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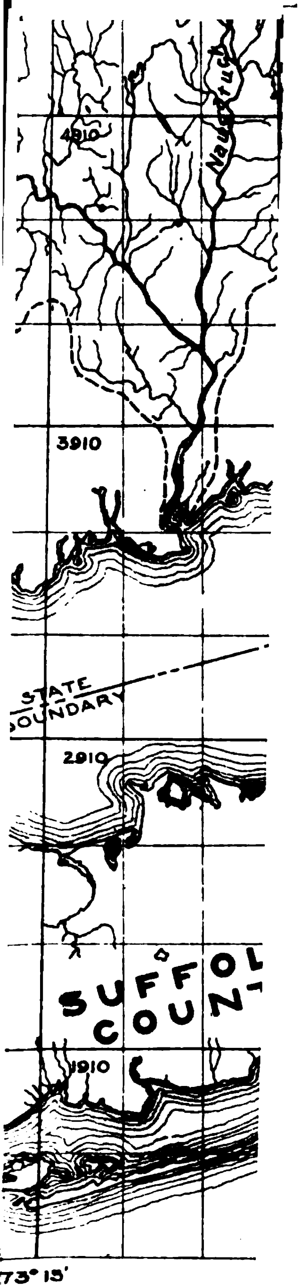

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REPORT

OF THE

Commission on Additional Water Supply

FOR

THE CITY OF NEW YORK

MADE TO

ROBERT GRIER MONROE,

Commissioner of Water Supply, Gas and Electricity.

COMMISSION:

WILLIAM H. BURR, Chairman.
RUDOLPH HERING.
JOHN R. FREEMAN.

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that the different branches of work might be effectively begun on the date of formal appointment. Since the inception of the Commission's work there have been held seventy-one stated meetings and visits of personal inspection in the field at the points of operations of the various engineering forces, besides many informal conferences with the heads of departments and visits of inspection to the works completed and in progress of the Metropolitan Water Supply of the City of Boston as well as at other points where useful information bearing directly upon the work of the Commission could be secured. Papers and reports of investigations bearing upon the general problem of additional supply for New York have been examined and made use of wherever they could be found.

The area covered by the present City of New York is about 300 square miles and about one-quarter of it only is served with public water supplies. The population of Greater New York is about 3,700,000, of which about 1,900,000 are found in the Borough of Manhattan, 1,290,000 in the Borough of Brooklyn, 268,000 in the Borough of The Bronx, 183,000 in the Borough of Queens and 73,000 in the Borough of Richmond. The total population in the City is increasing at the rate of 33 per cent. in ten years. The most rapidly growing borough is The Bronx, where the population is increasing at the rate of about 120 per cent. in ten years. With the completing of the bridges and tunnels across the East River, a much more rapid growth in the Boroughs of Brooklyn and Queens must be anticipated and provided for than shown by recent growth.

The Boroughs of Manhattan and The Bronx are supplied almost entirely by water from the Croton Watershed, having a drainage area of about 360 square miles, a small amount being supplied from 22 square miles of the drainage area of the Bronx and Byram Rivers. When the new Croton Dam is completed the total available storage capacity in the Croton Watershed will be about 70,000 million gallons. The present (November, 1903) draft from the Croton supply is at the rate of about 272 million gallons per day and about 13 million gallons per day from the Bronx and Byram supply.

Two aqueducts are available for conveying Croton water to the City; the Old Croton Aqueduct having a capacity of about 80 million gallons per day and the New Croton Aqueduct having a capacity of about 300 million gallons per day. The old aqueduct in its present condition can, however, scarcely be considered available except as a resort in case of emergency. The new aqueduct is practically the sole reliance of the City of New York for the conveying of water from the Croton basin to the distributing system.

Inasmuch as the area of the Croton basin is about 360 square miles, and as it is rarely safe to depend upon an average maximum draft greater than 750,000 gallons per square mile per day from such a watershed, even with the storage fully developed, it is evident that the Boroughs of Manhattan and The Bronx are already drawing from the Croton supply an amount dangerously close to the limit of its yield in ordinary years. The current season has been one of phenomenal rainfall and the dangerous shortage of this portion of the water supply of New York City has been obscured. If the City should experience either one year of low rainfall, or, still worse, two such years in succession, as has occurred a number of times in the near past, the capacity of the Croton basin would be exhausted unless the consumption were restricted. It will be shown later in this report that any practicable retrenchment due to the restriction of preventable waste cannot be relied upon to give substantial relief from this condition of exhaustion of the Croton supply.

The Borough of Brooklyn secures its supply from the surface waters and ground waters of Long Island. Some of the surface waters are rapidly becoming so polluted that they will not be safely available much longer, but the ground waters can be developed to a greater extent than heretofore. A large portion of the Brooklyn supply is taken from shallow and deep wells penetrating the saturated sands underlying the surface of the southerly portion of Nassau County. The demands of this Borough have already exceeded the present supply and additional works are being constructed for the purpose of securing an increased quantity of ground water. The completion of the works at present contemplated will give but a small relief. Other additional supply in large amount must be secured in the immediate future.

The needs of the Borough of Queens are probably more immediately pressing than those of any other part of The City of New York. Its present supply is derived from the ground water secured from wells driven within its limits, the yield being both insufficient in quantity and unsatisfactory in quality. It is imperative that its supply should be increased at the earliest practicable date from some source yielding a sufficient volume of pure water.

The Borough of Richmond is also in need of an improved supply which it is not practicable to obtain within its own limits. Its present supply is from wells driven on Staten Island, some of which yield water of poor quality and of insufficient volume.

In all parts of the City, therefore, it is seen that the demands are either equal to or greater than the present supply in a year of low rainfall. Although the Croton water is of fair quality for a surface water, it may be stated that not in any one of the boroughs is the quality of the water as excellent as it should be.

Modern advances in the sanitation of public water supplies are such as to indicate with a force equivalent to demonstration that there are few, if any, public supplies of surface waters of sufficiently high degree of excellence in all respects to obviate the necessity of filtration. The general problem before this Commission is, therefore, to provide for Greater New York such sources of additional water supply as will make abundant provision for a long period in the future, both as to abundant quantity and satisfactory quality.

Since the completion of the New Croton Aqueduct there have been no systematic investigations for the purpose of finding sources of additional water supply for The City of New York accompanied by extended and accurate surveys. It has been known that the Housatonic River yields an abundant quantity of water for such a purpose and that it could be brought to the distribution system of the City without serious difficulty or relatively great expense. Also that a smaller quantity could be obtained from Ten Mile River. The Catskill and Adirondack Mountain streams and filtered water from the Hudson near Poughkeepsie have been recognized as available, but complete quantitative investigations of an extended character have not before been undertaken. The most comprehensive examinations of a general character which have been completed are those of Mr. John R. Freeman in his extended "REPORT UPON NEW YORK'S WATER SUPPLY," made to Hon. Bird S. Coler, Comptroller, 1900, and "AN INQUIRY INTO THE CONDITIONS RELATING TO THE WATER SUPPLY OF THE CITY OF NEW YORK," conducted by a number of eminent engineers and others of The City of New York for the Merchants' Association of New York, 1900. These two reports contain a mass of most valuable information relating not only to the present water supply of the City, but also to sources available for the contemplated additional supply, and the information contained in them has been constantly used in these investigations.

This Commission has been limited in its operations to the drainage areas of streams lying wholly within the State, by instructions transmitted to it through the Commissioner of Water Supply, Gas and Electricity, from the Corporation Counsel. These instructions, given for the purpose of avoiding any interstate litigation, have prevented this Commission from considering streams like the Housatonic or Ten Mile River or other interstate streams which have hitherto been regarded as available for the purposes of additional supply.

The wide scope of the investigations to be undertaken by the Commission made it necessary at the outset of its work to appoint a large force of engineers, biologists, chemists and others. The organization was completed by dividing the main portion of its work into six departments, at the head of which were placed engineers of extended experience in similar recent large water works constructions near New York, Boston, Philadelphia, Eastern New Jersey and elsewhere. These departments were:

1. Aqueduct and Reservoir Department, E. G. Hopson, Engineer.
2. Catskill Department, Walter H. Sears, Engineer.
3. Filtration Department, Wm. B. Fuller, Engineer.
4. Chemical and Biological Department, Geo. C. Whipple, Engineer.
5. Long Island Department, Walter E. Spear, Engineer.
6. Pumping Department, Will J. Sando, Engineer.

There was also assigned to the Commission the investigation of the waste of water in the City. This, however, had already had been begun in the Boroughs of Manhattan and The Bronx by Mr. Nicholas S. Hill, Jr., Chief Engineer, and it was found advisable to co-operate in and make use of his operations in the regular work of the Department having charge of valves, meters and distribution pipes, rather than to establish a department for the independent study of this question. Mr. I. M. De Verona, Chief Engineer of the Borough of Brooklyn, also inaugurated similar investigations in that Borough. The Commission has made use of the results of both of these fields of investigations in its conclusions.

A detailed statement of the organizations made in the six chief departments of the Commission's work will be found in Appendix X.

