through an aperture in thin plate 50 inches wide, 2 inches deep, and under a head of 3 feet from the surface of the water to the center of the aperture; but in 1859 a series of measurements were carefully made under the direction of the late James B. Francis, using an old canal lock as a measuring chamber. These measurements showed that the old standard corresponded to about 5.9 cubic feet of water per second. As a result 6.0 cubic feet of water per second, under 20 feet head, was taken as a new standard constituting a mill power. On this basis a mill power is equivalent to 13.63 gross horsepower, which, at $200 per mill power per annum, costs $14.67 per gross horsepower per annum. At 75 per cent efficiency the annual rental for water per net horsepower becomes $19.57. In regard to just what is paid for by the annual rental, both at Oswego and Cohoes, it may be remarked that the foregoing prices are for water in the raceway, the company maintaining the dams, headworks, and main raceways, the lessee taking the water at the face of the raceway and maintaining his own head gates, flumes, bulkheads, wheels, and any other appliances necessary for utilizing the water in the production of power.

The waterpower at Lockport. owned by the Lockport Hydraulic Company, is formed by the drop of the surplus water of the Erie canal through a distance of 58 feet. A run of water at Lockport does not appear to be very well defined, but the rental charge ranges from $12.50 to $16.67 per effective horsepower. So far as known to the writer, just what constitutes an effective horsepower has not been defined.

At Niagara Falls the rental price of undeveloped hydraulic power has been fixed at from $8 to $10 per gross horsepower per annum, the party renting the power taking the water at the face of the head race and making its own connection with the discharge tunnel. Electric power by a two-phase alternating current as it comes from the generator is sold in blocks of 2000 or 3000 horsepower, at $20 per net horsepower per annum, the purchasers furnishing transformers, motors and all other electric appliances. In small blocks the price has been fixed somewhat higher.

A small amount of power has also been sold at different times at Rochester, but since the power at this place is nearly all held by manufacturers who use it at first hand, nothing like a uniform price has been made at Rochester. Generally, power rented has been in small quantities and in connection with floor space, the rental price being really for floor space with small power furnished. Reckoning on this basis, small powers have frequently been rented at Rochester at as high a price as $100 per horsepower per year, this being for power on the shaft, all expenses of maintaining wheels, transmission shafts, etc., being borne by the owner.

The electric companies at Rochester furnish electric power in small blocks at 3 cents per electric horsepower per hour, which, on the basis of ten hours a day and three hundred and ten days a year, becomes $93 per electric horsepower per annum.

FUTURE USE OF WATERPOWER IN NEW YORK

In the foregoing pages we have seen that the Erie canal was a development from the necessities of commerce, not only for the State of New York, but, as a means of connecting the Atlantic ocean with the waters of the Great Lakes, for accelerating the industrial development of the northwestern States. However, in the nineteenth century events move rapidly, and what was true of the Erie canal thirty to fifty years ago is not necessarily true today. Railway systems have now developed to such completeness as to compete successfully with water transportation by a channel of the size of the Erie canal.

During the period covered by the rise and decline of the Erie canal as the important factor in through transportation between the east and a large portion of the west the economic conditions of the interior portion of New York have entirely changed. Cheap transportation, by way of the Erie canal and the Great Lakes, has led to a phenomenal development of agriculture on the broad plains of Minnesota and the Dakotas, where, by the use of modern agricultural machinery, grain can be raised at a profit at such prices as to drive the New York grain grower from the market. The cheap transportation afforded by the Erie canal has, therefore, to a considerable degree, led to the passing of supremacy from the hands of the eastern farmer, a loss which can only be regained by the development to the fullest extent of the manufacturing industries of New York, thus making a home market for farm products that can not be transported a long distance, such as garden truck and small fruits. The people of the State of New York can purchase the western breadstuffs as cheaply as they can be produced at home, and this condition is likely to continue indefinitely.

The long supremacy of the navigation interests has led to the incorporation in the law, jurisprudence, and public policy of this State of certain rules of action as to the right to use the water of inland streams, which have tended to discourage the full development of manufacturing interests which now appears desirable, although the writer views with satisfaction the rapid change of public sentiment now taking place on these questions. That manufacturing industries by waterpower are rapidly increasing in the State is made sufficiently clear by the following statistics:

According to the United States censuses of 1870 and 1880 the total developed waterpower of the State of New York was, in 1870, 208,256 horsepower; in 1880, 219,348 horsepower; increase in the ten years, 11,092 horsepower. The increase in ten years of 11,092 horsepower is equivalent to an increase of 5.4 per cent. The United States census of 1890 did not include any statistics of waterpower, and it is impossible therefore to state definitely the horsepower in that year; according to the returns of the Twelfth Census (1900) there was over 368,000 horsepower in the State of New York.[1] The manufacture of mechanical wood pulp alone consumes nearly 125,000 gross horsepower. These figures, while very suggestive as to the future, are nevertheless rendered more pertinent by considering that with full development of the water-storage possibilities of the State, as well as the possibilities of power development on the Niagara and St Lawrence rivers, we may hope ultimately to reach a waterpower development in New York something like the following:

	Gross horsepower
Streams tributary to Lake Erie	3,000
Niagara river (in New York State)	350,000
Genesee river and tributaries	65,000

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[1] See statements on p. 570.

	Gross horse-power
Oswego river and tributaries	40,000
Black river and tributaries	120,000
Other tributaries of Lake Ontario	10,000
St Lawrence river	400,000
Oswegatchie, Grasse, Raquette, St Regis, Salmon, Chateaugay, and other streams tributary to the St Lawrence	150,000
Saranac, Ausable, Lake George outlet, and other streams tributary to Lake Champlain	40,000
Hudson river and tributaries, not including Mohawk river	210,000
Mohawk river and tributaries	60,000
Streams tributary to Allegheny river	5,000
Streams tributary to Susquehanna river	25,000
Streams tributary to Delaware river	30,000
Waterpower of Erie canal	10,000
Total	1,518,000

OBSTRUCTIVE EFFECT OF FRAZIL OR ANCHOR ICE

A very serious difficulty in operating waterpowers on many of the more rapid streams of this State is that caused by the formation and agglomeration of frazil and anchor ice, and probably there is no subject in connection with waterpower development which presents so many difficulties as this. So far as can be learned, nothing has been done in the State in the way of studying these phenomena, although the waterpowers on many New York streams are reported as subject to interruption nearly every year on account of the formation of frazil and anchor ice. The way to find a remedy is first to ascertain all that can be learned in regard to the difficulty to be overcome. From this point of view it is deemed proper to include herein a short account of studies of frazil and anchor ice made in the neighboring Dominion of Canada.

Under the direction of John Kennedy, Chief Engineer of the Harbor Commissioners' works at Montreal, very extensive studies of the formation of frazil and anchor ice have been made. The terms "frazil" and "anchor ice" have been used synonymously, and are apparently often understood as the French and English words for the same thing, but the following from the report of the Montreal Flood Commission of 1890 will serve to define the difference. According to this report, frazil is formed over the whole unfrozen surface wherever there is sufficient current or wind agitation to prevent the formation of border ice; whereas the term anchor ice includes only such ice as is found attached to the bottom. Frazil is frequently misused by being made to include ice formed on the bottom, as well as throughout the mass and on the surface of a river, although properly it should be only applied to floating ice. The common theory has been that anchor ice first forms on the bottom, subsequently rising. The Montreal studies, however, show that this is hardly true. At times the whole mass of water from surface to bottom is filled with fine needles which actually form throughout the water mass itself.

As to the remedy, the studies are hardly complete enough to indicate the best course to pursue. As practical hints, it may be stated that in locating dams on streams specially subject to this difficulty they should be placed with reference to as long a stretch of backwater and as great depth as possible, all the studies thus far made tending to show that the formation is most extensive in shallow, rapid-flowing water. Usually, trouble from frazil and anchor ice extends through a period of a day or two; and at very important plants, where even a short interruption would be a serious matter, arrangements may be made for using steam at the headworks for keeping the racks open. This plan has been successfully pursued at the waterworks intakes of several of the Great Lake cities. In the case of power plants, where much larger quantities of water are required and the stream flows with greater velocity, the amount of steam required may be very large.[1]

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[1] For literature of frazil and anchor ice see (1) Report of the Montreal Flood Commissioners of 1886; (2) Reports of the Harbor Commissioners of Montreal for the years 1885, 1887, and 1895; (3) Paper on Frazil Ice and Its Nature, and the Prevention of Its Actions in Causing Floods, by George H. Henshaw, Trans. Can. Soc. C. E. Vol. I, Part I, p. 1-23; and (4) Paper on the Formation and Agglomeration of Frazil and Anchor Ice, by Howard T. Barnes, in Canadian Engineer, Vol. V (May, 1897).

MUNICIPAL WATER SUPPLIES IN WESTERN NEW YORK[1]

In 1894, in a paper read before the Buffalo Academy of Medicine on The Application of Intermittent Filtration to Domestic Filters, the writer stated that a number of years before he had had occasion to examine somewhat in detail every possible source from which either a temporary or permanent supply of potable water could be drawn for the city of Rochester. In the course of the study something like eighteen distinct sources were examined, with the result of showing that, taking into account everything, the choice was really narrowed to Hemlock lake, the source formerly selected, but which, while admittedly of unexceptionable quality, was still, in the opinion of many citizens, hardly available as an additional supply by reason of the great distance (thirty miles) which the water must be transported.

The result of a fairly exhaustive examination was to show, however, that taking into account quality as well as cost of obtaining a given quantity, it followed that Hemlock lake, even though thirty miles distant, was by far the preferable source of supply for the city of Rochester.

Western New York, looked at casually, would be considered a well-watered region, and since making the examination in question it has always seemed an exceedingly interesting fact that the repeated selection of Hemlock lake as a natural source of a potable water supply for the city of Rochester, by all the engineers who have examined the matter in detail since about 1860, when it was first proposed, down to the present, should show clearly that potable water of high quality and in large quantity is in reality rather a scarce commodity in western New York.

Since that time employment upon water supplies in different parts of western New York has still further shown how exceedingly scarce potable water is in this part of the State. Pure water is a scarce commodity here, and the study must be very broad in order to select the most available and least expensive supply of proper quality for a town.

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[1] Partly condensed from Report of Executive Board of Rochester for 1890.

On account of similarity of conditions the facts gained in the Rochester study are of general interest to the towns of western New York, and accordingly a brief account of the studies made in 1890 is herewith given.

Domestic Water Supply of Rochester

The object of the investigation was to determine the cheapest source from which a proper temporary supply of water for the city of Rochester could be obtained. A number of sources within short distances were examined, but it was found that in every instance where the quality was satisfactory the quantity was not. On the other hand, where the requisite quantity was available, the contamination was such as to necessitate filtration. The deficiency in the supply was estimated at 1,500,000 gallons per day, and since Rochester was growing rapidly, the shortage was likely to amount to 2,000,000 gallons per day before a new conduit could be constructed. We will first refer to Hemlock lake, the main source of supply for Rochester.

Hemlock lake. In 1872 Hemlock lake was decided upon as the water supply of the city of Rochester. This lake lies at an elevation of 386 feet above the Erie canal aqueduct at Rochester, and a gravity conduit was therefore constructed capable of carrying 7,000,000 gallons per day, although in 1876, immediately after its completion, this conduit was reported as carrying 9,300,000 gallons per day. No systematic tests had been made until 1890, when it was found to be carrying only 6,700,000 gallons per day. In the meantime, the city had developed from a population of 89,000 in 1880 to 134,000 in 1890, and the natural increase in the use of water had exhausted the available supply. At least two years was required to construct a new conduit and accordingly it became necessary that a temporary supply of some sort be provided to tide over the emergency. The investigation considered every possible source from which a supply could be obtained. Mount Hope reservoir is about two miles south of the center of the city and Rush reservoir ten miles south. Just south of Mount Hope reservoir there is a deep, broad valley several miles wide, while south of Rush reservoir is the valley of Honeoye creek.

Table No. 97 comprises the averages of the regular weekly sanitary analyses, as made for the Health Department of Rochester by Fred R. Eilinger:

TABLE NO. 97.—ANALYSES OF HEMLOCK LAKE WATER FOR 1902
(Parts per 100,000)

Month	Total solid residue dried at 100 degrees C	Fixed residue at a low red heat	Volatile at a low red heat	Free ammonia	Albuminoid ammonia	Chlorine in chlorides	Nitrogen in nitrates	Nitrogen in nitrites
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
January	9.875	6.375	3.500	0.0010	0.0092	0.2200	Trace	None
February	9.500	5.875	3.625	0.0010	0.0081	0.2200	“	“
March	9.500	6.000	3.500	0.0010	0.0087	0.2175	“	“
April	9.125	5.750	3.375	0.0010	0.0087	0.2200	“	“
May	9.125	6.000	3.125	0.0010	0.0091	0.2225	“	“
June	9.875	5.875	4.000	0.0010	0.0091	0.2275	“	“
July	10.666	6.666	4.000	0.0010	0.0091	0.2200	“	“
August	10.125	6.437	3.687	0.0011	0.0090	0.2200	“	“
September	9.750	6.250	3.500	0.0010	0.0090	0.2150	“	“
October	9.125	5.375	3.750	0.0011	0.0086	0.2150	“	“
November	9.125	6.125	3.000	0.0010	0.0086	0.2175	“	“
December	9.250	5.875	3.375	0.0020	0.0088	0.2175	“	“
Average 1902	9.586	6.050	3.536	0.0011	0.0088	0.2177	“	“
“ 1901	9.833	6.239	3.594	0.0010	0.0089	0.0221	“	“

Hardness is not ordinarily determined because it does not vary much, being nearly constant from year to year. The following by Mr Eilinger shows the small variation:

Total hardness, parts per 100,000

December 7, 1895	6.70
December 21, 1895	6.70
January 18, 1896	6.20
February 1, 1896	6.80
April 10, 1897	6.20
May 8, 1897	6.80
July 9, 1898	7.30
June 19, 1903	6.80
June 10, 1904	6.70

The following shows the more important results of the weekly biological examinations of Hemlock lake water which have taken place from 1896-1902, inclusive. These determinations have been made by Prof. Charles Wright Dodge, of the University of Rochester, using for the plant and animal organisms, exclusive of bacteria, amount of amorphous matter, average number of moulds, etc. the Sedgwick-Rafter method.[1] The determinations of bacteria have been made by standard bacteriological methods.

	1896	1897	1898	1899	1900	1901	1902
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Average number of plant and animal organisms (exclusive of bacteria) per cubic centimeter of unfiltered water, *i. e.*, water as it comes from the tap...	135.95	83.26	62.82	74.94	56.88	88.07	141.69
Average amount of amorphous matter, *i. e.*, iron rust from the pipes, earthy matter, etc., in standard units per cubic centimeter of unfiltered water..	74.41	48.84	43.0	41.37	37.71	38.59	41.87
Average number of bacteria per cubic centimeter of unfiltered water........	334.0	101.0	94.0	51.0	52.2	103.75	102.70
Average number of moulds per cubic centimeter of unfiltered water........	3.8	10.6	14.4	8.4	8.9	16.0	16.45
Average number of genera of organisms per examination......................	9.4	8.2	6.6	7.5	5.6	6.1	5.14

The following eighteen sources were considered: Gates bored well; driven or bored wells in the bottom lands south of Mount Hope reservoir; Irondequoit creek and its tributaries; Red creek; Little Black creek; springs and well at Coldwater; Snow springs; Hubbard springs; Black creek; Oatka creek; Caledonia springs; Mendon ponds; pond near Bushnell Basin; Irondequoit bay; Lake Ontario; Erie canal; Honeoye creek at East Rush, and Genesee river. The following is a brief description of these several sources as mostly taken from the reports of the Executive Board of Rochester.

The Gates well. This well is situated about one mile west of the Rochester city line. The surface of the ground at the well is 27.5 feet above the Erie canal aqueduct, or 96.5 feet below the normal water surface in Mount Hope reservoir. A test of the quantity of water to be obtained from this well was made by the writer in the latter part of May, 1890, and a full report of the results of

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[1] This method of biological analysis is described in The Microscopical Examination of Potable Water, by Geo. W. Rafter. See also The Microscopy of Drinking Water, by Geo. C. Whipple.

such test, together with analyses of the water, was submitted to the Executive Board on June 1, 1890. From a sanitary point of view the water was considered good, although having a hardness of 21° and containing a slight amount of sulphureted hydrogen. The well was drilled about forty years ago for testing the existence of oil in the locality, but on obtaining a large flow of water it was partially plugged up and abandoned, and only a small quantity of water had been allowed to escape from it for the whole time prior to May, 1890. Soundings indicated that the 6.5-inch casing extended twenty feet below the surface of the ground, at which depth limestone rock was encountered, and at a depth of fifty-five feet stones or other obstructions were found. The actual depth of the boring is not definitely known, but according to the memory of persons interested in the venture, it was continued to a depth of from 140 to 160 feet.

From the 25th to the 31st of May, 1890, 6,630,000 gallons were pumped from the well at an average rate of about 947,140 gallons in 24 hours, while the natural flow from the unplugged hole before beginning the pumping was about 300,000 gallons in the same length of time. After the pumping test was ended the natural flow continued as before. These results gave promise of obtaining a sufficiently large supply for temporary purposes at a comparatively small cost, specially if another well of equal capacity could be drilled in the same locality. With this object in view the well was leased for three years, and a pumping engine of a capacity of 2,000,000 gallons per day was purchased. Some doubt, however, was entertained with respect to the permanency of the flow from the well, chiefly because the month of May was very wet, 6 inches of rainfall having fallen in that month at Rochester. On the contrary, June, July and August, 1890, were very dry, only 6.59 inches falling in the three months. Accordingly, before the arrival of the new engine, a second and longer test was made.

This second test was commenced August 18, 1890, and continued with few intermissions until September 10, 1890. At the beginning it was found that the natural flow had greatly diminished, and that only a small quantity of water ran over. After pumping for one week at the average rate of 818,750 gallons in 24 hours, the machinery was stopped, whereupon the water fell to a level of 6 feet below the top of the casing, and rose only 1.6 feet during the following seventeen hours, at the end of which time pumping was resumed. From August 26 to August 29 an average of 714,780 gallons per 24 hours was pumped, with the result of reducing the water in the well to a level of 8.8 feet below the top of the casing. During the interval between 2.52 p. m. of August 29 and 3.30 p. m. of September 2, the water-level gradually rose to a point 0.46 foot below the top of said casing. At the last named time the pump was again started and continued in full operation until 7 p. m. of September 10, discharging on the average 653,000 gallons per 24 hours, and finally lowering the water level to 9.58 feet below the top of the casing.

The result of the foregoing test was discouraging; and as the geologic characteristics of the region were unfavorable to the presumption that a sufficiently large and permanent supply of good water could be obtained from the underlying strata, even though a number of other experimental wells were sunk in the vicinity, and also because the owner of the premises refused to permit another well to be drilled on his land without much additional compensation, it was deemed more prudent to examine other available sources before incurring the further large expense involved by the construction of the proposed pumping station and force main to the city.

The following are the analyses of water from this well, as made by Prof. S. A. Lattimore. (1) was taken on May 9, 1890, before beginning any test; (2) was taken on May 27, 1890, after three days continuous pumping, and (3) was taken on May 31, 1890, after seven days continuous pumping.

(*Parts per 100,000*)

	(1)	(2)	(3)
Total solids....................	35.00	35.50	35.50
Loss on ignition................	10.50	10.50	10.50
Fixed residue...................	24.50	25.00	25.00
Sodium chloride................	trace	trace	trace
Ammonia, free...................	none	none	none

	(1)	(2)	(3)
Ammonia, albuminoid	none	none	none
Nitrites	none	none	none
Nitrates	none	none	none
Hardness	21.50	21.00	21.00

The preceding analyses show that the quality of the water is, from a sanitary point of view, quite beyond reproach. Chemical, microscopical and bacteriological examinations have been made and all point to the same conclusion—that this water is safe for domestic use, although its hardness is higher than that of the Hemlock lake water and it contains a small amount of sulphureted hydrogen, but too small to be detected when the samples arrived at the laboratory.

Wells in low district south of Mount Hope reservoir. An examination of the shallow wells in the valley to the south of the Mount Hope range of hills showed that the water was not only very hard, but in many cases also tainted with sulphur. None of these wells has ever overflowed, nor has their yielding capacity been tested by pumping. From the geologic and topographic characteristics of the valley there was no hope that the required quantity of suitable water from a series of driven or bored wells therein could be secured.

As a matter of interest it may be mentioned that after the eighteen sources had been thoroughly investigated, a private company known as the Rochester Water Supply Company undertook to furnish an additional supply of 2,000,000 gallons per day from the wells situated in this low district south of the Mount Hope reservoir. They put down a considerable number of driven wells, but were unable to pump more than about 500,000 gallons per day. Efforts were made to increase this quantity by boring more wells and providing pumps of larger capacity, but without avail—the subterranean supply was found to be limited to the amount named. The prediction, therefore, in the original report that there was no hope for a water supply from this point was abundantly verified.

Irondequoit creek. This source may be reached at its nearest point to Mount Hope reservoir in a distance of five miles. The point in question is near the mouth of the tributary, Allen's creek, and the catchment area above the same is large enough to justify the assumption of a minimum flow of 2,000,000 gallons per day. The lift to Mount Hope reservoir, including friction head in a 16-inch force main, would be at least 300 feet. Filtration of the water would be required, and the total cost of the works on this plan may be placed at $100,000.

Allen's creek was the only available tributary to Irondequoit creek, and may be reached at a distance of two miles from Mount Hope reservoir. At this point, however, the minimum flow was probably much less than the desired quantity, so that storage works would have become necessary. The water was, moreover, liable to contamination from the sewage of the county buildings.

Red creek. This stream rises in the southeastern part of Henrietta, and after flowing northwesterly, enters Genesee river a little over one and one-half miles southerly from Mount Hope reservoir. Its catchment area was too small to insure the required daily volume in periods of drought, and its waters were often highly discolored by swamp drainage—in consequence of which it is named Red creek.

Little Black creek. This stream rises near the middle of the town of Ogden, and after a short southerly course flows through the southern parts of Ogden and Gates to Coldwater station and thence to Genesee river. Its mouth is about three and one-half miles southwest from Mount Hope reservoir, and the water in the river is here about 127 feet below said reservoir. All of the springs in the vicinity of Coldwater, as well as Snow springs farther west, discharge into this creek after flowing through extensive swamps. Casual examination of the stream near Coldwater showed not only that the water could not safely be used for drinking purposes without filtration, but also that its flow was not more than 1,500,000 or 2,000,000 gallons per day. Under these circumstances this source could not be recommended, as it was certain that the flow would diminish greatly during a dry season.

Wells at Coldwater. It was rumored that a large supply of excellent water could easily be obtained from wells at Coldwater, and that the New York Central & Hudson River Railway Company was pumping regularly about 300,000 gallons per day from a single deep well at this point. In order to obtain authentic information, application was made to the railroad officials, from whom it was learned that said well was adjacent to the creek and had a depth of not more than ten feet; also that the bottom of the well did not reach the rocky strata below, and that the entire pumpage did not exceed 100,000 gallons per day; and during the summer months they had difficulty in obtaining a sufficient supply for their engines, and that their well affected another well in the vicinity, which would indicate that the supply was limited. It was also stated that both the railroad officials and several brewing companies in Rochester had made a thorough study of the availability of this point as a source for obtaining a large supply of water, and the adverse reports of a number of experts led to the abandonment of the enterprise. It was obvious, therefore, that little confidence could be placed in well or springs in this locality for municipal purposes.

This view is likewise shared by an experienced well-driller who has sunk more than one hundred deep wells in the vicinity of Rochester, and who asserts that the yield of the Gates well is without precedent in this county. No guarantee can be given that a sufficient quantity of water will be found at any depth, or from any number of wells within such distance of each other as would admit of their being coupled together and controlled by a single pumping engine. It may be remarked that Coldwater is about 25 feet above the level of the Erie canal aqueduct in Rochester and about six miles west of the City Hall.

The Snow springs. These springs are situated on the farm of John Snow, on both sides of the Buffalo road, and about seven miles west of the center of the city of Rochester. The surface of the ground in the locality is stated at 60 feet above the level of the canal aqueduct. It was thought that by properly developing all of these springs a combined flow of from 100,000 to 200,000 gallons per day could be obtained during the dry season. The water was said to be of excellent quality and entirely free from sulphur, but the quantity available was altogether too small to justify the expense of its collection and delivery separately to the city. The following are analyses of the water from Snow springs as made by Professor Lattimore:

(*Parts per 100,000*)

	(1)	(2)
Total solids	26.5	26.0
Loss on ignition	10.0	10.0
Fixed residue	16.5	16.0
Sodium chloride	trace	trace
Ammonia, free	none	none
Ammonia, albuminoid	none	none
Nitrates	none	none
Nitrites	none	none
Hardness	18.0	17.5

The Hubbard springs. These springs are also situated on both sides of the Buffalo road in the village of North Chili, about 9.5 miles distant from the center of Rochester. On July 8, 1890, their combined discharge was about 375,000 gallons per day, as determined by weir measurement. A portion of this flow, however, came from a spring which was slightly tainted with sulphur, being similar in this respect to the water of Gates well. Whether the flow could be materially and permanently increased by excavating, boring or pumping operations, could not be foretold, but it was considered improbable that it could be increased sufficiently to yield 1,500,000 gallons per day. The elevation of these springs is estimated at about 61 feet above the canal aqueduct, or about the same level as Snow springs, two and one half miles east. The discharge is into Black creek.