Water Waste.

One of the first subjects to which the attention of this Commission was directed was that of water waste and its prevention. At the preliminary meeting of the Commission on December 8, 1902, a conference was had with the Commissioner of Water Supply, Gas and Electricity, at which Mr. N. S. Hill, Jr., Chief Engineer of Water Supply for Manhattan and The Bronx, presented a full explanation of the work that he was inaugurating for the measurement of water consumption and waste in typical districts, by means of the pitometer, an instrument recently perfected and made convenient for practical use.

A public hearing was given by this Commission at the request of the City Club on Tuesday, December 23, at 3 P. M., at the City Hall, at which several prominent citizens presented their views and suggestions upon the subject of water waste and its prevention. The statements were chiefly of opinions and suggestions. These statements emphasized the need of house to house inspection for leaky fixtures. The views expressed at this hearing were given due consideration by the Commission in planning its work.

The plans of the Chief Engineer received the hearty approval of this Commission, and it became plain that the work of water waste investigation could be best carried on through the regular channels of the Department of Water Supply, Gas and Electricity; mainly because of its having at command a corps of men most familiar with the locations of the pipes and gate valves. Moreover, many of the data necessary for this work could best be secured in connection with the work of preparing new plans and records of the pipe system already begun by the Chief Engineer of the Department.

The organization of a new corps for this work, necessarily made up of men unfamiliar with the details mentioned, would have involved much additional expense and delay and would have taken much of the Commission's time from its pressing duties connected with the organization of investigations for new sources of supply. This Commission has, therefore, relied for its data on water waste in Manhattan and The Bronx, upon the researches and observations made under the Chief Engineer, who from time to time promptly placed the results of his studies on this subject before the Commission. The methods and results have been the subject of frequent conference. From his oral and written reports and from the sheets of computed results, the account of the methods and results presented in Appendix IX. has been prepared.

Scope of Work.

It was obviously impossible, within the time and means available, to explore the mains and service pipes and house plumbing throughout the entire City, and the work of investigation was, therefore, concentrated upon certain typical districts in different parts of the City. These comprise a principal hotel district with large transient population, two residential districts with houses of an expensive class, two East Side tenement-house districts, two large downtown commercial districts having a large day population but a small population by night, a few others of intermediate grade and two typical districts in The Bronx, one of which contained the large railway terminal yards on the Harlem River.

There were two distinct branches of inquiry; one along the street mains and the other along the house pipes or plumbing; the first comprised a measurement of the quantity of water delivered daily into each district and the observation of its rate of draft continuously, day and night, so that the mean rate of flow in working hours could be compared with that in the quietest hour of the night and also on Sunday; the second inquiry comprised an inspection and search for leaky plumbing fixtures within each house of the district, including a measurement of the rate of each leak where possible by catching the escaping water in a small measure.

The street measurements were supplemented by an examination of the operative condition of the gate valves on the mains around the margin of the district, and a record of their location and of the number of turns of the wrench required to open each; meanwhile the gates found defective were repaired or replaced.

The house to house observations of leaky plumbing were supplemented by obtaining a variety of data upon the absence of ball cocks on tanks, the size of house tanks, the indications of waste through tank overflow pipes and a variety of other data that will be found in the appendix.

The street measurements and the house measurements were further supplemented by an examination of the rate of flow after midnight in the sewers of the district, in the course of which the spur from every building was inspected for signs of leakage so far as practicable. The inspector reported that the night sewer flow in most sections was surprisingly small in view of the large night flow shown by the pitometer measurements, indicating that the night flow was due largely to refilling tanks.

Methods of Measurement of Consumption and Waste.

The method of measurement of the rate of draft of water by each district consisted in cutting off the main pipes of this district from those of the surrounding territory by closing the gate valves on the street mains crossing the boundary and thus concentrating the inflow into a single pipe or into the smallest number of feed pipes practicable. The rate of flow was then measured and recorded by means of a pitometer in the form of a continuous diagram which shows this rate of draft per minute throughout the twenty-four hours. With ordinary occupancy and ordinary conditions it is found that the real use of water between 3 A. M. and 4 A. M. is very small, and that the large and uniform draft of water night after night at these hours indicates leaky pipes or leaky fixtures.

It is obvious as a matter of general experience that very few persons draw water between 2 A. M. and 4 A. M., and that the non-resident suburban population is then absent from Manhattan, but there are peculiar conditions in this Borough that may lead to a large legitimate night draft. Chief among them is the use of large house tanks, many of which were put into the upper stories of buildings just below the hydraulic grade in districts where the pressure in the street mains is drawn down by day. These tanks may refill by gravity during the night after the pressure rises with the lessened draft.

Unfortunately, local conditions did not permit these district measurements to be made so elaborately in detail as has been found practicable in other cities. The principal limitations were:

1st. It was not deemed prudent to test the tightness of the shut-off of the pipes of the districts under test from those of the adjacent territory, completely closing the feed pipes into the district for a half hour more or less after midnight, and opening hydrants, lest damage be caused by collapse of house boilers, or lest damage be caused to those who legitimately use large quantities of water at night in almost every district. The engineer in charge, however, made other examinations for testing the completeness of isolation. The same reasons appeared to forbid, save in a few instances, shutting off street mains within the district, block by block, after midnight, noting the time of closing and opening these gates for subsequent comparison with the continuous chart of flow to see if the flow of water dropped or rose at the same time, thereby indicating the presence of a leak on the section shut off.

2d. There is an almost universal absence of curb stop-cocks on the service pipes into buildings, so that it is not possible to shut these off in succession along a street after midnight, noting the time and listening by a "waterphone" for the hissing sound denoting flow when the cock is nearly closed, and subsequently comparing these times of shut-off with the autographic chart of the district meter.

3d. The extensive use of large house tanks, already mentioned, interfered with the interpretations of the measurements and, therefore, it is uncertain how much of the night flow after 3 A. M. goes to refill these tanks, particularly those tanks set nearly at the level of the hydraulic grade line which is below the water surface in the tanks by day and above it at night. It is obviously impracticable to inspect the height of water in any large number of these house tanks during the night.

4th. The absence of ball-cocks on the feed pipes of a large proportion of all the house tanks in the City, thus permitting them to overflow through the waste pipe, adds an amount to the flow after midnight, and perhaps earlier, which is difficult to estimate.

Notwithstanding these limitations, a large amount of valuable data has been secured, the principal results of which are condensed into tabular form in Appendix IX.

Street Mains Generally not Leaky.

New data on the probable waste from leaky street mains have been secured during the past two or three years in connection with the large amount of street excavation carried on for electric subways and Rapid Transit tunnels. The Department inspectors are said to have carefully followed the progress of all such excavations and although notable leaks have been occasionally discovered, they have been few and the leakage small in proportion to the large extent of pipes thus exposed.

Conclusions Regarding Water Waste.

The data found in the course of these investigations briefly described above, and more fully in the appendix, appear to justify the following conclusions:

1st. The leakage from the mains is much less than heretofore supposed. The distribution system of New York needs many new gate valves and hydrants to bring it into satisfactory condition, but the deterioration of the street mains is not such as to require extensive renewals to prevent waste.

2d. The main sources of waste are probably leaky plumbing fixtures, the overflowing of tanks not provided with ball-cocks, defective plumbing design, and possibly abandoned service pipes.

The house to house inspection in typical districts in the Manhattan and Bronx Boroughs indicates that the loss from leaky and defective plumbing fixtures probably exceeds fifteen per cent. of the total supply, or upward of 40 million gallons per day.

The omission of ball-cocks on tank feed pipes can be remedied by more stringent regulations of plumbing through proper ordinances and inspection. The waste due to leaky fixtures can be largely reduced by the universal application of water meters to the house service pipes or by constant inspection, or best by both combined. That much reduction of waste certainly has been accomplished in the typical districts tested during the last twelve months is demonstrated by the returns of the Chief Engineer submitted to us. The permanency of this reduction can only be secured by the continuance of the system of house to house inspection.

Under the usual and defective design in plumbing, hot and cold water pipes are placed side by side as run through the house, without proper circulation, requiring the waste of large quantities of water before securing either the hot or cold water desired. We do not believe it feasible to reduce materially that extravagant use of water due largely to this defect in the plumbing design in present structures, because of the great expense of changing the pipes and the trouble to householders, but a careful revision of the plumbing laws should remove this cause of waste in all future plumbing.

3d. The reduction of all waste is effectively aided by the use of meters, which tends to make each householder an inspector of leaks, and thus brings prompt remedy for all obvious waste from leaky fixtures, and furthermore lessens the temptation to waste water at night for fear that poorly protected pipes may freeze, and lessens the tendency to waste large quantities of water while trying to obtain cooler water from the pipes.

The Commission strongly recommends that the use of meters be extended to other classes of buildings than those now metered, and particularly that all buildings more than five stories in height be metered at the earliest practicable date. This will cover the large modern apartment houses which now being on frontage rates pay an inadequate return to the City for the water used, and are prolific in water waste.