It was suggested that the flow from the Hubbard and Snow springs should be united in a single conduit which would convey the water by gravity to a pumping station located at or near Coldwater, whence it would be forced into the city mains. The two series of springs are on different catchment areas, and it was probable that the expense of cutting through the intervening ridge would have been too great to render such a project feasible, even if there was a possibility of securing the requisite quantity.

Black creek. This stream flows into the Genesee river on the west side at a point about four miles southwest of the Mount Hope reservoir. Its catchment area is so large that there could be no question as to the sufficiency of the stream to furnish the desired amount of water. The quality of the water is, however, very objectionable, since it contains 73.4 grains of solid matter per gallon. The stream also flows through extensive swampy districts so that filtering would be indispensable in order to fit the water for domestic use. The cost of the necessary filtering and pumping plant, with force-main to the reservoir, would amount to at least $80,000.

Oatka creek. The confluence of this stream with the Genesee river is about one mile east of Scottsville and a little more than nine miles in a direct line southwest of the Mount Hope reservoir. At Scottsville the entire dry weather flow is diverted into the old Genesee valley canal, through which it flows to the southern portion of Rochester, where it is carried in a pipe under the river into the Erie canal feeder. During the season of navigation on Erie canal the State has the first claim upon the water, and it was considered doubtful whether permission to use any portion thereof could be obtained. Assuming, however, that such consent was obtained, it would not be advisable to use the water for drinking purposes without filtration, as the creek receives considerable sewage from the villages of Warsaw and Leroy, besides the waste water of the salt works in the Wyoming valley and the surface drainage from Scottsville and a number of other small villages.

The suggestion was also made to obtain the needed temporary supply from the old Genesee valley canal within the city limits, it being taken for granted that permission to do so could be secured from the canal authorities. If this had been carried out, the same objection to the use of the water without filtration would likewise be valid, and might even become stronger when it is remembered that in many places between Scottsville and Rochester the old canal prism contains dense growths of aquatic vegetation, the emanations from which have been the cause of much complaint from persons residing in the vicinity. This vegetation, furthermore, greatly retards the flow of the water; hence, if an adequate supply for both the Erie canal and the city were to be furnished by the old canal, the channel would have to be thoroughly cleared out for a distance of several miles and maintained in this condition. The cost of such an undertaking, in addition to the necessary expense of filtering the water, rendered this source undesirable.

Caledonia springs. These springs are nineteen miles southwest of Rochester and have a flow of from 2,000,000 to 4,000,000 gallons per day. A considerable length of the outlet is now used by the State Fish Commissioners for hatching purposes, so that if the water had been taken by the city, the intake would doubtless have had to be located below the hatching station. Such a location would have been undesirable unless the water were filtered. In regard to elevation, Mr Marsh stated that this water could be conveyed to the city in pipes, but, on account of the distance, not at a hight sufficient for distribution by gravity. A pumping station would therefore have been required in this case also and the expense of constructing the works was estimated at more than $200,000, exclusive of the filters. The permanent hardness of the Caledonia springs is stated at about 70 parts per 100,000. Their source is in the horizon of the gypsum.

Mendon ponds. These four ponds are situated in the northwestern part of Mendon, and are the sources of the main branch of Irondequoit creek. The one which was considered best adapted as a source for a temporary supply for Rochester is called Deep pond, and is about three and one half miles east of the Rush reservoir and seven miles south of the Mount Hope reservoir, both distances being measured in direct lines. Its surface is from 100 feet to 110 feet below the level of the former reservoir, as determined by a barometric observation. The outflow is about 500,000 gallons per day. Under these circumstances they could not be regarded as available for the needs of the city of Rochester.

Pond near Bushnell Basin. This pond is located in the southwestern part of Perinton, and is somewhat more than eight miles southeast of the Mount Hope reservoir in a direct line, while its surface is about 208 feet below the level of said reservoir. Considered by itself, the pond could not be regarded as capable of furnishing a daily supply of 2,000,000 gallons for a long period, since it has a very small catchment area, no visible outlet, and does not appear to be fed copiously by springs. It was proposed by a private corporation in Rochester to supply this pond from Irondequoit creek and certain springs in the vicinity, thus treating it as a storage basin from which a large quantity of water could be pumped daily into the Mount Hope reservoir. It was, however, certain that the expense of obtaining a temporary supply from this source would be large, a preliminary estimate of the cost of works capable of delivering 2,000,000 gallons per day, being about $180,000. This plan was therefore not adopted.

Irondequoit bay. This body of water is 390 feet below the Mount Hope reservoir and the distance from said reservoir to the nearest point where an intake could be located in deep water, free from extensive growths of flags, etc. is about 6.25 miles. The unsanitary condition of the water, resulting from the presence of a vast quantity of aquatic vegetation as well as the discharge of sewage from populous districts on the east side of the city, rendered this source undesirable.

Lake Ontario. By constructing a pumping station on the lake shore at a point about one mile west of the mouth of the Genesee river and a force main about eight miles long, water from Lake Ontario could have been temporarily delivered into the 16-inch distribution main at the intersection of Jay and Child streets, and thence throughout the northwestern portion of Rochester. The water would of course have had to be delivered at a pressure somewhat greater than that which is due to the elevation of the Mount Hope reservoir, so that the total lift, including friction, would have amounted to about 440 feet, the lake being 390 feet below said reservoir. Owing to the prevalence of westerly winds the intake would necessarily have been west of the river in order to avoid pumping the polluted water of the latter. During an easterly wind the operation of the pumps would be suspended and the whole supply taken from the reservoirs, since the influence of the river, under such conditions, has been traced as far west as Manitou Beach, about eight miles from the mouth of the river. The proposed nearest site for the intake of a temporary supply was therefore entirely unsuitable for permanent use, and would have to have been abandoned after a permanent additional supply had been obtained from some other locality. The cost of the temporary works for a capacity of 2,000,000 gallons per day was estimated at $150,000, which is somewhat less than the estimate made for the Bushnell's basin project. For delivering an average of 2,000,000 gallons per day, the operating expenses would have amounted to $18,000 per year.

The following analyses of Lake Ontario water were made in 1902–03. (1) was taken about one and one-half miles out from Manitou Beach and the analysis made by Fred R. Eilinger; (2) was taken a few feet below the surface of water, about one mile west of the mouth of the Genesee river and about 2000 feet out; (3) was taken at the mouth of the Genesee river, 2000 feet out from the end of the pier. The chemist making the two latter analyses is unknown—they were furnished by the courtesy of J.W. Ledoux, of the Lake Ontario Water Company.

(Parts per 100,000)

	(1)	(2)	(3)
Total solid residue dried at 100° C.	12.93	14.15	15.10
Fixed residue at low red heat	8.53	......	......
Volatile at low red heat	4.40	......	......
Sodium chloride	0.74	1.32	1.57
Ammonia, free	0.001	none	none
Ammonia, albuminoid	0.008	trace	0.006
Nitrates	none	trace	trace
Nitrites	none	none	none
Temporary hardness	9.42	......	......
Permanent hardness	1.19	......	......
Total hardness	10.61	......	......
Sulphate of lime	......	2.16	2.41
Carbonate of lime	......	6.21	6.30
Carbonate of magnesia	......	2.58	2.32

The Erie canal. It was also suggested that a temporary supply be taken from the Erie canal at either the eastern or the western wide waters. The possibility of a failure of the canal banks and the fact that the water is entirely withdrawn from the prism every winter or spring for some weeks for the purpose of making repairs interfered greatly with the usefulness of this source; and the further fact that the water is badly polluted with sewage from Buffalo, Lockport and a number of villages along the route to Rochester made it unfit for domestic use without filtration. It was also doubtful whether the canal authorities would permit any such abstraction of the water, but if the necessary consent were obtained the water could have been filtered and pumped directly into the large distributing main at Smith street at less expense than was entailed by any other plan for securing a temporary additional supply, which has yet been mentioned. The risk of failing to get water at times was considerable, although when this occurred a temporary draught could have been made upon the storage of the Rush reservoir.

Honeoye creek. At the village of East Rush, this creek is about 1.53 miles south of the Rush reservoir and 215 feet below the level of the same. Water therefrom would require filtration before being fit for domestic use. The estimated cost of the necessary works, including $24,000 for the purchase of a filtering plant, was about $58,000, the water to be delivered into the Rush reservoir through a 12-inch main with a pumping engine of a capacity of 2,000,000 gallons per day. The principal objection to this plan was that the water was not delivered directly into the Mount Hope reservoir, where it was most needed.

The following are analyses of water of Honeoye creek as made by Professor Lattimore. (1) was taken from the creek at a point south of North Bloomfield; (2) just below Honeoye Falls, and (3) at East Rush:

(*Parts per 100,000*)

	(1)	(2)	(3)
Total solids	13.50	12.50	19.00
Fixed residue	8.50	7.00	12.50
Loss on ignition	5.00	5.50	6.50
Sodium chloride	0.31	0.30	0.33
Ammonia, free	0.002	0.002	0.003
Ammonia, albuminoid	0.006	0.006	0.006
Nitrites	none	none	none
Nitrates	none	none	none
Hardness	8.10	8.60	9.70

Genesee river. In considering the Genesee river as a source for a temporary supply for Rochester, the intake might be located either in the vicinity of the south end of the Erie railway bridge or at Elmwood avenue. The former location is nearer to Mount Hope reservoir, but the proximity of the oil works and a storm outlet for a new sewer on the west side makes the Elmwood avenue site somewhat more desirable. The latter is about 1.63 miles from the reservoir, and the usual low-water surface of the river is about 128 feet below the same. To render the water fit for domestic use it would need to be filtered, and in this respect it stands on practically the same scale as the water of all the other streams previously mentioned and that of the Erie canal. The principal advantage of this site was that the pumping station would become available for supplying water to South Park as soon as its use for supplementing the flow from Hemlock lake ceased; also the force main would serve as a future distributing pipe for the southern districts of the city on both sides of the river. All of the plant except the filters would thus have had a permanent value for two city departments. The estimated cost of the works with a 12-inch force main and including filters was about $51,000, but if the force main were increased to 16 inches in diameter, the cost was estimated at $60,000. With the filter plant rented for a few years the costs would be about $15,000 less than the amounts named.

The following is an analysis of Genesee river water as made by Professor Lattimore in 1890:

(*Parts per 100,000*)

Total solids	37.50
Fixed residue	23.50
Loss on ignition	14.00
Sodium chloride	6.27
Ammonia, free	none
Ammonia, albuminoid	0.002
Nitrites	none
Nitrates	none
Hardness	13.80

The following series of analyses of Genesee river water was made by Fred R. Eilinger, of the Rochester Health Department, in 1902. The first column of table No. 98 gives the flow of the river in cubic feet per second on the date of each analysis:

TABLE NO. 98—ANALYSES OF GENESEE RIVER WATER, TOGETHER WITH THE FLOW, FOR CERTAIN DAYS IN 1902

(Parts per 100,000)

DATE (1)	Flow of the river in cubic feet per second (2)	Total residue (3)	Organic and volatile (4)	Suspended matter (5)	Sodium chloride (6)	Temporary hardness (7)	Permanent hardness (8)	Total hardness (9)
1902								
June 18	1,325	22.00	5.00	22.40	2.20	9.92	3.09	13.01
“ 25	850	39.00	17.00	4.80	8.58	11.57	7.76	19.33
July 2	3,975	25.00	11.00	36.25	3.96	8.39	4.42	12.81
“ 9	18,750	26.00	8.00	34.10	1.82	10.08	5.30	15.38
“ 16	2,350	30.00	14.00	12.00	3.63	13.43	4.63	18.06
“ 23	11,450	24.00	11.00	182.60	2.85	11.42	2.66	14.08
“ 30	3,510	25.00	10.00	6.30	2.97	14.93	3.52	18.45
Aug. 6	1,750	25.00	11.00	40.00	4.29	11.80	5.15	16.95
“ 13	1,175	35.00	15.00	26.00	6.60	13.50	5.92	19.42
“ 20	910	36.00	19.00	18.00	8.91	6.85	6.95	13.80
“ 27	850	46.00	24.00	2.80	9.57	15.77	10.04	25.81
Sept. 3	810	49.00	25.00	1.20	13.20	15.64	8.92	24.56
“ 10	740	54.00	21.00	*	11.88	17.02	15.01	32.03
“ 17	440	75.00	38.00	*	19.24	18.54	16.30	34.84
“ 24	830	60.00	26.00	2.00	14.52	17.16	14.33	31.49
Oct. 1	1,020	35.00	14.00	2.40	7.59	12.81	7.85	20.66
“ 8	1,020	45.00	22.00	2.00	20.46	12.58	6.70	19.28
“ 15	850	38.00	16.00	2.00	8.91	13.05	10.12	23.17
“ 22	1,275	28.00	12.00	22.00	6.60	10.56	5.63	16.19
“ 29	820	39.00	19.00	1.40	10.56	12.85	8.80	21.65
Nov. 5	730	40.00	18.60	1.00	8.25	13.09	10.21	23.30
“ 12	575	45.00	21.00	0.80	13.20	14.56	9.82	24.38
“ 19	590	56.00	23.00	0.40	14.19	14.27	13.77	28.04
“ 26	715	46.00	22.00	0.50	13.37	14.40	9.18	23.58
Dec. 3	850	38.00	16.00	1.00	7.26	12.92	8.49	21.41
“ 10	590	33.00	16.00	2.50	8.91	11.22	7.60	18.82
“ 17	750	39.00	17.00	0.50	9.24	13.61	9.82	23.43
“ 24	8,300	22.00	8.00	35.80	4.29	8.71	4.75	13.46
“ 31	1,100	31.00	12.00	0.10	6.93	12.39	6.74	19.13

* Not determined.

A few other temporary sources were proposed, but their distance rendered them practically out of consideration. Of the whole series in which the requisite quantity of water was in sight, Erie canal was doubtless the most economical, and following that, Genesee river. Moreover, both these plans could have been carried out in a short time. Serious objections to their adoption, however, were raised, not only on the ground that filtration is inadequate to render the water safe for drinking, but also that the owners of waterpower on the various races would prevent any abstraction of water from the Genesee river.

The objection to the use of the river water by the mill owners rested principally on the ground that their waterpower would be damaged by the abstraction of the proposed quantity. On March 20, 1891, a committee of owners of the Johnson and Seymour race, the Rochester, Carroll and Fitzhugh race, the Hydraulic Power Company's race and the Rochester and Brush Electric Light Companies, reported that the majority of such owners would permit the city to take 2,000,000 gallons per day from the river on the payment of an annual rental of $14,600; and on the same day the mill owners on Brown's race resolved that they would oppose with all reasonable persistency any proposition to draw any further supply from the Genesee river or its tributaries.

Lake Erie

In May, 1895, the writer examined Lake Erie somewhat carefully as a source of water supply for the manufacturing town of Lorain on the south shore, twenty miles west of Cleveland. The results of that study are given in a paper, Lake Erie as a Source of Water Supply for the Towns of its Borders, and little additional reference will be made to the matter in this place, except to state that there are a considerable number of chemical analyses given in said paper.

Table No. 99 gives monthly chemical, microscopical and bacteriological analyses of Lake Erie water at Buffalo from April, 1902, to March, 1903, inclusive. Only one chemical analysis was made per month, but there were several determinations of bacteria. The chemical analyses are by Prof. Herbert M. Hill, while the bacteriological determinations are by Dr. Wm. G. Bissell. In order to fully understand the indications of these latter, one needs to study them in detail as given in the monthly bulletins of the Health Department.

TABLE NO. 99—MONTHLY CHEMICAL, MICROSCOPICAL AND BACTERIOLOGICAL ANALYSES OF LAKE ERIE WATER AT BUFFALO, FROM APRIL, 1902, TO MARCH, 1903, INCLUSIVE
(Parts per 100,000)

ELEMENTS DETERMINED	April 29, 1902	May 28, 1902	June 28, 1902	July 29, 1902	August 29, 1902	September 26, 1902
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Temporary hardness	6.72	6.86	5.00	3.17	3.07	2.57
Permanent hardness	4.10	4.20	5.39	4.34	4.13	7.89
Total hardness	10.82	11.06	10.39	7.51	7.20	10.46
Total residue at 100° C.	29.74	12.69	18.53	14.75	14.56	17.15
Residue after ignition	21.98	10.12	9.77	7.55	9.77	10.29
Organic residue	7.76	2.57	8.76	7.20	4.79	6.86
Chlorine	0.77	0.96	0.76	0.75	0.57	0.62
Oxygen absorbed in fifteen minutes	0.012	0.011	0.012	0.011	0.009	0.013
Oxygen absorbed in four hours	0.068	0.046	0.051	0.042	0.041	0.059
Dissolved oxygen	0.96	0.83	0.86	0.89	0.86	0.84
Dissolved oxygen, per cent of saturation	99.8	101.2	101.2	95.6	93.2	102.4
Ammonia, free	0.005	0.002	0.0014	0.00	0.001	0.002
Ammonia, albuminoid	0.016	0.017	0.018	0.006	0.006	0.014
Nitrites	trace	none	none	none	none	trace
Nitrates	trace	trace	0.002	0.004	0.01	none
Algae	present	present	present	present	present	present
Bacteria*	740 to 5,200	80 to 3,800	200 to 900	140 to 640	160 to 540	160 to 720

*Maximum and minimum number found in month.

TABLE NO. 99—MONTHLY CHEMICAL, MICROSCOPICAL AND BACTERIOLOGICAL ANALYSES OF LAKE ERIE WATER AT BUFFALO, FROM APRIL, 1902, TO MARCH, 1903, INCLUSIVE *(concluded)*

(Parts per 100,000)

ELEMENTS DETERMINED	October 15, 1902	November 26, 1902	December 29, 1902	January 31, 1903	March 2, 1903	March 25, 1903
(8)	(9)	(10)	(11)	(12)	(13)	(14)
Temporary hardness	2.09	5.67	6.97	6.33	7.02	6.31
Permanent hardness	8.49	5.31	2.45	3.45	2.50	3.12
Total hardness	10.58	10.98	9.42	9.78	9.52	9.43
Total residue at 100° C	20.58	15.61	16.29	16.33	14.24	15.78
Residue after ignition	15.78	8.92	11.49	11.83	7.55	10.46
Organic residue	4.80	6.69	4.80	4.50	6.69	5.32
Chlorine	0.86	0.56	0.65	0.82	0.84	0.73
Oxygen absorbed in fifteen minutes	0.012	0.032	0.024	0.048	0.038	0.021
Oxygen absorbed in four hours	0.083	0.062	0.104	0.098	0.072	0.045
Dissolved oxygen	0.91	....	1.21	1.13	1.15	1.12
Dissolved oxygen, per cent of saturation	01.9	....	108.7	99.8	104.2	102.1
Ammonia, free	0.0026	0.0013	0.002	0.001	0.0022	0.001
Ammonia, albuminoid	0.036	0.015	0.009	0.008	0.013	0.011
Nitrites	none	none	none	trace	none	trace
Nitrates	0.05	none	none	trace	trace	none
Algae	....	present	present	present	present	present
Bacteria*	180 to 1,760	200 to 800	100 to 500	220 to 1,200	270 to 1,320	160 to 620

*Maximum and minimum number found in month.

Plate 39.

Mill of the International Paper Company at Piercefield.

As further illustrating the quality as well as the quantity of water obtainable for municipal water supplies in western New York, the villages of Brockport and Holley have for a number of years had insufficient supplies from dug wells—the same thing is true of the village of Albion. The village of Medina is stated to be supplied from the Erie canal, although some pretence is made of taking the supply from a well, and the city of Lockport has never had any supply except from the Erie canal. At all these places the supply of pure, potable water is scanty and of high value—the same thing is true generally throughout western New York. The study at Rochester can be duplicated almost anywhere in the region from Seneca lake to the western limits of the State.

Quality of Water in the Vicinity of Medina

In order to show some facts in regard to the quality of water near Medina, the following analyses are herewith included. (1) is from a disused shallow well, one mile south of Shelby Center; (2) is from a bored well not far from the preceding, taken after a few days pumping. These two analyses were made by Prof. Herbert M. Hill, of Buffalo; (3) is also from a bored well, in the same locality, and (4) is from the Oak Orchard creek, a mile south of Shelby Center. The two latter were made by Fred R. Eilinger, chemist of the Rochester Health Department:

(Parts per 100,000)

	(1)	(2)	(3)	(4)
Residue after ignition........	30.53	28.82	21.00	36.00
Organic and volatile residue..	18.86	4.70	12.00	12.50
Total residue dried at 100°C..	49.39	33.52	33.00	48.50
Chlorine	1.73	0.83	0.90	1.50
Ammonia, free	trace	0.00	0.002	0.001
Ammonia, albuminoid	0.003	0.003	0.006	0.019
Nitrites	trace	none	none	none
Nitrates	trace	0.10	0.10	0.04
Temporary hardness	3.50	5.40	18.00	18.00
Permanent hardness	6.35	9.00	4.00	17.00
Total hardness	9.85	14.40	22.00	35.00

The well from which (3) was taken is about 1500 feet from Oak Orchard creek, with the ground surface only a few feet above the water level in the creek. The elevation of water in Oak Orchard creek directly opposite is substantially the same as in the well, and when pumping from the well the water is drawn to about 5 feet below the level of the water in the creek. Nevertheless, analyses (3) and (4) show that the quality of water in the well is quite different from that in the creek. In the case of the water from the well, permanent hardness is only 4°, while the water from the creek shows 17°, although it is difficult to understand, under the conditions, how the source of water in the well can be other than that from the creek—the more specially since the underlying rock is open. In regard to the permanent hardness of the creek water, as shown by analysis (4), it is probably due to Oak Orchard creek flowing over a bed of gypsum near Oakfield.

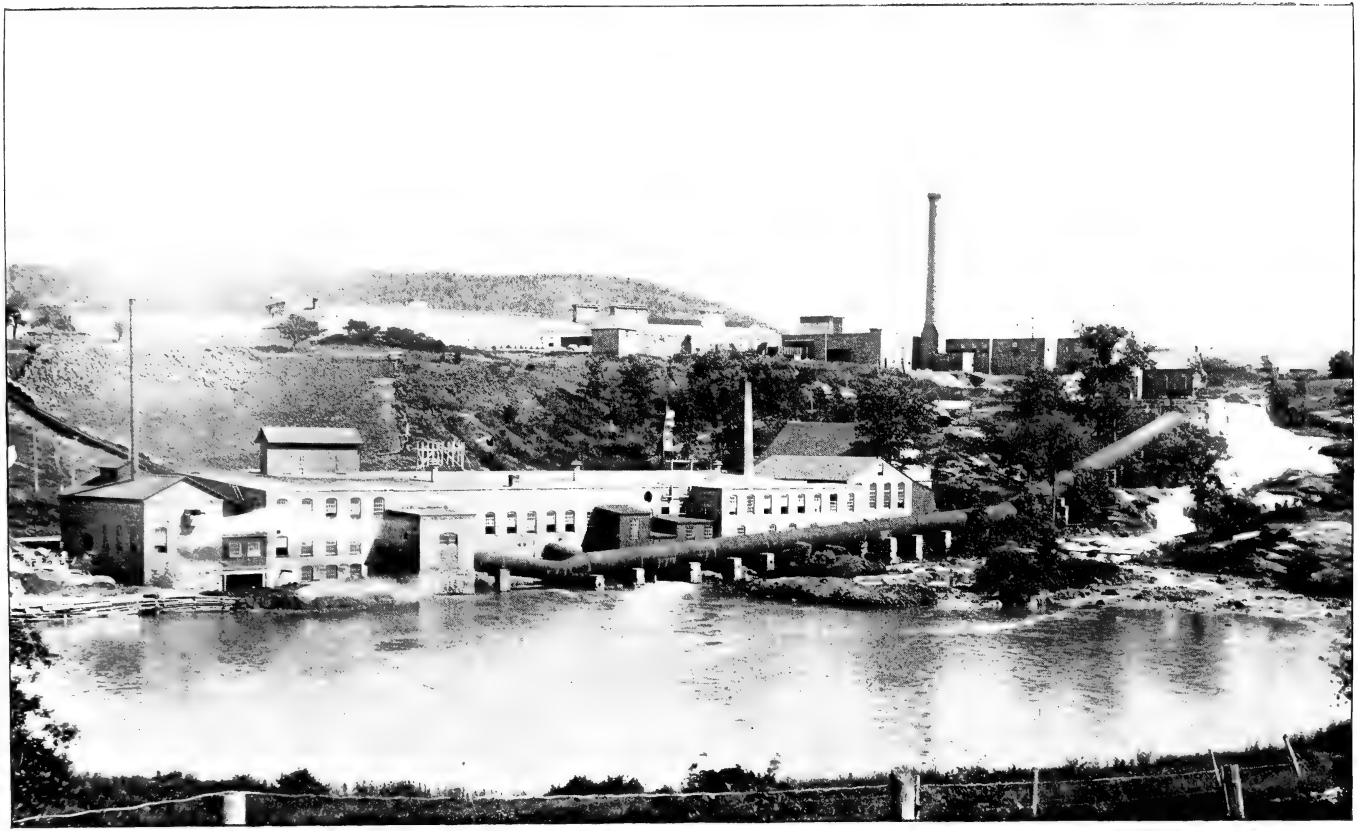
Quality of Water in the Vicinity of Batavia

In order to still further illustrate water supplies in western New York, the following analyses from the vicinity of Batavia, as made by Mr Eilinger, are of interest; (1) is from Devil's lake, a small body of water ten or twelve miles west of Batavia; (2) is from Mill springs, five miles north of Batavia; (3) is from Hamilton springs, two miles south of Batavia; and (4) is from Horseshoe lake, two and one-half miles east of Batavia. Mill springs, the analysis of which contains the most total hardness, are at the foot of a ridge from 100 to 150 feet in hight and probably is not far from the gypsum belt, as the permanent hardness in this water is difficult to account for on any other basis. Both Hamilton springs and Horseshoe lake are above that belt, and accordingly permanent hardness is not very serious in either of them.