All meters should be owned, installed and maintained by the City, and tested at regular intervals in order to secure reasonably effective service from them. The many cases where connections back of meters have been discovered by the Chief Engineer during the past year prove the unwisdom of permitting meters to be set by other than the employees of the Department.

4th. The recent measurements of water delivered and the analysis of the statistics of the Water Registrar's office for typical districts investigated demonstrate the absolute unfairness of the frontage charges, leading to marked inequality of burden on users in different portions of the city. This is most manifest in connection with the large apartment houses covered by our recommendation to extend meters to all buildings over five stories in height.

5th. These investigations have also demonstrated the necessity of considering the great transient population of the City when accounting for the per capita consumption. It is estimated by the Chief Engineer of the Department of Water Supply, Gas and Electricity that about 600,000 transients come into Manhattan each day, and that while the per capita use and waste for the Borough is 129 gallons daily, if based on the resident population, it becomes 100 gallons if based on the combined resident and non-resident population.

In the special census taken by the employees of the Water Department, during the investigations of waste in each of the four typical districts, the term non-resident was used as covering those non-resident to that district. In District No. 1, for example, it not only covered the hotel population, but also the proprietors, clerks, milliners, dressmakers, and other employees of the large shops, possibly a majority of whom lodge in the Borough of Manhattan. In this residence and hotel district the per capita consumption was found to be 175 gallons based upon the resident population and 121 gallons based upon the combined resident and transient population.

In the case of District No. 8, comprising the entire territory below Fulton street, filled with offices and commercial establishments, the non-residents were enumerated by counting the regular occupants of each office, shop, store, or other building. The per capita consumption of this district was 860 gallons per day when based upon the resident population, and 83 gallons per day when based upon the combined resident and non-resident population.

These investigations exhibit in a marked manner the effect of non-resident population on the per capita consumption of a given district. On the other hand the fact that the non-residents of one district are frequently the residents of another renders it impossible to draw conclusions for the Borough of Manhattan from the data of individual districts in it. Results applicable to the Borough can only be obtained from data covering the population resident and non-resident to the entire Borough.

6th. These investigations indicate that the greatest possible saving by reduction in waste and by decreasing extravagant use will not more than provide for the natural increase in demand due to growth of the City, and it may not be sufficient for that; hence the construction of an additional supply should be undertaken at the earliest practicable moment.

7th. This Commission finds the present average daily draft from the Croton sources to be so close to the utmost quantity that these can be relied upon to yield in a year of drought, that the natural growth of the City and the legitimate natural increase in the consumption per capita during the five years or more that must elapse before the additional supply can be ready for delivery may bring the City to the verge of a water famine should years of low rainfall occur, unless effective means be taken to restrict waste and lessen extravagant use. In the event of a drought it might even become imperative to throttle the supply of the distribution system.

Quantity of Water and Size of Aqueduct.

The quantity of water required for the additional supply of New York City within a given period of years will depend chiefly upon the increase of population during that period and the consumption per head of population. The investigation of the probable increase of population in the entire city has shown that by 1930, if not sooner, it is reasonable to expect a total population in all the Boroughs of Greater New York of about seven millions of people, or nearly three and one-half millions more than the population of 1903. It is a matter of experience that even when preventable waste of water is reduced to a minimum, the demand per head of population increases with the lapse of time. The use of water induces a more lavish use even for those purposes which must be considered legitimate and not wasteful. There may be reasonable doubt as to the amount of water to be required per head of population in The City of New York during the next twenty-five years, but even if measures for the restriction of waste are effienforced there are strong reasons for believing that the average quantity required over and above the preventable waste will increase to a substantial extent during that period of time. The Commission believes that it is not excessive to base an estimate of future requirements which the additional works must supply, on 150 gallons per day for each member of the population. If that amount be assumed for purposes of computation, the additional quantity required will be 3,500,000 × 150, or 525 million gallons per day, in addition to the quantity required by the increase in per capita consumption of the present population, amounting to about 85 million gallons daily. It is certain that a part of this additional supply, covering a portion of the increased amount required for the Borough of Brooklyn, will be taken from the ground waters of Long Island. The amount to be secured cannot be accurately estimated at this time, but it may reach from 25 to 50 million gallons per day from Nassau County. Under this estimate the additional quantity of water to be secured from the north and brought to the City through an aqueduct would be 500 million to 575 million gallons per day, not later than 1930 and probably sooner.

It appears, therefore, that works required for an additional supply of water for The City of New York within the next twenty-five years must have a capacity of not less than 500 million gallons per day. This daily requirement determines the capacity of the new aqueduct.

While it would be feasible to build two aqueducts instead of one, with a combined capacity of 500 million gallons per day, that construction would be much more expensive than a single aqueduct discharging the desired amount. The materials and processes at the command of engineers at the present time make it perfectly feasible, and quite within the limits of reasonable construction, to build a single aqueduct discharging 500 million gallons of water per day when running eight-tenths full.

The aqueduct designed by the Commission for this purpose, as shown by the accompanying plans, is of the usual shape, with the greatest width nearest the bottom. The interior vertical diameter is 18 feet 6 inches and the maximum width 19 feet, at about one-quarter of the height from the bottom. This aqueduct section would not ordinarily be expected to flow more than eight-tenths full, *i. e.*, with a depth of water 14 feet 10 inches. It could, however, at the depth corresponding to maximum delivery discharge about 550 million gallons per day.

High Level Aqueduct First Required.

Those portions of the Manhattan and Bronx Boroughs which are supplied with the low level Croton service, *i. e.*, from a maximum elevation in reservoirs not greater than 131 feet above mean high tide, already require nearly the full capacity of the New Croton Aqueduct. Furthermore, that supply covers the older portion of the City, which is growing at a comparatively slow rate. On the other hand, that portion of the City which is now supplied by the high service reservoir at Highbridge and the tower adjacent to it, requiring water to be pumped to an elevation ranging from 280 feet to 320 feet, is increasing at the remarkably rapid rate of over 120 per cent. in ten years. Again, the loss of head is so great in some portions of the low service supply that it has become necessary for great numbers of occupants of all classes of buildings to use small power pumps at much cost to lift water to tanks in the tops of buildings. Requirements for fire protection are also increasing, and it will be necessary to extend mains under high pressure for that purpose probably throughout the length of Manhattan Island. It is also necessary to contemplate the extension of mains across the East River into districts in the Boroughs of Brooklyn and Queens necessitating materially higher heads than those sufficient for the low service supply as it now exists. Indeed, it may be stated that by far the larger development of water supply for The City of New York hereafter will be such that it can only be supplied from a high level.

This Commission, therefore, recommends that the first works of construction for the additional supply shall be so designed as to bring the water into a suitable reservoir at the northern limit of the City, having its high water surface at an elevation of not less than 295 feet above mean high tide.

An excellent location for this reservoir is at the summit of high ground called " Hill View," in Westchester County, adjacent to the City line, about three miles north of Jerome Park Reservoir. The entire storage capacity would be 2,030 million gallons and 325 acres of ground would be required. The portion of the reservoir to be constructed first would have a storage capacity of about 600 million gallons.

The Watersheds Most Available for Future Supply.

Fishkill Creek.

Watersheds possessing the highest degree of availability for increasing the water supply of the City must, obviously, be so located as to require the least amount of construction work to bring the water into the distributing system. The watershed of Fishkill Creek fulfills this condition. It lies adjacent to the Croton shed on the north and its waters can be secured more quickly than those of any other supply of equal amount, the course of whose flow is located entirely within the State of New York. The chief difficulty to be overcome in securing the Fishkill waters, or those still farther north, and that which controls the shortest time in which a new supply can be obtained, is the large amount of tunnel construction for the aqueduct through the rough, mountainous region lying between it and the Croton shed.

It is feasible to utilize directly, without pumping, about 81 square miles, or more than one-half of the available Fishkill Watershed for the high service plan, by building two reservoirs, one at Stormville, on Fishkill Creek, covering 1,694 acres, and having a contributory drainage area of 49 square miles, and one at Billings, on Sprout Creek, a tributary of Fishkill Creek covering 969 acres, and having a contributory drainage area of 32 square miles. The high water surface of the Stormville Reservoir would be 364 feet above Croton datum, and its storage capacity would be 10,000 million gallons. The elevation of the high water surface of the Billings Reservoir would be 372.5 feet above Croton datum, and its storage capacity would be 6,800 million gallons.

A reasonable estimate of the yielding capacity of the Fishkill Watershed shows that the 81 square miles tributary to those two reservoirs may be counted upon to deliver at least 60 million gallons of water per day. This would be the first portion of the additional supply available for the City, so that the construction requisite to bring it to the distributing system should be pushed forward to the earliest possible completion. The total area of that portion of the Fishkill Watershed available for supplying water to New York is 153 square miles and lies above Brinckerhoff Station, about six miles easterly of Fishkill Landing.

If at any time in the future the needs of the City should make it advisable to secure the yield of the remaining and lower 72 square miles of the Fishkill Watershed, it can be done by constructing a dam across Fishkill Creek near Brinckerhoff, so as to raise the water surface as high as the avoidance of shallow flowage will permit. If the waters of Fishkill Creek were to be used to supply the low service system of New York, the construction of this reservoir would undoubtedly be most judicious, but it is not available for the high service gravity development recommended by this Commission, requiring an elevation of water surface of 335 feet at the Stormville filter site described elsewhere.