(Parts per 100,000)

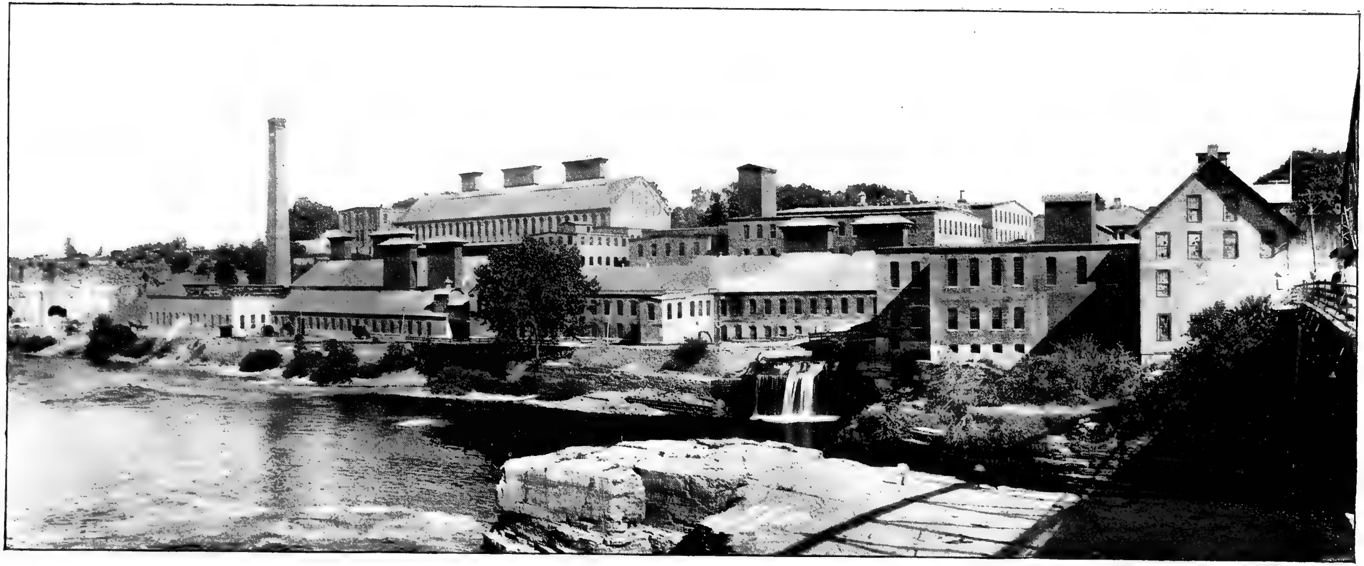
	(1)	(2)	(3)	(4)
Total residue dried at 100° C..	24.00	116.00	31.00	28.00
Fixed residue at low red heat.	11.00	88.00	18.00	16.50
Volatile at low red heat......	13.00	28.00	13.00	11.50
Ammonia, free	0.06	0.003	0.001	0.002
Ammonia, albuminoid	0.044	0.003	0.003	0.002
Chlorine in chlorides.........	0.16	0.24	0.30	0.80

Plate 40.



Mill of the International Paper Company at Lake George.

Plate 41.



Mill of the International Paper Company at Glens Falls.

	(1)	(2)	(3)	(4)
Equivalent to sodium chloride	0.26	0.40	0.50	1.32
Nitrites	none	none	none	none
Nitrates	none	0.01	0.20	0.20
Temporary hardness	*	22.00	17.50	20.00
Permanent hardness	*	50.00	2.50	4.50
Total hardness	*	72.00	20.00	24.50

There are a number of other springs in the vicinity of Batavia, although none of them has a very large flow. The following is a list of the various springs, with an estimate as to their probable minimum yield:

	Gallons
Horseshoe lake	1,000,000
Mill springs	450,000
Harkley springs	300,000
Shepherd springs	500,000
Hilton and Damon springs	150,000
Lincoln springs	200,000
Baldwin springs	100,000
Devil's lake	100,000
Hamilton springs	500,000
Total	3,300,000

Probably all of these springs may be taken for a safe minimum yield at 3,000,000 gallons in twenty-four hours, although this is an estimate merely, based on experience, no weir measurements having been made.

At Williamsville, near Buffalo, there is a spring flowing at the rate of 2,000,000 or 3,000,000 gallons per day, which probably issues from the horizon of the gypsum. At a number of other places in western New York springs appear, specially along the ridge at the foot of which is the gypsum belt, but the waters issuing are so hard as to render it undesirable to use them. A marked case of this character is near Akron, where an excavation developed a flow of 3,000,000 or 4,000,000 gallons per day, but of which the permanent hardness was equal to one part in a thousand.

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*Not determined.

THE DRAINAGE OF SWAMP AREAS IN NEW YORK

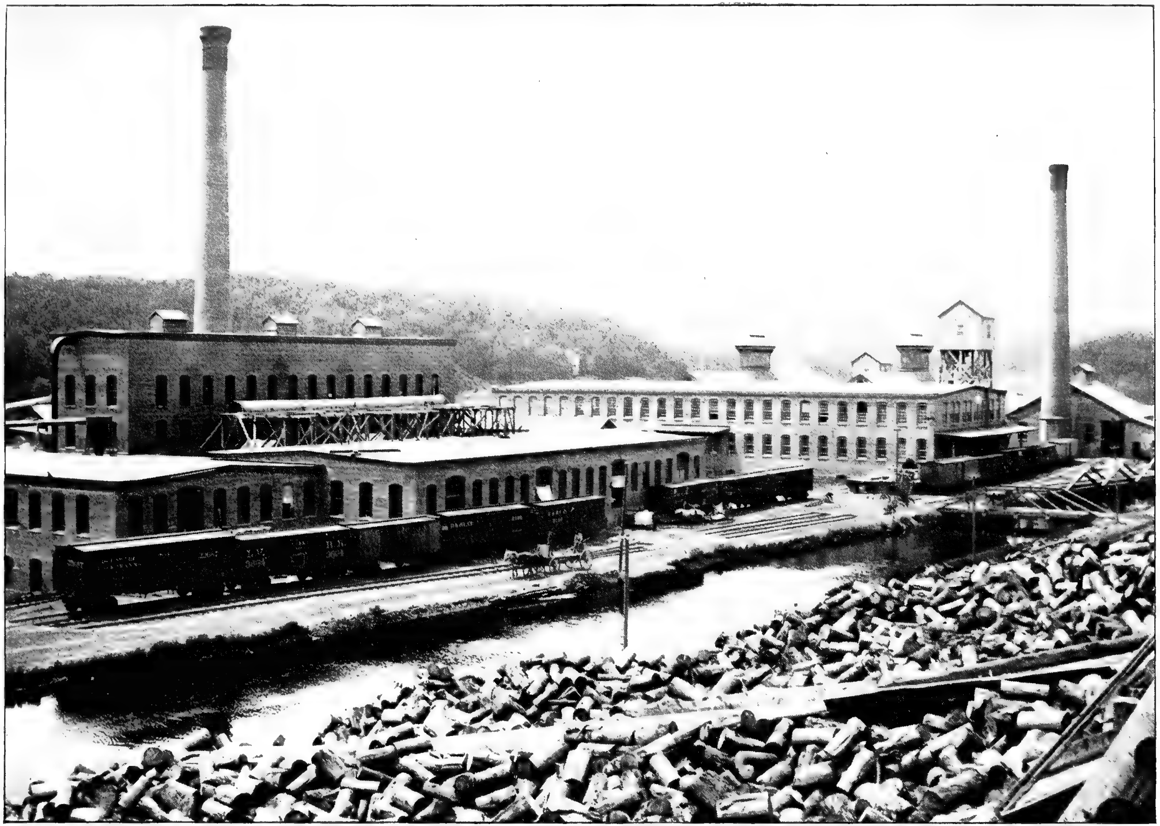
There are a large number of swamp areas in New York State, the major portion of which is situated in the western part of the State, in Chautauqua, Cattaraugus, Erie, Niagara, Orleans, Genesee, Ontario, Yates, Wayne, Seneca, Cayuga, Onondaga and Oswego counties. There are also extensive swamp areas in the northern part, as well as in the southern part of the State. The following are the approximate areas of some of the more important of these swamps:

	Acres	
Conewango swamp	12,000	
Tonawanda	20,000	
Oak Orchard	25,000	
Montezuma	26,000	
Flint creek	3,600	
Weedsport	7,500	
Cicero	16,000	
Wallkill valley	26,000	
In addition, there are in various parts of the State small swamps aggregating at least	107,000	
Total	243,100	acres = 380 sq. miles

The Water Storage Commission received urgent requests to drain some of the larger of these swamps, and since such work was clearly in line with the work of this commission, particular attention was paid to such improvement. Some attempt was made to drain Montezuma marsh in previous years, but owing to neglect of the fundamental principles, comparatively little improvement has resulted. As regards Montezuma swamp, its drainage will be effected as incidental to the construction of the barge canal, but the drainage of the numerous other swamp areas, such as Conewango, Tonawanda, Oak Orchard, Cicero, Flint Creek, etc. can only be effected by works specially designed for each local case.

In order to give some idea of the value of draining these swamps, it is understood that swamp lands now sell at from $2

Plate 42.



Mill of the International Paper Company at Fort Edward.

to $4 per acre. If such lands were effectually drained, so that they could be cultivated every year, they would be the most valuable in the State, and worth at least $60 per acre. But in order to make them of this value, even after the drainage is accomplished, they must be cleared and put in shape for cultivation, which will require a large amount of labor in addition to the drainage. Assuming them to cost, with some of the adjacent low flatlands, an average of $5 per acre, the net gain would be $55 per acre, amounting for 380 square miles to $13,370,500. It is difficult to say what the cost of the drainage would be, although it is doubtful if it would cost, including fitting them for cultivation, more than $30 per acre, or for the entire area, the total cost may possibly be $7,293,000, leaving a net profit on the transaction of $6,077,500. This expense should be borne partly by the land owners and partly by the State, the proportion to be fixed on further consideration. There is no good reason why the State should not inaugurate an improvement like this.

THE PAPER INDUSTRY IN NEW YORK

In view of the fact that the paper industry in this State is almost entirely dependent upon waterpower for its profitable operation, the following chapter is included.

According to the Twelfth Census (1900) out of a total capital invested in the paper industry in the United States of $167,507,713, there was invested in the State of New York $37,349,390, or about 22½ per cent of the total capital invested in the whole country.

The total cost of materials used in this industry in New York in 1900 was $14,563,222, of which there were 225,327 cords of domestic spruce used for ground pulp, which cost $1,260,593, or at the average rate of $5.60 per cord. Domestic spruce for sulphite and soda fiber was used to the extent of 138,098 cords, costing $724,822. Canadian spruce was used for ground pulp to the extent of 54,923 cords, while for sulphite and soda fiber there were 86,606 cords of Canadian spruce used.

In addition to the preceding, 51,208 cords of Canadian poplar wood and other woods were used. The total use of wood, therefore, was 556,162 cords.

Rags were used to the extent of 17,899 tons, which cost $420,-870, or at the rate of $23.51 per ton; 37,244 tons of old waste paper were used, costing $428,531, and 13,947 tons of Manila stock, including jute, bagging, rope, waste, thread, etc. which cost $646,776; 17,644 tons of straw were used. In addition, 93,-749 tons of ground wood pulp were purchased at a cost of $1,485,176, or at the rate of $15.81 per ton; 20,447 tons of soda wood fiber were purchased and 66,769 tons of sulphite wood fiber. In addition, other chemical fiber was purchased to the extent of 8,554 tons.

The total value at the point of manufacture of the paper product in New York in 1900 was $26,715,628, of which newspaper amounted to 162,153 tons, valued at $5,405,452, or at the rate of $33.33 per ton. There were 27,611 tons of bookpaper made, worth $1,706,565, or at the rate of $61.81 per ton. In addition, a considerable quantity of lithographic plate paper, cardboard, bristolboard, fine writing paper, etc. was made.