Wappinger Creek.

The next watershed in geographical order available for increasing the additional supply is that of Wappinger Creek, lying north of and adjacent to the Fishkill Watershed. The reservoir available for the high service development must be built at Hibernia, where a reasonably good dam site is found. This Hibernia Reservoir has a contributory area of 90 square miles. The high water surface of this reservoir would stand at an elevation of 372.5 feet above Croton datum. The area overflowed by it would be 4,350 acres, and its storage capacity would be 30,500 million gallons.

This creek has a total drainage area available for a low service supply of 172 square miles above the point where a reservoir dam for such a plan could be constructed at Rochdale, about six miles east of Poughkeepsie. The elevation of high water in this reservoir would be 271 feet above Croton datum and the area submerged 7,040 acres. It would possess a storage capacity of 47,200 million gallons. If it should be considered advisable in the future to secure the water yielded by the remaining 82 square miles of this watershed, the dam at Rochdale could be constructed so as to form a great reservoir at that point, from which water could be raised by pumping into the Hibernia Reservoir and flow from there by gravity into the high service system.

Also in the watershed of Wappinger Creek at Clinton Hollow, about two miles northwest of Hibernia Reservoir, on a tributary of the main creek, there is a good site for a dam, where a reservoir having a storage capacity of 13,900 million gallons may be constructed. The area tributary to this reservoir is 26 square miles and the high water elevation in it would be 387 feet. The area submerged at that elevation would be 2,157 acres. In view of this small drainage area it would not be advisable to construct this reservoir except as a feature of more extended development.

Examinations which this Commission could not complete should be continued on the Jansen Kill, below Silvernails, to determine whether a reservoir below that point may not be feasible so as to connect with the Clinton Hollow Reservoir by a short aqueduct, mainly in tunnel, rather than to connect Silvernails and Hibernia Reservoirs by the aqueduct hereafter described and provisionally adopted for this report. The Clinton Hollow Watershed could then advantageously be developed as an incidental feature on the main aqueduct line.

Jansen Kill.

Adjacent to the drainage area of Wappinger Creek, on the north, lies the watershed of the Jansen Kill. At a point called Silvernails on this creek, about 12 miles northeasterly of Rhinebeck, an excellent dam site is found where the high water surface of the reservoir would be 465 feet above Croton datum. The drainage area tributary to this Silvernails Reservoir is 149 square miles, and its storage capacity is 17,200 million gallons, the flowage area of the reservoir being 2,014 acres.

The natural development of these watersheds for an additional supply would be in accordance with their geographical location, viz.: Fishkill, Wappinger, and, lastly, the Jansen Kill, the total drainage area, including that of the Clinton Hollow Reservoir, being 346 square miles. If the yielding capacity of these three drainage areas be taken at 750,000 gallons per square mile per day, the addition to the present supply of the City would be 260 million gallons per day. This estimate is probably lower than would be found under actual development, and it may, therefore, be stated that this additional drainage area east of the Hudson River would give to New York City an increased high service supply practically equal to that which it is now drawing from the Croton Watershed, which has substantially the same area.

As shown by a detailed investigation in another part of this report the waters of the Fishkill and Wappinger Creeks and the Jansen Kill are materially harder than the Croton water now supplied to the City, in consequence of the large limestone areas found in all three watersheds. It is highly desirable to include in the new system of additional supply softer waters, which, mingled with those from the easterly side of the river, will bring the average hardness down at least to that of the Croton water. This may be done by taking the waters of Esopus Creek.

Esopus Creek.

The upper watershed of the Esopus Creek lies on the southeasterly slope of the Catskill Mountains, and no limestone is found in all its area. Its waters, therefore, are of unusual softness. Esopus Creek empties into the Hudson at Saugerties after having flowed northerly and parallel to the Hudson from a point immediately back of Kingston. The turbidity occasionally appearing after heavy storms arises from clay banks on a few small tributaries. It can be readily eliminated by protecting these banks.

At a point called Olive Bridge, on the Esopus, about 13 miles westerly from Kingston, there is an excellent dam site for a larger reservoir, the Ashokan, than ever yet constructed for storage purposes in connection with municipal water supply. This reservoir, as planned, has an area of 5,978 acres, or about 9.34 square miles, and the elevation of its high water surface is 560 feet above Croton datum.

This watershed is characterized by extensive, steep mountainous slopes and wooded areas of such character that it is safe to estimate its yielding capacity in connection with this reservoir at 1 million gallons per square mile per day. It may, therefore, be counted as yielding 250 million gallons per day in the system of additional water supply. This, added to the yield of about 260 million gallons per day from the three watersheds on the easterly side of the Hudson, will give a total additional yield of about 500 million gallons per day, even without the Clinton Hollow drainage area. The same amount may also be obtained by substituting the softer waters of Rondout Creek for the yield of the Jansen Kill. This fills the proposed 500 million gallon aqueduct to be constructed northward from the City to Stormville, in the Fishkill Watershed, through which point the water from all the additional areas must pass on their way to the distribution system of the City.

The freedom of the upper Esopus drainage area from limestone, its rocks being of a slaty character, makes the water of Esopus Creek by far the best for municipal use of all the waters available for that purpose under the instructions given to the Commission, except those of the upper Rondout Watershed, amounting to about 100 million gallons daily, which are of the same character and the availability of which will be considered later in this report.

It is the judgment of the Commission that the waters of Esopus Creek should be brought down directly to Stormville and that an aqueduct of about 400 million gallons daily capacity should be completed for that purpose, as soon as practicable after the completion of the main aqueduct between New York City and Stormville. It is recognized that the waters of the Fishkill shed are the first to be secured by the City, but as they are somewhat harder than the Croton supply, the Commission recommends that the Ashokan Reservoir should be constructed and that the aqueduct, with the capacity of about 400 million gallons per day, should be built at the earliest practicable date, so that even with the subsequent development of the Wappinger Creek and Jansen Kill sheds, a desirable softness of the additional water may be secured.

Availability of Schoharie Creek.

The upper part of the Schoharie drainage area lies adjacent to and immediately north of the upper portion of the drainage area of Esopus Creek, although it forms a part of the western slope of the Catskills, and as its general elevation is greater than that of the Esopus it is entirely feasible to divert the upper waters of Schoharie Creek into the Esopus Watershed by means of a tunnel about 10 miles long through that ridge of the Catskill Mountains which forms the divide between the two drainage areas. The line of this tunnel is shown on the accompanying plans. It runs from the Prattsville Reservoir on Schoharie Creek to Bushnelville in the Esopus shed.

The total drainage area of the Schoharie Creek available for diversion into the Esopus Valley is 228 square miles. It is a mountainous district of steep wooded slopes and of such a character as to afford a relatively large runoff. Its high elevation gives it an abundant rainfall, although records to establish the precise yearly amount do not exist. Reconnaissance has shown that reservoir capacity to supply 750,000 gallons per square mile per day from this watershed of 228 square miles can be developed. The average yield to be passed through the diverting tunnel would, therefore, be about 170 million gallons per day.

It has been impossible with the time and means at the command of the Commission to make complete surveys for these proposed storage reservoirs on Schoharie Creek, but the reconnaissance shows ten such sites, affording storage capacity aggregating about 60,000 million gallons.

The high cost of the necessary diversion work, added to the compensation which would have to be paid to satisfy the riparian rights on Schoharie Creek and Mohawk River, make it exceedingly doubtful whether this plan for increasing the additional water supply will ever be executed. There is a large amount of water much more available which can be taken from Rondout Creek. Again, in the more distant future it would be economical and entirely satisfactory to take the water of the Hudson River a short distance above Poughkeepsie.

It is essential for the complete treatment of the work before the Commission to set forth the availability of the upper waters of Schoharie Creek, but the Commission has no recommendation to make in regard to their diversion.

Other Available Watersheds.

The two other streams on the west side of the Hudson River available for additional supply are Rondout and Catskill Creeks, the former discharging into the Hudson at Kingston, and the latter at Catskill. The drainage area of Rondout Creek lies adjacent to that of Esopus Creek on the south, while the drainage area of Catskill Creek is immediately north of a portion of the Esopus Watershed and east of the Schoharie. The available part of the upper watershed of Rondout Creek lies above Honk Falls, near Napanock, and has an area of 131 square miles. The available part of the Catskill Watershed lies above East Durham and has an area of 163 square miles.

Rondout Creek.

The water of Rondout Creek is of the same excellent quality as that of Esopus Creek. This fact, and the proximity of the Esopus aqueduct line, make it highly advisable that further surveys and investigations should be conducted in this watershed for the purpose of determining precisely its yield and the cost of its development. The engineers of the Commission have made sufficient reconnaissances to show conclusively that it is available, but it was not possibie to make complete surveys. The Commission recommends urgently that these surveys of watershed, reservoir sites, and for the location of an aqueduct connecting with that from Ashokan Reservoir to the Stormville filter, be immediately completed. The character of this water is so similar to that of Esopus Creek that there probably would be no objection to their mingling before reaching the filters at Stormville.

Catskill Creek.

The same reasons that limited the operations of the Commission on the Roundout Watershed prevented complete surveys and examinations in the watershed of Catskill Creek, although reconnaissances sufficient to determine certain of its general features were made. The water of Catskill Creek is not so pure and soft as that of either Esopus or Rondout Creek and it is subjected to periods of greater turbidity. It is a less desirable addition to the increased supply of the City than either of those two. When the needs of the City in the more remote future require an increased supply over that to be afforded by the three principal watersheds on the easterly side of the Hudson, and by the Esopus and Rondout on the westerly side, it may be advisable to make complete investigations as to the availability of the water of Catskill Creek; but the Commission is clearly of the opinion that its development, if ever made, should follow that of Rondout Creek.

The reconnaissances show an aggregate storage capacity of about 21,000 million gallons in the Rondout Watershed and about 24,000 million gallons in the Catskill Watershed.

The exact elevation of the high water surfaces in these reservoirs have not all been determined, but they are abundantly high for the high service distribution of New York City, ranging more than 660 feet above Croton datum.

The Yield of the New Sources of Supply.

The water available from any watershed is that which flows off in times of flood and during other seasons. This yield or runoff varies much with the slopes and character of the watershed. If the slopes are steep and rocky, with little soil to hold back the rainfall, there will be a rapid and large runoff. If, on the other hand, the slopes of the drainage area are gentle, the yield or runoff will not only be less rapid, but smaller in amount.

The three watersheds on the easterly side of the Hudson are, generally speaking, similar in character to the Croton shed, and as they are not far removed from it the general features of rainfall and runoff are not likely to be much different. The watersheds of the Catskill Mountain region, on the other hand, are essentially different from those on the easterly side of the Hudson. The drainage area of the Esopus has steeper slopes and a surface in general from which storm waters will run off much more rapidly than from the drainage areas available east of the Hudson and it is at much greater elevation above sea level. From these and other considerations a greater yield per square mile may be expected and it has been found in our observations. A safe estimate of the greatest available runoff from any drainage area for purposes of municipal water supply must be based upon observations of rainfall and stream gaugings extending over a long series of years. Such extended observations, unfortunately, have not been made for any of the watersheds contemplated for the additional supply. Certain comparative deductions may be made from extended observations on other and similar drainage areas not too remote from those under consideration and not radically different in character. For this purpose the results of the most extended observations available upon the Croton Watershed of the New York supply, upon the Sudbury and Nashua Watersheds of the Boston supply, those obtained by Mr. Emil Kuichling for the proposed barge canal across the State of New York, those obtained by this Commission from short periods of observation and from other reliable sources, were examined and studied.

The available yield of a watershed is also largely dependent upon the storage capacity or volume which can be developed in it, as the storage reservoirs must hold the surplus flood and other waters until they are needed in seasons of low water. The storage capacity of each watershed considered was, therefore, definitely determined, those capacities for the Rondout and Catskill Creeks being of a more approximate character than the others, for the reasons already given.

The following tabular statement exhibits the aggregate amount of storage which it is entirely feasible to create in each watershed:

	Area.	Gallons.
Fishkill Watershed	153 sq. miles	52,680,000,000
Wappinger Creek	172 sq. miles	52,200,000,000
Jansen Kill	149 sq. miles	17,150,000,000
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The preceding totals for Fishkill and Wappinger Creeks include portions available for high service distribution only by pumping, but they are available totals.

As a result of these studies the Commission believes it safe to estimate an available yield of 1,000,000 gallons per square mile per day for Esopus Watershed, and 750,000 gallons per square mile per day for each of the others. Those rates of yield will afford the following daily supplies for the watersheds first recommended for high service development and in the order of their recommendation:

	Area.	Gallons Per Day.
Fishkill Watershed	81 sq. miles	60,000,000
Esopus Watershed	255 sq. miles	255,000,000
Rondout Watershed	131 sq. miles	98,000,000
Wappinger Creek Watershed	90 sq. miles	67,500,000
Jansen Kill Watershed	149 sq. miles	112,000,000
		592,500,000

If the Clinton Hollow drainage area be included, 26 square miles should be added to the Wappinger Creek drainage area and 19,500,000 gallons to its daily yield.

It is essential not to overestimate the yield of a given territory in which reservoirs are to be constructed, for the reason that the daily draft of the distribution system will at times deplete the storage and expose a margin around the perimeter of the reservoir. If this uncovered margin is exposed through too long a period, vegetation will spring up on it and prejudice the quality of the water when the reservoir is again filled. It has been found in experience with the Metropolitan Supply for the City of Boston that a daily draft of 750,000 gallons per square mile of drainage area tends at times to keep the reservoir from refilling for periods as long as two years. The Croton records show a similar result with a daily draft of about 850,000 gallons. This latter result appears to indicate that a somewhat greater yield than 750,000 gallons per square mile per day might be taken on the easterly side of the Hudson, north of the Putnam County hills, but it is considered safer to limit the estimates to that amount. Any additional yield of which the drainage areas are capable will be a corresponding advantage both in quantity and quality by decreasing the period of exposed margins of reservoir.

Other Possible Reservoir Sites.

Although the Commission recommends certain specific reservoirs in the drainage areas on both sides of the Hudson, including the great Ashokan Reservoir on the Esopus Creek, other possible reservoir sites have been studied in each of the drainage areas considered. It has been the purpose of the Commission to indicate specifically those reservoirs, together with the aqueducts connecting them, leading to the best immediate development in the four drainage areas first available. It is not advisable to construct a large number of relatively small reservoirs, even should such a plan lead to some economy in first cost. Small and shallow reservoirs are easily affected by organic growths, producing disagreeable tastes and odors. They are sensitive to the influence of vegetation, swampy areas and other prejudicial features of reservoir sites. Furthermore, water passes through them in a comparatively short time, so that the sterilizing effect of lying in a large reservoir for a long period is lost. Reservoirs of great capacity, on the other hand, with their increased depth and greater volume of storage, are far less affected by organic growths or by other more or less prejudicial effects in smaller volumes of water. The time required for the passage of water through a great reservoir has a most important influence in sterilizing the water as most of the pathogenic bacteria in the water of a storage basin will die in two to four weeks. The beneficial effects of the storage of water in reservoirs of great capacity are too pronounced to be ignored and the Commission has had them constantly in view in devising the system of additional supply.

Sites for reservoirs of large capacity are few on the Fishkill and Wappinger Creeks and on the Jansen Kill, the principal of which have been selected in the plans outlined. On the Esopus Creek, on the other hand, there are a number of good reservoir sites, which it may be judicious to develop in the future, but which are not needed for early construction.

Aqueduct Construction Necessary for the Additional Supply of 500 Million Gallons Per Day.

The aqueducts required for conveying the water from the watersheds on both the easterly and the westerly sides of the Hudson River, as set forth in the preceding description, will not differ greatly whatever may be their order of development. The site selected for the filter beds for all waters of the additional supply is at Stormville, on Fishkill Creek, about 12 miles easterly of Fishkill Landing, and all waters secured north of that point on either side of the river must be brought to this site for filtration before flowing southward to the City. An aqueduct of 500 million gallons capacity must, therefore, be constructed from Stormville to an equalizing reservoir at the northern limit of the City (Hill View Reservoir). The length of this aqueduct from the Stormville filter beds to the Hill View Reservoir is 49.1 miles, of which 29.2 miles is of the cut and cover type, 17.3 miles of tunnel in the mountainous portion of Putnam County and 2.6 miles of steel pipe siphon in the valleys crossed by that line.

The total fall or loss of head in flowing from the filters to the Hill View Reservoir will vary slightly with the condition of the filters and the elevation of the water in the reservoir, but it will be about 45 feet. The gradient of the cut and cover and tunnel sections of the aqueduct has been made .61 foot per mile, while the gradient of the steel pipe section has been made 2.429 feet per mile, so as to secure maximum economy in construction.

From the Stormville filters one aqueduct of about 400 million gallons capacity will be constructed, first, in a northerly and then in a northwesterly direction to the Ashokan Reservoir. At a point beyond the Hudson the future Rondout Aqueduct will join that from the Ashokan Reservoir. It is considered advisable to build the aqueduct from this point to the Ashokan reservoir of the full 400 million gallons capacity to meet possible emergencies of operation in connection with the future development of Rondout Watershed.

A second aqueduct of about 250 million gallons capacity should be built from the Stormville Reservoir to the Billings Reservoir. Although the assumed average draft would require the Billings Reservoir to be connected with the Hibernia Reservoir by an aqueduct, having a capacity of only 200 million gallons per day, there are operative reasons given in Appendix I. why it would be advisable to make the capacity of this aqueduct 250 million gallons per day, especially as it is only 3.5 miles long and the difference in cost would be comparatively small. From the Hibernia Reservoir on Wappinger Creek it will be advisable to build a short tunnel and open channel of about 220 million gallons daily capacity to the Silvernails Reservoir on the Jansen Kill, which will complete the chain of aqueducts and reservoirs required to secure the high level yield of the Fishkill and Wappinger Creeks and the Jansen Kill, the general direction from the Stormville Reservoir to the Silvernails Reservoir being a little east of north.