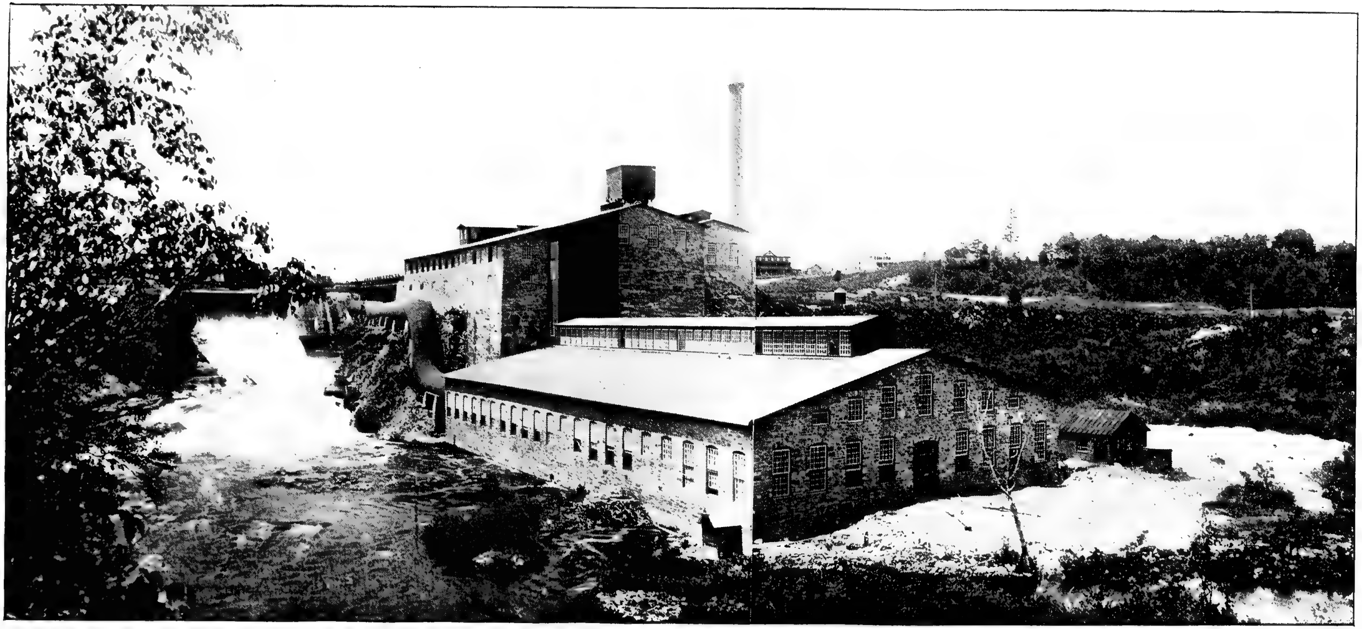
The number of establishments making paper in New York in 1900 was 179, of which 39 were owned by individuals, 44 by firms and limited partnerships and 96 by incorporated companies.

In 1890 the total value of the exports of paper from the United States amounted to $1,226,686, while in 1900 this had increased to $6,215,833. These figures do not include the value of 82,441 tons of wood pulp.

In order to show relative figures, we will briefly compare New York with Massachusetts. The total number of paper establishments in Massachusetts in 1900 was 93, of which 13 were owned by individuals, 13 by firms and limited partnerships and 67 by incorporated companies. The total capital invested in Massachusetts was $26,692,922. The total cost of materials used was $11,918,802, while in New York it was $14,563,222. We learn, therefore, that in New York the total cost of materials used was $2,644,420 more than in Massachusetts, and that the total value of the product in Massachusetts was $22,141,461 as against $26,715,628 in New York, or the value of the product in New York was $4,574,167 more than in Massachusetts.

A reason for these differences is found in the fact that there are more mills in Massachusetts than in New York which

Plate 43.



Mill of the International Paper Company at Cadyville.

make fine paper. The use of rags, including cotton, flax, waste and sweepings in that State amounts to 86,715 tons, while in New York there are only 17,899 tons used. Book papers are made in Massachusetts to the value of $3,120,867 as against $1,706,565 in New York. Lithographic papers, cardboard, bristolboard, etc. amounts in Massachusetts to $2,013,920 as against $200,315 in New York. There is an annual product in Massachusetts of fine writing paper of $8,751,566 as against $70,115 in New York, while other fine papers are valued in Massachusetts at $2,547,072 as against $66,844 in New York.

If Massachusetts had the same area as New York, with the paper industry proportionately developed over the whole State, the total capital invested in Massachusetts would amount to, roundly, $160,000,000. Since paper making is the one great industry depending upon waterpower, the reason for this may be again placed very largely in rational State laws and thorough development of waterpower.

In order to illustrate the foregoing proposition, it may be mentioned that the total power derived from steam, water and other kinds of power used in paper making in New York in 1900 was 228,478 horsepower, while in Massachusetts it was 82,893 horsepower. Of this 191,117 horsepower was from water in New York and 44,935 was from water in Massachusetts, leaving 37,361 horsepower derived from steam and other motive power in New York and 37,958 horsepower derived from the same sources in Massachusetts.

The yearly capacity in tons of paper in New York is given at 611,179 and of pulp 495,668.[1] In Massachusetts the yearly capacity of the mills is 283,576 tons of paper, and of pulp 31,920 tons. These figures show the great difference in the quality of the business in the two States. In New York a large amount of pulp is ground, whereas in Massachusetts there is only about one-sixteenth as much. The mills there are producing high-grade papers, for which steam power is less objectionable than for a lower grade. It is common to run the paper machines proper by steam, as steam power is preferable for this purpose, because of yielding more uniform power, but for making ground pulp

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[1] These figures are as given in the Census Report, Vol. IX, p. 1035.

waterpower is indispensable. At least 65 horsepower per twenty-four hours is required to produce a ton of mechanical pulp.

In 1900 New York ranked first not only in the number of establishments and in the amount of capital invested, but also in the number of wage-earners and the wages paid, as well as in the cost of materials and in the value of the product. Massachusetts was second and Maine third, although as we have seen if we make the comparison on unit areas, Massachusetts was first. As to the different classes of products, New York was first in wood pulp, newspaper, wrapping paper and other products not specially designated, while Massachusetts was first in the production of bookpaper and fine writing paper.

The principal wood from which paper is made is spruce. It forms 76 per cent of all the wood used in the United States for both mechanical pulp and chemical fiber. Gray pine, white pine, white fir, balsam, hemlock and larch are also used for the production of mechanical pulp and occasionally for chemical pulp. The wood chiefly used for the soda process is poplar, although aspin, cottonwood and sweet-gum are sometimes used. Cypress and several of the preceding timbers are also used for sulphite pulp. Beech, silver maple, basswood, white birch and paper birch are sometimes used.

The chief processes of reduction to pulp are three in number—the mechanical, the soda process and the sulphite process. The mechanical process consists in grinding the wood on a grindstone after removing the bark. All the sound wood of the tree is used, provided it is free from knots. A cord of spruce wood will produce about one ton of pulp.

The soda process is based on the solvent action of alkali at high temperature. Poplar is the wood chiefly used in the soda process, although considerable quantities of pine, spruce and hemlock are consumed, while maple, cottonwood, white birch and basswood frequently replace poplar. About two cords of wood are required to produce one ton of soda pulp.

The sulphite process consists in treating vegetable substances with a solution of sulphurous acid, heated in a closed vessel under a sufficient pressure to retain the acid gas until the intercellular matter is dissolved. Any coniferous wood, which is not

Plate 44.

Dam and flume of the International Paper Company at Cadyville.

too resinous, may be used, although the woods chiefly used are spruce, hemlock and balsam. About two cords of wood are required for one ton of the sulphite pulp.

Newspaper and common wrapping papers consist chiefly of mechanical pulp, with from 10 per cent to 25 per cent of sulphite pulp added to hold the stock together. One class of strong wrapping paper is made entirely of sulphite pulp.

Soda fibre is used as soft stock in book and writing papers. It came into use earlier than sulphite fiber, but owing to the greater cheapness of the sulphite process, and the superior strength of the fiber, the use of the latter has increased more rapidly than the soda.

In order to show the comparatively recent development of the paper industry, it may be mentioned that mechanical pulp was invented in Germany in 1844, but was not made in this country until 1867. It, however, reached no commercial importance anywhere until considerably later than 1867. There were in the United States, in 1900, 168 mills in operation, of which 81 were in New York.

The soda process was introduced into this country from Europe in 1854. The number of mills in the United States in 1900 was 36, of which 2 were in New York.

The sulphite process is an American invention, used at Providence in 1884. The number of mills in operation in the United States in 1900 was 69, of which 17 were in New York.

Modern paper making began with the introduction early in the nineteenth century of the Fourdrinier machine, which was a development of an invention made by Louis Roberts, of Essonne, France, about 1798. Paper was made mostly from rags, which continued to be the materials used until past the middle of the nineteenth century, when wood fibre was introduced. The use of rags for making newspaper has been largely superseded by wood.

Paper making, however, is an ancient art, probably originating in China as early as 150 A. D. Several centuries later, the Arabs learned the art of paper making from the Chinese, who in turn introduced the art into western Europe. Paper was made in France in 1189 A. D., and in England about two hundred years later.

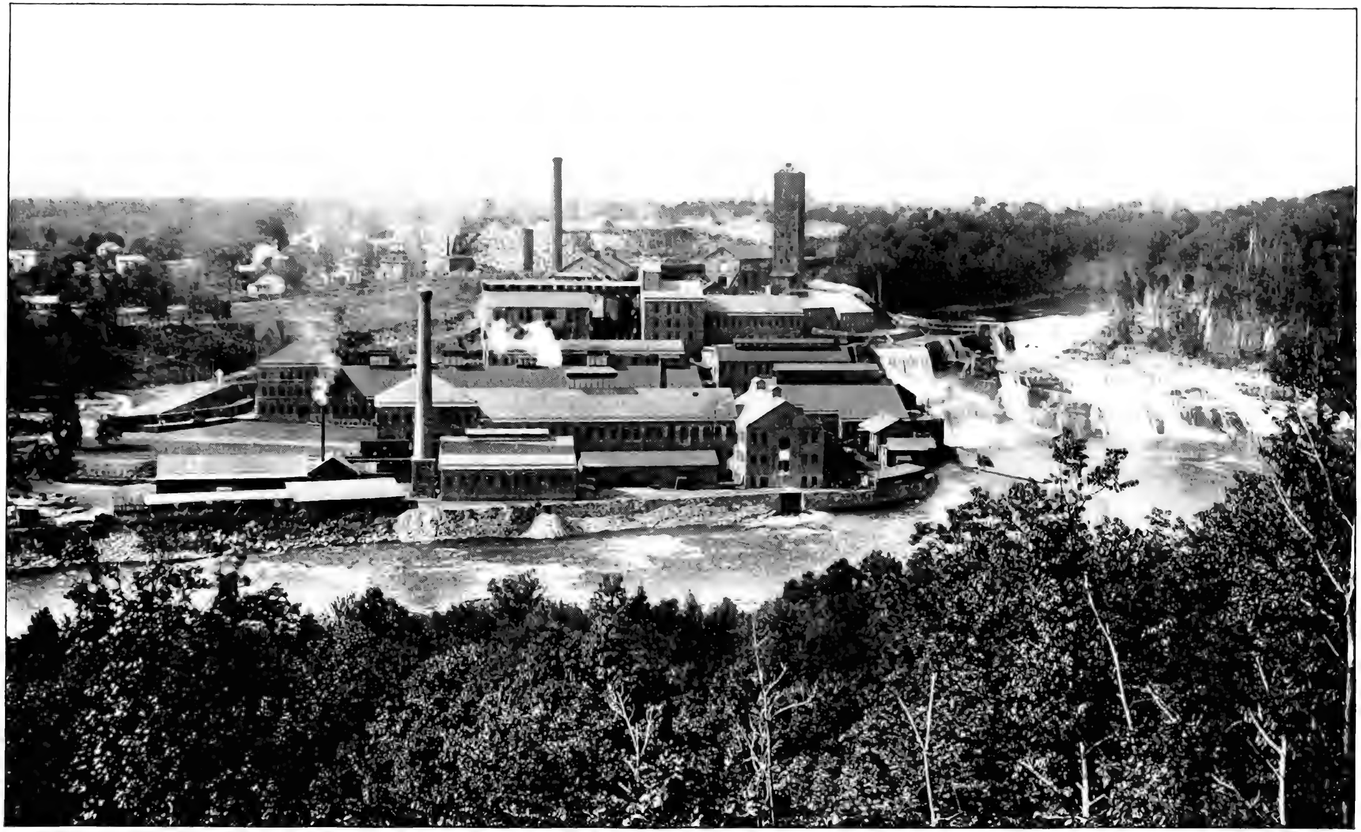
Until one hundred years ago the method of paper making had been the same as originally practiced by the Chinese—fibrous materials being beaten into a pulp, mixed with water and molded into sheets by manual labor.

Among the interesting industrial developments of the present day, the International Paper Company, incorporated under the laws of New York State in January, 1898, may be mentioned. This company acquired at the time of its incorporation nearly all the larger mills manufacturing newspaper in the eastern States and later on has acquired several additional paper and pulp mills, timber lands, waterpowers and other properties. Its manufacturing plants, waterpowers and timber lands are located in Maine, New Hampshire, Vermont, Massachusetts, New York, Michigan and Canada. In New York the International Paper Company owns the following mills: Glens Falls, Fort Edward, Palmers Falls, Niagara Falls, Lake George, Ontario (near Watertown), Piercefield, Herkimer, Lyon Falls, Cadyville, Watertown (at Watertown), Woods Falls (near Watertown) Underwood and Harrisville.