The length of aqueduct from the Stormville filters to Ashokan Reservoir is 38.9 miles and includes a crossing of the Hudson River near Hyde Park. This aqueduct line has been completely surveyed and mapped between the Stormville filters and Wappinger Creek at Rochdale, so that data for final location are available. From West Hurley, the point at which the aqueduct leaves Ashokan Reservoir to Wappinger Creek, the line has been carefully reconnoitred, so that its feasibility has been completely determined and its approximate alignment is known. It was the purpose of the Commission to complete detailed surveys of the aqueduct line between Wappinger Creek and Ashokan Reservoir, but the funds available for its work were not sufficient. Enough data have been secured to predict confidently the approximate location and cost. The approximate amount of cut and cover section of this aqueduct is 16.1 miles, with about 6.4 miles of tunnel and 14.5 miles of steel pipe. The Hudson River may be crossed by means of four lines of 60-inch cast-iron pipe laid in tunnel beneath the bed of the river or in a dredged channel.

The aqueduct line from Stormville Reservoir to Silvernails Reservoir has been completely surveyed so as to give data for final location and close estimates of cost. The 250 million gallon aqueduct from Stormville filters to Billings Reservoir would have a cross section 14 feet in height and 14 feet 4 inches in width, each dimension being a maximum. The grade would be 0.61 feet per mile both in cut and cover work and in tunnel. In this aqueduct there would be 6.2 miles of cut and cover work and 1.7 miles of tunnel, making a total of 7.9 miles.

The aqueduct from Billings Reservoir, on the Fishkill Watershed, to Hibernia Reservoir, on Wappinger Creek, would be 3.5 miles in length, nearly all of which would be in tunnel.

The 220 million gallon aqueduct between the Hibernia and Silvernails Reservoirs would leave the latter at Pine Plains and enter the Hibernia Reservoir at its upper end, so that its total length would be 7.56 miles, 6.98 miles of which would be in open channel and .58 mile in tunnel. The gradient of the tunnel portion would be 1.37 feet per mile, and of the open channel 1.35 feet per mile.

If it should be desired to secure the yield of the Clinton Hollow Waterhead of 26 square miles, it would be necessary to construct a tunnel 2 miles long from the Clinton Hollow Reservoir to the Hibernia Reservoir. As the yield which could be depended upon from this watershed would be but about 19.5 million gallons per day, the Commission is not of the opinion that that amount of supply will justify the requisite expenditures for the construction of the dam and tunnel required to obtain it.

If an advantageous reservoir site should be found on the Jansen Kill lower down on the stream than Silvernails, it might prove advisable to connect such a reservoir with that at Hibernia by way of Clinton Hollow, instead of using the line from Silvernails direct to Hibernia already described. Under such a plan the development of the Clinton Hollow Watershed would become desirable.

Order of Development.

The Commission has given prolonged consideration to the question whether it is most advisable to develop either the yield of Wappinger Creek or of that creek combined with the Jansen Kill before or after the development of the supply from Esopus Creek. The waters of Wappinger Creek are much nearer to the Stormville filter site than the waters of Esopus Creek. It will even require materially less expense to secure the waters of the Jansen Kill after the development of the Fishkill Watershed, than those of Esopus Creek. The waters of both Wappinger Creek and the Jansen Kill, however, are relatively hard, having a mean or average hardness of fully double that of the Croton water, and perhaps more. The waters of Esopus Creek, on the other hand, as well as those of Rondout Creek, are remarkably soft, having a degree of hardness about half that of the Croton. Indeed, as has been before stated in this report, the waters of Esopus and Rondout Creeks are exceptionally desirable for public supply; they are the best waters that are available in any direction for an additional supply for New York City. The Commission, therefore, is strongly of the opinion that the waters of Esopus Creek should be secured and brought to the Stormville filter site as soon as it is practicable to do so; and it is further of the opinion that in consequence of the exceptionally excellent character of the water that it should be brought in a separate aqueduct to Stormville without mingling with waters of either the Wappinger or the Fishkill Creek. It will probably also prove advisable to develop the yield of Rondout Creek immediately after securing the waters of the Esopus. The separate delivery of these waters at the point of intake to the main aqueduct may at times be of great value to the City. Many waters are occasionally subject to temporary bad tastes or odors, although the probability of such characteristics are greatly reduced when water is stored in large reservoirs. The excellent character of the Esopus and Rondout waters renders highly improbable these temporary prejudicial characteristics, and it is desirable to control the mingling of such waters with others of less excellent quality, should tastes and odors develop in them. An independent aqueduct for the Esopus and Rondout waters makes them completely available for this desirable kind of control, which, in the judgment of the Commission, should be secured even at some additional expense.

Quickest Availability of Fishkill Waters.

The construction of the new tunnel through the mountainous portion of Putnam County, together with the construction of the main aqueduct from the northerly limit of The City of New York to the southerly extremity of the tunnel, may involve more contract work than would be advisable before securing the Fishkill waters, which the investigations of this Commission show it to be imperative to secure at the earliest possible date. It would be feasible to turn the water from the Fishkill Watershed into the new Croton Lake immediately after the completion of the new aqueduct and tunnel north of it without awaiting the completion of the 500 million gallon aqueduct between the tunnel and the City. If work were concentrated upon the construction of the tunnel it could be completed within four to five years under energetic management.

In this plan for making the Fishkill waters available in the earliest possible time it would be necessary to build the Stormville and Billings Reservoirs, and 28.56 miles of aqueduct, of which 14.60 miles would consist of cut and cover work and by pass through the filter beds, and 13.96 miles would be tunnel.

The cost is estimated as follows:

Stormville Reservoir, complete	$2,503,000
Billings Reservoir, complete	1,806,000
12.60 miles cut and cover aqueduct	5,289,000
13.96 miles tunnel	7,812,000
Total	$17,410,000

In this cost the damages to mill owners and others for diverting the Fishkill Creek are not included.

For a total expenditure, therefore, of about 17 or 18 million dollars, the waters of the Fishkill Creek could be turned into the new Croton Lake.

As the watershed tributary to the Stormville and Billings Reservoirs is 81 square miles, by the construction of this aqueduct and tunnel from Billings to a point near Yorktown, near the new Croton Lake, a supply of 60 million gallons per day could be added to the yield of the Croton Watershed. If the full capacity of the new Croton Aqueduct should be required for the daily draft of the Croton water alone, the old aqueduct could be put into commission for the additional 60 million gallons, or more, supplied through the new aqueduct from Stormville. It is possible that the exigencies attending the completion of the new works for the additional supply may make it advisable to resort to this temporary measure.

Filtration.

The advance of knowledge in the filtration of public water supplies, the experience now available regarding the efficient and economical methods of such filtration and the late demonstrations of the sanitary value of properly filtered water in reducing the sick and death rates, particularly in cases of typhoid and diarrhœal diseases, have convinced this Commission that all waters to be secured for an additional supply of New York City should be either naturally filtered, such as spring or ground water, or artificially filtered according to the most efficient processes. Consequently, its efforts were directed to studying the possibilities of the future developments of the ground water supply which is available on Long Island, and to studying the best plans for filtering those surface waters which it will be necessary to use.

Formerly the chief desire was to remove from the surface waters the occasional turbidity due to surface washings, also the vegetable stain of many waters, the vegetable growths associated with objectionable tastes and odors, or in other ways to improve the palatableness of such waters. Later, since the true relation between polluted water and health was discovered, it became a recognized necessity that bacteria, some of which are characteristic of disease, should also be removed from the water.

Filtration, according to the best practice of to-day, is capable of removing all of the objectionable elements at a reasonable cost. More than 25 millions of people are now supplied with filtered water in Europe alone, and further millions are on the eve of being supplied with it in America. In every well studied case of the introduction of efficient filtration, water-borne diseases have been found to be greatly reduced.

To-day, two classes of water purification are known to be efficient. One embodies the slow or sand filters, and the other the rapid or mechanical filters. The former operate essentially by passing water slowly downward through beds of sand of medium-sized grains resting upon a layer of gravel, the beds being contained in water-tight basins. The speed of such filtration varies, in accordance with local conditions, from two to six million gallons per acre per day, or with a vertical motion from 6 to 18 feet per day. Ordinarily, the sand filter is from 3 to 4 feet thick and the gravel 1 foot thick. The filter units range in area from one-half to one acre. The raw water flows to the filter, enters above the sand, usually stands upon it to a depth of from 3 to 4 feet, or even more, and thence passes through the sand and gravel into collecting pipes or drains laid on the floor of the basin, which take it to the reservoirs and pipes leading to the consumers. To prevent freezing, it is desirable in the New York climate to cover the filters.

Rapid or mechanical filters operate essentially by passing water rapidly downward through beds of very coarse sand, resting upon metal strainers. These filters consist of small units, generally less than 1,000 square feet, and the water passes perhaps 40 times as fast as through the slow filters, which brings the quantity filtered up to 125 million gallons per acre per day, or a vertical speed of 375 to 400 feet per day.

While the slow filters depend for their efficiency upon a gelatinous coating which naturally forms and covers the sand grains of the upper layer, producing what is called ripeness, the rapid filters depend upon a gelatinous coating which is artificially produced by the coagulation and breaking up of a very small quantity of sulphate of alumina or iron into aluminum or iron hydrate. The films thus formed by the introduction of these materials permit the bacteria and the suspended matter to be retained and removed later by a cleaning process.

The cleaning of slow filters is accomplished by the removing of the upper layer of sand from ½ to 1 inch in thickness. This material is removed, then washed and finally returned to another filter ready to receive a fresh supply of sand. The wash water is delivered under pressure and is also utilized to carry sand from the old to a new or clean filter, where it is again distributed. The cleaning of rapid filters consists in allowing filtered water to pass upward through the entire sand layer at a sufficiently high velocity to float the sand grains of the entire mass and thereby remove the suspended matter attached to it by a stirring of the sand caused either by the escape of compressed air or by revolving rakes. The sand, after washing, settles back into its place and the filter is then again ready for service.

The efficiency in producing clear water free from bacteria is nearly the same with both classes of filters. The slow filters require a larger area and a greater investment of money, while the rapid filters require much less land, but a greater cost for operation. The total cost, however, generally does not differ materially. The slow filters are somewhat more simple in operation and less likely to get out of order, while the rapid filters are more efficient for waters that are very turbid or highly colored.

This Commission recommends for the additional water supply from the Hudson River watershed the slow filters, because there is sufficient area of suitable land available, and because the character of the turbidity and color of the water is such that a coagulant would rarely if ever be required to obtain clear and colorless water, and because the magnitude of the works render the conditions of operation more simple and, therefore more easily managed. It is necessary to add, however, that emergency conditions may exist where rapid filters may be preferable, because of the rapidity with which they can be installed and the smaller expense of installation.

To protect the artificially purified water as well as the ground water from deterioration by exposure to sun, heat, and dust, it must be kept in covered reservoirs for distribution, and thus not be exposed in passing from the filters to the point of consumption. The sole object of the distributing reservoirs is to afford storage of enough water near to the consumers to compensate for the varying hourly drafts and to provide against sudden large drafts in case of fires or bursting mains. An excessive size is, therefore, required, and a covering of the necessary area is feasible and not expensive. For the supply of Manhattan and The Bronx the proposed Hill View Reservoir will serve this purpose. The Jerome Park Reservoir when covered can be utilized as a distributing reservoir for the present low level supply after it is filtered. For Brooklyn, the Prospect Park Reservoir can be readily adapted for the same purpose by providing a cover. Suitable sites for additional distributing reservoirs should soon be secured, both for the rapidly developing Boroughs of Brooklyn and Queens on the ridge in the centre of the Island, and for the Borough of Richmond on the highest portions of Staten Island.

The Commission has made an extended study of the filtration of the proposed additional supply of waters from the Hudson River valley, from which the next increase of supply should be obtained. It has not been able to enter with the same detail into the study of filtration works for the existing supplies of the Croton and of the Long Island surface waters. Regarding the latter, it is urged that investigation be made to ascertain the expediency of erecting filters for the purification of those surface waters which are subject to the pollution from a growing population, and which for some time it may be deemed best not to abandon in favor of another source of supply. Regarding the Croton water, the Commission urges that suitable lands be secured at once, upon which to erect a filter plant sufficient in size to purify the entire supply obtained from this source. There are but a few sites still available for such a plant of slow filters, and a long delay in procuring it may seriously affect its future cost. Examinations of the sites have been made sufficiently extended to determine their feasibility and to ascertain their approximate cost.

The chief work of the Filtration Department consisted in the discovery, surveying, and mapping of all areas suitable for filter sites for the different water supplies which were investigated to supplement the present Croton supply. The reconnoissance and first surveys were based upon the existing maps of the United States Geological Survey, but accurate levels were run over all the territory under consideration. The detached positions of the various locations surveyed for the above purpose made it desirable to locate them accurately by means of latitude and longitude measurements, and these were based upon the data furnished by the United States Government. A large number of locations were closely investigated with reference to their suitability for different propositions of additional supply, namely, for a low level aqueduct and a high level aqueduct, and also for obtaining the waters through different combinations of the available sources. After the location of the best filter site for the recommended project to be much different. The watersheds of the Catskill Mountain region, on the other hand, are essentially different from those on the easterly side of the Hudson. The drainage area of the Esopus has steeper slopes and a surface in general from which storm waters will run off much more rapidly than from the drainage areas available east of the Hudson and it is at much greater elevation above sea level. From these and other considerations a greater yield per square mile may be expected and it has been found in our observations. A safe estimate of the greatest available runoff from any drainage area for purposes of municipal water supply must be based upon observations of rainfall and stream gaugings extending over a long series of years. Such extended observations, unfortunately, have not been made for any of the watersheds contemplated for the additional supply. Certain comparative deductions may be made from extended observations on other and similar drainage areas not too remote from those under consideration and not radically different in character. For this purpose the results of the most extended observations available upon the Croton Watershed of the New York supply, upon the Sudbury and Nashua Watersheds of the Boston supply, those obtained by Mr. Emil Kuichling for the proposed barge canal across the State of New York, those obtained by this Commission from short periods of observation and from other reliable sources, were examined and studied.

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York City are all under fairly good sanitary supervision and that the quality of work by the sanitary patrol and the frequency of tests of the quality of the water supplies have made marked progress in recent years.

The analyses made for the Brooklyn Water Department have shown that the ground water supplies are substantially free from pollution dangerous to health, or, in other words, the natural filtration which these waters receive on their passage through the ground purifies them, so that, generally speaking, they are safe, notwithstanding that considerable sources of surface pollution lie in their path.

Analyses of Present Supplies.

Under the present rules, samples for analyses are collected every day from the terminus of the Croton aqueduct at One Hundred and Thirty-fifth street, Manhattan, and from the terminus of the Brooklyn aqueduct at the Ridgewood Pumping Station, also at several taps in Manhattan and Brooklyn. Once a week samples are collected from all the distributing reservoirs, supply ponds, and storage reservoirs. Once a month, or once a quarter, every driven well supply is analyzed and all apparent sources of dangerous pollution of which any notification reaches the Department of Water Supply, Gas, and Electricity, are made subject to an immediate investigation.

As to the tests of these samples it may not be amiss to state here that the character of water analysis has entirely changed during the past 15 years, under the development of the sciences of Biology and Bacteriology, and the proof that certain diseases, notably typhoid fever, are water borne. Fifteen years ago the only water analysis made was the chemical analysis; but so far as the public health is concerned this by itself now would be regarded as of little value. To-day, a complete sanitary water analysis consists of four parts—the bacteriological examination, the microscopical examination, the physical examination, and the chemical analysis, and for the best interpretation of these an inspection of all the sources of the water and their surroundings is also necessary.

Bacteriological Examinations.

The bacteriological examination, as practiced in the present investigation, consisted of a determination of the total number of bacteria and the test for Bacillus coli made upon three different quantities of the water in question. In bacteriological examinations of water supplies no distinction is made between the harmful and the harmless bacteria, and the method of counting the total number of bacteria in a sample has chiefly a relative value for comparing different sources of supply, while the test for Bacillus coli is chiefly of value as demonstrating the freedom from pollution, and in tracing such pollution as has its origin in the intestines of warm-blooded animals.

Microscopical Examination.

This is of value chiefly as a measure of the probable freedom of waters from aromatic, grassy, and fishy odors in unclean reservoirs, to which they are sometimes subject, for surface waters contain many forms of animal and vegetable life which, although too small to be observed with the naked eye, may, by their growth and decomposition, make a water unpalatable and offensive to the taste. This examination is made by filtering out the organisms and transferring them to the stage of a microscope, where they can be identified and counted.

Physical Examination.

The physical examination is chiefly of value as demonstrating the qualities of the water evident to the senses, such as temperature, turbidity, color and odor. The color and turbidity at the present time are measured by comparison with well-defined standards. The color is caused chiefly by vegetable matter in solution coming largely from swamp lands on the watershed, being practically an extract of the leaves, twigs, etc., which accumulate upon the wet surface of the ground. While color in water is not distinctly harmful, if great enough to be noticeable in a glass it may detract from its palatableness, or if so high as to be distinctly noticeable in a washbowl, or porcelain bath tub, may give the suggestion of uncleanliness. The color in water, being due to substances in solution, must be distinguished from turbidity which may be in a large part removed by subsidence. Turbidity is chiefly objectionable because of rendering water unattractive.

Chemical Analysis.

The chemical analysis is useful mainly as indicating the presence or absence of previous pollution by an excess of chlorine or by the amount and character of the nitrogenous matter present, but it is also of great practical importance for showing the hardness and alkalinity of the water and its effect when used in steam boilers.