The capital stock of this company is $25,000,000 preferred, of which $22,406,700 had been issued June 30, 1903, and $20,000,000 common, of which $17,442,800 had been issued at the same date; $10,000,000 of first consolidated mortgage gold bonds have been authorized, bearing interest at the rate of 6 per cent per annum, payable semiannually, February 1 and August 1. The plants of the company were valued in 1903 at $41,925,446. The gross income for the fiscal year ending June 30, 1903, was $20,142,771. The cost of raw materials and manufacturing, including expenses of administration, sales, and cost of selling, was for the same year $16,529,310.

The International Paper Company has been of considerable value not only in this State, but in the other states where it operates, in that it has modified the conditions prevailing before it came into existence. Competition was so severe as to have blinded many manufacturers to the fact that there was any future to be considered. As soon as the company was formed

Plate 45.



Mill of the International Paper Company at Palmer's Falls.

its officers realized that the investment in the plants was so large that one of the first steps was to guarantee their permanency by providing for a future supply of raw materials. This led to an extensive acquisition of timber lands by this company, as well as by a number of independent companies. At the present time, in 1904, the most of the large companies operating in this State own their timber lands, from which by a rational system of forestry they produce their own timber.

The company has given attention to forest fires and has made considerable outlays for preventing and extinguishing the same. It has also supported such legislation in this State as will provide for a patrol system, and has in various ways tried to interest the public in this subject in Maine and other states. Thus far its work in this connection has been largely missionary, but practical good will undoubtedly follow.

The first great benefit, therefore, which has resulted from the formation of the International Paper Company is its effect upon forestry.

This company has also advocated a rational system of water storage in New York and other states where water storage is applicable. Indeed, the whole subject has been quickened by this company, as has forestry. The powerful influence of the International Paper Company has made water storage a live subject in New York, and the attention of the paper industry generally has been specially directed to this consideration. One value of such an aggregation of capital is the amount of influence it may bring to bear upon subjects like this, where individuals acting independently could accomplish little or nothing because of their inability to act together. The second work accomplished by this company, therefore, is of very material assistance in the inauguration of water storage.

The company has also spent large sums of money improving its plants, balancing its pulp and paper producing capacity, and bringing its mills to a higher state of efficiency, the fundamental idea being to give stability and permanency to the industry. Not only have foreign markets been sought, but it has introduced improvements in organization and administration of its mills and affairs. It has also introduced scientific methods, as shown by the establishment of a bureau of tests for making experiments, both physical and chemical.

Before the establishment of the International Paper Company very great and wasteful abuses had grown up in the use of paper by the various newspapers. It has very largely succeeded in reforming these.

In the general account, therefore, there may be placed to the credit of the International Paper Company the introduction of rational forestry, and material assistance to water storage, the introduction of scientific methods of manufacture, and finally a reformation of abuses in the paper trade. These improvements have already been of benefit to the paper trade as a whole and done much to enhance the value of the industry to this State.

We will now discuss another phase of the subject. There is great exaggeration in the public mind as to the effect of the pulp industry upon the streams of the State. There is a popular impression that the wood-pulp industry is responsible for the denuding of forest areas, although anybody who visits the forested portions of the State understands that this cannot be true. At the present time nine-tenths of all the timber cut in New York for pulp is spruce, and very rarely is the spruce more than one quarter of the total stand of timber. Usually the spruce is not cut to below eight to ten inches in diameter. The effect of taking out the spruce from a timber area has been discussed on a previous page and will not be referred to here any further than to say that, while the effect is slightly apparent, it can be held responsible in only a slight degree for fluctuation in stream flow.

Moreover, the paper and pulp industry is not responsible for all the timber cut in this State, as may be shown by considering the following figures for the year 1900, from the Seventh Report of the Forest, Fish and Game Commission of New York. From these figures it appears that the total cut of lumber and pulp wood from the Adirondack and Catskill forests amounted to 651,135,308 feet B. M. Adding to this 349,000,000 feet B. M. cut for firewood, we have a total cut of, roundly, 1,000,000,000 feet B. M. The cut of spruce for pulp mills was 230,649,292 feet

B. M. The cut of spruce, therefore, amounted to only about 23 per cent of the whole.

It seems to the writer that many people in New York have taken unsound ground on this question of the relation of the State to great manufacturing enterprises. Paper has been justly stated to be the index of a people's civilization, but if popular clamor were considered, one might suppose it was an index of exactly the opposite. The manufacturers are not to blame for a continual increased use of this product, and so long as paper can be produced from wood pulp at considerably less cost than from other raw material, it is idle to expect that anything else will be used.

THE PROPER FUTURE COMMERCIAL POLICY OF NEW YORK

In the foregoing pages we have seen that by virtue of its position, New York is naturally so situated as to be the principal manufacturing area of the United States, but that because of developing on narrow lines it has realized only a portion of the manufacturing naturally its due. After the Revolutionary war, the United States was an agricultural region purely—aside from agricultural products, substantially everything used was manufactured abroad.

About ninety years ago Erie canal was inaugurated for the purpose largely of carrying agricultural productions—grain, lumber, etc,—to market. It was not realized that the natural destiny of the State of New York was for manufacturing rather than for internal commerce. The result of this was that the natural flow of streams throughout the central part of the State was mostly appropriated for the use of the Erie canal, and restrictive laws enacted which have discouraged the development of manufacturing. Hence the New England States, where an opposite policy prevailed, have developed far more manufacturing per unit area than New York, although farther away from the centers of trade and commerce.

Now that we realize the great mistake made, the first thing to be done is to remove restrictions as to the use of water of every sort and kind. We need to enact a constitutional amendment substantially on the lines laid down by Mr Herschel in 1894, and also we need such further legislation as will permit of development of the water storage capacity of New York streams to its fullest degree.

Another mistake in New York has been in largely confining the agriculture to the production of grain and dairy products. Had manufacturing been the general policy of the State for the last hundred years, the population would easily be anywhere from 2,000,000 to 4,000,000 greater than it is under present conditions and a much larger proportion of the agriculture would be garden truck, fruits and berries than it now is. These products yield very much better profit to the producer than grain, cattle, dairy products, etc. The result of this policy would have been that the aggregate wealth of New York farmers would be much higher than it is, and the same thing is true of all other classes.

The construction of the 1000-ton barge canal is expected to greatly increase the manufacturing possibilities of the State by bringing into it the raw material for the manufacture of iron and steel. These industries have clustered around Lake Erie, at Lorain, Cleveland, Ashtabula, etc. but the industry at these points is burdened by the necessity of bringing coal and limestone for flux by railway transportation from a considerable distance. The barge canal will permit of the development of iron and steel manufacturing at points very near the coal and flux. This manufacturing ought to develop extensively along the line of the canal between Rochester and Utica.

Another difficulty has been, until within a year or two, the great cost of incorporating companies in this State. Previous to 1902 the State tax required from corporations was one-eighth of one per cent. The result was that nearly all large corporations were incorporated in New Jersey, but in 1902 this was so far modified that the fee now is merely nominal.

At the legislative session of 1904, an act was passed authorizing the appointment of a permanent River Improvement Commission, and while this act is hardly all that can be desired, nevertheless it makes a beginning towards the rational improvement of the streams of the State to their fullest extent. We still need a mill act which will permit of constructing dams on the smaller streams without any further grant of powers from the Legislature than those granted in the general act. We also need to repeal all acts in any way inconsistent with the provisions of either the river improvement act or the proposed mill act. With these and other improvements in legislation we may hope to inaugurate a commercial policy which will make New York in a larger degree the Empire State.

In a word, therefore, the proper future commercial policy of New York should be such as to permit of bringing into the State the largest possible amount of raw material to be manufactured there, together with the removal of restrictions of every sort and kind which in any way tend to hamper the free development of internal commerce.

LIST OF WORKS REFERRED TO IN PREPARING REPORT ON THE HYDROLOGY OF NEW YORK

In the following list the works which have been referred to in the preparation of this report are arranged alphabetically:

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New York State Education Department

New York State Museum

PUBLICATIONS

Postage or express to places outside of New York State must be paid in addition to the price given. On 10 or more copies of any one publication 20% discount will be given, the buyer to pay transportation. Editions printed are only large enough to meet special claims and probable sales. When the sale copies are exhausted, the price for the few reserve copies is advanced to that charged by secondhand booksellers, in order to limit their distribution to cases of special need. Such prices are inclosed in [ ]. All publications are in paper covers, unless binding is specified.

Museum annual reports 1847-date. *All in print to 1892, 50c a volume, 75c in cloth; 1892-date, 75c, cloth.*

These reports are made up of the reports of the director, geologist, paleontologist, botanist and entomologist, and museum bulletins and memoirs, issued as advance sections of the reports.

Geologist's annual reports 1881-date. Rep'ts 1, 3-13, 17-date, O; 2, 14-16, Q.

The annual reports of the early natural history survey, 1837-41, are out of print.

Reports 1-4, 1881-84, were published only in separate form. Of the 5th report 4 pages were reprinted in the 39th museum report, and a supplement to the 6th report was included in the 40th museum report. The 7th and subsequent reports are included in the 41st and following museum reports, except that certain lithographic plates in the 11th report (1891) and 13th (1893) are omitted from the 45th and 47th museum reports.

Separate volumes of the following only are available.

Report	*Price*	*Report*	*Price*	*Report*	*Price*
12 (1892)	$.50	17	$.75	21	$.40
14	.75	18	.75	22	.40
15, 2v.	2	19	.40	23	*In press*
16	1	20	.50		

In 1898 the paleontologic work of the State was made distinct from the geologic and was reported separately from 1899–1903. The two departments were reunited in 1904.

Paleontologist's annual reports 1899-1903.

See fourth note under Geologist's annual reports.

Bound also with museum reports of which they form a part. Reports for 1899 and 1900 may be had for 20c each. Those for 1901-3 were issued as bulletins. In 1904 combined with geologist's report.

Entomologist's annual reports on the injurious and other insects of the State of New York 1882-date.

Reports 3-19 bound also with museum reports 40-46, 48-57 of which they form a part. Since 1898 these reports have been issued as bulletins. Reports 3-4 are out of print, other reports with prices are:

Report	*Price*	*Report*	*Price*	*Report*	*Price*
1	$.50	9	$.25	15 (En. 9)	$.15
2	.30	10	.35	16 (" 10)	.25
5	.25	11	.25	17 (" 14)	.30
6	.15	12	.25	18 (" 17)	.20
7	.20	13	.10	19 (" 21)	.15
8	.25	14 (En 5)	.20	20 *In press*	

Reports 2, 8-12 may also be obtained bound separately in cloth at 25c in addition to the price given above.

Botanist's annual reports 1867-date.

Bound also with museum reports 21-date of which they form a part; the first botanist's report appeared in the 21st museum report and is numbered 21. Reports 21-24, 29, 31-41 were not published separately.

Separate reports 25-28, 30, 42-50 and 52 (Botany 3) are out of print. Report 51 may be had for 40c; 53 for 20c; 54 for 50c. Since the 55th these reports have been issued as bulletins.

Descriptions and illustrations of edible, poisonous and unwholesome fungi of New York have been published in volumes 1 and 3 of the 48th museum report and in volume 1 of the 49th, 51st, 52d, 54th and 55th reports. The descriptions and illustrations of edible and unwholesome species contained in the 49th, 51st and 52d reports have been revised and rearranged, and, combined with others more recently prepared, constitute Museum memoir 4.

Museum bulletins 1887-date. O. *To advance subscribers, $2 a year or 50c a year for those of any one division:* (1) *geology, economic geology, mineralogy,* (2) *general zoology, archeology and miscellaneous,* (3) *paleontology,* (4) *botany,* (5) *entomology.*

Bulletins are also found with the annual reports of the museum as follows:

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The figures in parenthesis indicate the bulletin's number as a New York State Museum bulletin.

Geology. G1 (14) Kemp, J. F. Geology of Moriah and Westport Townships, Essex Co. N. Y., with notes on the iron mines. 38p. 7pl. 2 maps. Sep. 1895. *10c.*

G2 (19) Merrill, F: J. H. Guide to the Study of the Geological Collections of the New York State Museum. 162p. 119pl. map. Nov. 1898. [*50c*]

G3 (21) Kemp, J. F. Geology of the Lake Placid Region. 24p. 1pl. map. Sep. 1898. *5c.*

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Eg7 (17) —— Road Materials and Road Building in New York. 52p. 14pl. 2 maps 34x45, 68x92 cm. Oct. 1897. *15c.*

Maps separate *10c each, two for 15c.*

Eg8 (30) Orton, Edward. Petroleum and Natural Gas in New York. 136p. il. 3 maps. Nov. 1899. *15c.*

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Simpson, G: B. Preliminary Descriptions of New Genera of Paleozoic Rugose Corals.

Loomis, F: B. Siluric Fungi from Western New York.

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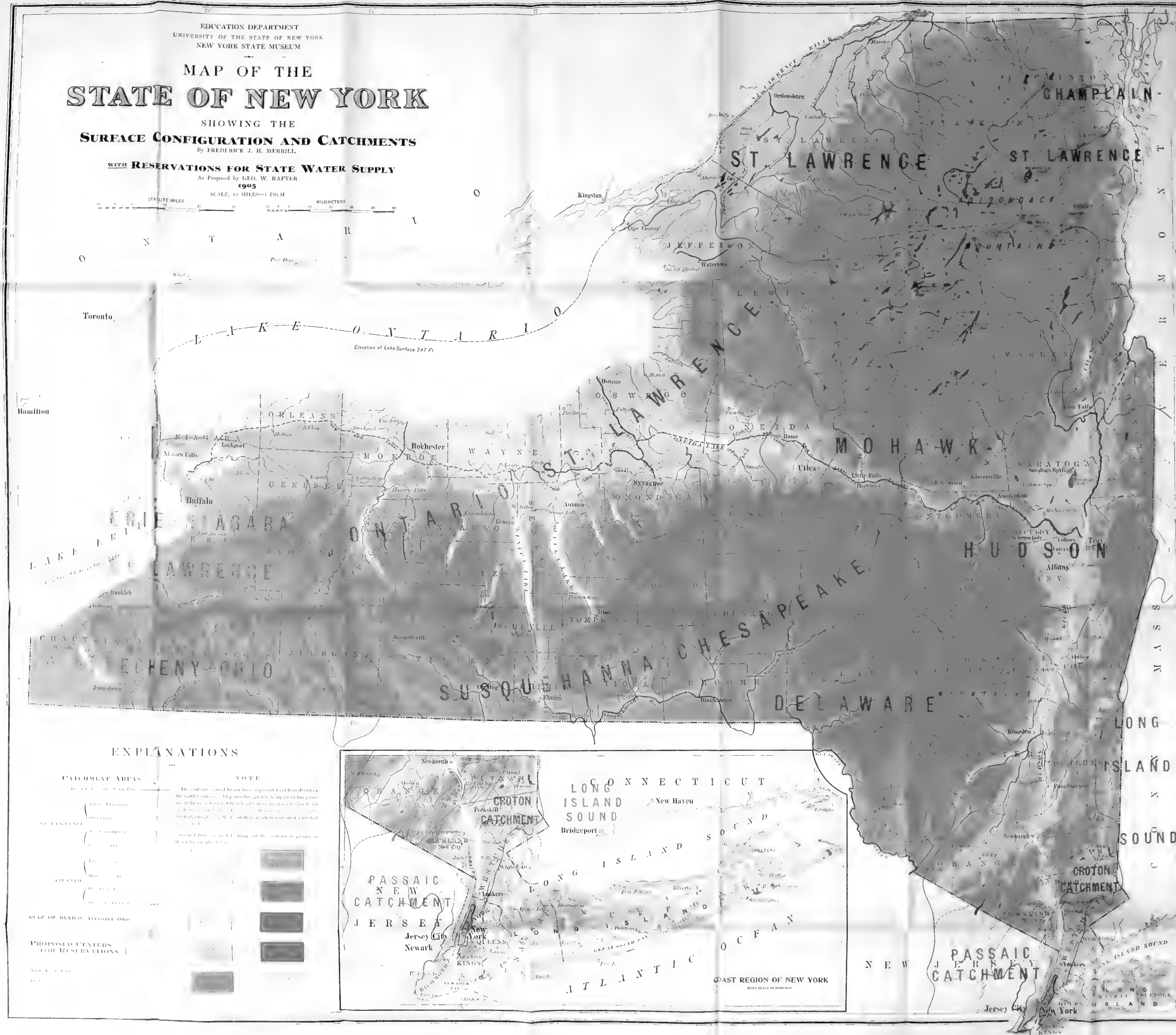
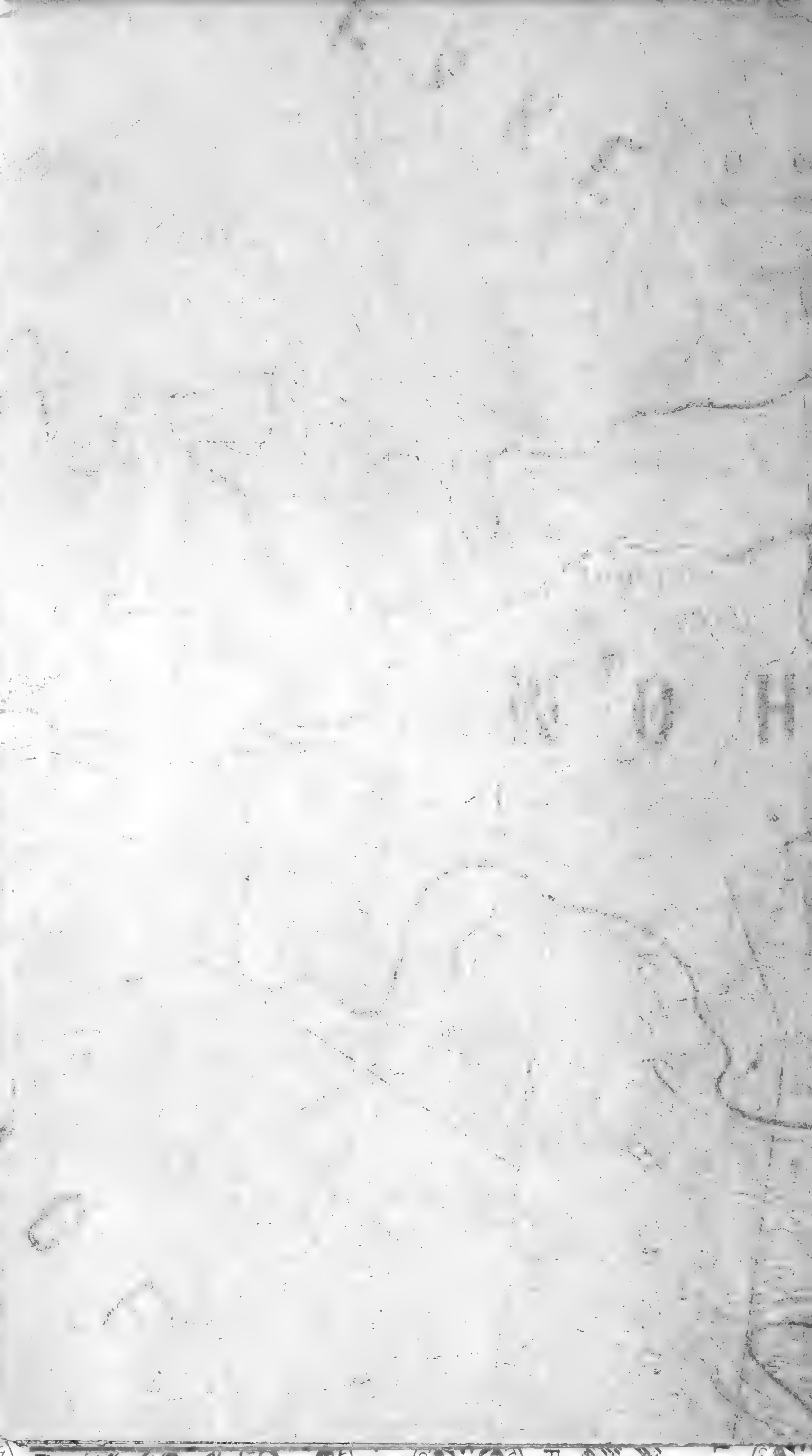


EDUCATION DEPARTMENT
UNIVERSITY OF THE STATE OF NEW YORK
NEW YORK STATE MUSEUM

MAP OF THE STATE OF NEW YORK

SHOWING THE
SURFACE CONFIGURATION AND CATCHMENTS
By FREDERICK J. H. MERRILL
WITH RESERVATIONS FOR STATE WATER SUPPLY
As Proposed by GEO. W. RAFTER
1905
SCALE, 12 MILES=1 INCH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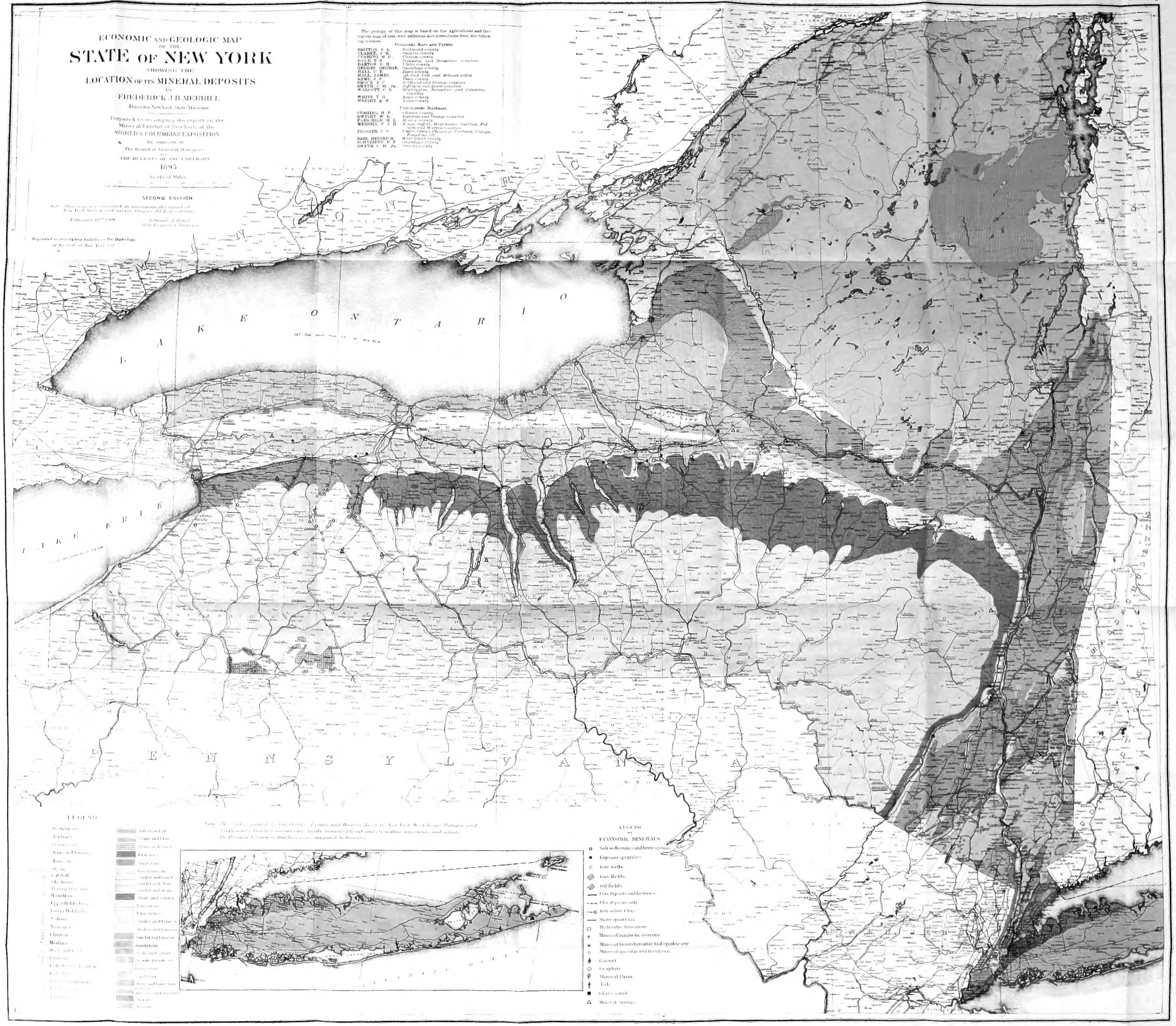

ECONOMIC AND GEOLOGIC MAP
OF THE
STATE OF NEW YORK
SHOWING THE
LOCATION OF ITS MINERAL DEPOSITS
BY
FREDERICK J. H. MERRILL
Director New York State Museum

Prepared to accompany the report on the
Mineral Exhibit of New York at the
WORLD'S COLUMBIAN EXPOSITION
By authority of
The Board of General Managers
and
THE REGENTS OF THE UNIVERSITY
1895

SECOND EDITION

Note. This map is reprinted to accompany the report of New York State Canal Survey, Chapter 411 Laws of 1900.

February 12th 1901 *Edward A. Bond, State Engineer & Surveyor*

Reprinted to accompany bulletin on the Hydrology of the State of New York 1905

The geology of this map is based on the Agricultural and Geological map of 1844, with additions and corrections from the following sources:

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