The present and proposed sources have been studied by repeated samples throughout all seasons of the past year, and an abstract of these results will be found in Appendix VI.

Character of the Croton Water.

The Croton water has frequently been turbid during the past few years and occasionally malodorous. The occasional odors are due not to pollution but chiefly to the effect of microscopic organisms which grow at certain seasons of the year, mainly in the reservoirs in Central Park. These basins have not been cleaned for many years and there must be considerable deposits of mud at the bottom. With 200 million gallons of water per day passing through these reservoirs computations based on analysis show that a deposit of about an inch in depth every ten years may be expected, but the amount of this sediment is of less importance than its character. It is largely organic and contains many micro-organisms, and these basins have thus become so seeded with algae, protozoa and other organic life that at times the water emptying from the basins is found to be objectionable, while that entering is in good condition. Obviously these reservoirs should be cleaned more frequently.

The impounding reservoirs of the Croton system show conditions not materially different from those that occur in storage reservoirs elsewhere. These reservoirs were constructed without the removal of the turf, stumps, peat deposits, and other organic matter from their beds. When the reservoirs were flooded some of this organic matter decomposed during the first few years and water drawn meanwhile from the lowest sluices was offensive. This decomposition has now practically come to an end and the reservoirs are apparently but little different from natural lakes having mud bottoms. Most of the reservoirs of the Croton system are deep and undergo the process of stagnation and overturning. Under the differences of density due to the varying temperature from top to bottom vertical circulation ceases during a portion of the year and the free oxygen in the lower strata becomes exhausted, after which organic matter at the bottom is liable to give off offensive odors.

In general, the conditions of the Croton water appear such that filtration is all that is needed to make it entirely satisfactory, providing it is subsequently stored in covered reservoirs, so subdivided into compartments that the bottom of the reservoir can be conveniently cleaned. It is desirable that attention be given to this question of removing organic matter from the bed of the reservoir to be formed by the new Croton Dam. If the Croton supply is soon to be filtered, as recommended by this Commission, this work of freeing the reservoir bed from organic matter may be done on very economical lines.

With the advent of filtered water the problem of caring for the stored water and keeping it free from objectionable organisms will become more difficult, for to turn filtered water into a reservoir which is seeded with the germs of so many micro-organisms as the Central Park reservoirs would largely destroy the benefit of filtration.

It may ultimately be found necessary to provide for the further subdivision of these reservoirs and to cover them by masonry arches similar to those proposed for the Hill View Reservoir. In such an event these arches would be covered by a few feet of level earth, grassed over and made available for park areas.

The effect of the longer storage of the Croton supply in the new Croton Lake and in Jerome Park Reservoir prior to filtration will tend materially to improve the sanitary quality of the water.

The hardness of the Croton water differs greatly in different portions of the watershed, but as the water reaches the City it averages about 40 on the ordinary scale of hardness, which is not objectionable. Moreover, this hardness consists mainly of the carbonates, and is of the temporary kind which does not form a hard scale in steam boilers as does the hardness due to sulphates.

The Bronx and Byram water is, in general, superior to the Croton and, notwithstanding their drainage areas are nearer the city, they now have a lower population per square mile. The excellent sanitary condition of this water is indicated by the low typhoid death rate in the Borough of The Bronx.

Quality of Brooklyn Supply.

The water supplied to the Borough of Brooklyn may be considered of reasonably good sanitary quality under ordinary conditions. It is occasionally turbid and sometimes high in color. It is fairly soft, although it contains relatively high sulphates, nitrates, and chlorides, making the water unsatisfactory for boiler use, but not high enough to cause trouble in domestic use. The large and increasing population of the watershed, the small size of the supply ponds permitting delivery of surface wash into the aqueduct, are such unsatisfactory conditions that the filtering of all this surface supply should be accomplished at the earliest practical date.

Mr. I. M. de Varona, Chief Engineer of the Brooklyn Water Supply Department, has for five years past given attention to the analysis of the water supplied by all portions of the Brooklyn drainage area, and care appears to have been taken to shut off any sections of the gathering ground in which pollution was imminent. Bad growths of micro-organisms sometimes occur in the Ridgewood and Mt. Prospect reservoirs, imparting to the water unpleasant odors and rendering it unsightly, and it has frequently been necessary to by-pass these reservoirs and cut them out of the general circulation during periods of offensive organic growths. The Mt. Prospect Reservoir has much heavier growths of organisms than the Ridgewood Reservoir, and is also subject to contamination by clouds of dust blown from the street, and it should be covered if it continues to be used. These reservoirs should be covered by some such method as shown in the plans of the Hill View Reservoir, and provision should be made for cleaning them regularly as long as unfiltered surface water continues to be used.

There are no limestone deposits which outcrop on Long Island and the surface waters are comparatively soft, but increase in hardness from east to west, this being due apparently to the increased density in population Several of the driven well waters are very hard, but this hardness is so diluted by admixture with the surface water that the average total hardness is but slightly more than that of the Croton. The chlorine entering the water from certain of the wells adds materially to the corrosive effect of this water on boilers. Chloride of magnesia appears to be the most active agent of corrosion, but is doubtless aided by the amount of dissolved free carbonic acid in the water and also by the nitrates that it contains. All hardness due to sulphates, nitrates, and other similar salts, are generally higher than in surface waters of the Croton Watershed.

Sanitary Studies for the Additional Supply.

The following qualifications were regarded as essential for the new supply:

1st. Absolute freedom from pollution, or from organisms capable of producing disease or discomfort.

2d. Freedom from odor and from noticeable turbidity and color.

3d. Softness.

4th. Freedom from iron in solution.

5th. Freedom from substances liable to corrode metal work, either in boilers or service pipes.

6th. A cool and equable temperature is desirable.

Unfortunately the characteristics which may render a water dangerous do not always make it unpalatable, and a water which may be attractive and pleasant to the taste may contain disease germs, but on the other hand, waters that are high in color and turbid may not be at all unsanitary. Special attention has been given to the hardness and alkalinity of the samples of water investigated. The temporary hardness coming from carbonates and bi-carbonates in comparison with the hardness from sulphates, which in boilers form a hard scale, has also been given much attention. All of these questions of hardness will be found fully discussed in Appendix VI. An interesting study has been made to determine what additional value to the community a water supply would have which should contain only half the hardness of the present Croton supply, or, on the other hand, what would be the probable extra cost of soap and boiler compounds with a water which would have double the hardness of the present Croton supply, and, in fact, the final decision of this Commission lay on the desirability of the hardness of the waters of the Wappinger Creek, and the Jansen Kill in comparison with those of the Esopus and Rondout.

Assuming that one gallon per inhabitant per day is used in washing requiring soap and taking the total horse power of steam boilers from the Police Department's report, an estimate shows that the consumers may be compelled to expend $100,000 annually for soap and boiler compounds for every increase of 10 points of the scale of hardness for a public water supply of 275 million gallons per day, the present consumption of Manhattan. On this basis, comparing the waters of the Fishkill and Wappinger Creeks and Jansen Kill, having an average hardness of over 90, with the waters of the Esopus and the Rondout Creeks, having a hardness about 20, it is found that the excess of cost, due to this difference in hardness, would amount to the surprisingly large sum of $700,000 per year. While this estimate is not to be accepted as exact, at least it serves to point out the commercial value of softness in a water supply.

Stream Investigations.

The investigations of the quality of water in the various streams considered as possible sources at first covered a wide range of territory, comprising all of the principal tributaries of the Hudson, the Ten Mile, the Housatonic, and the northeasterly headwaters of the Delaware, but as the work progressed many of these courses were eliminated from further consideration and the work confined to a narrower field. Stations were established on all the important streams and local representatives were engaged to collect daily samples, observe the height of the river by reading the staff gauge and record the meteorological condition. Thirty-four stations were established but not all were continued. At nine of these stations rain gauges were located. In all cases the points were selected with care to secure representative samples.

In addition to these analyses, inspection tours were made over the drainage areas to determine the sources of pollution, the character of the vegetation and extent of the cultivation of the land, the appearance of the banks of the streams, and the general topography and geological features. The completeness of these investigations varied according to the probability of the water being used. Two general inspections were made of all the drainage areas, while in those selected for future sources three detailed inspections were made. A sanitary survey was made of the drainage areas of the Fishkill Creek, Wappinger Creek and Roelif Jansen Kill, also of the Esopus, Catskill and Schoharie Creeks, to secure reliable data concerning the amount of transient population along these streams, the number and size of summer hotels, the character of the villages and their method of sewage disposal. The inspectors counted the houses and located them on the maps, estimating the number of summer boarders from inquiry and by conferences with the postmasters. Sources of pollution were of course noted and located on the maps.

Consideration of a supply of filtered water from the Hudson taken near Hyde Park required a careful study of the tributaries above that point. The results of these various lines of investigation may be stated briefly as follows: The Adirondack streams were found free from pollution, conspicuously free from turbidity, even during spring freshets, and very soft, but the water is about twice as dark as the Croton, due to the presence of swamps. The Batten Kill, the Hoosac and Mohawk Rivers were found polluted and their waters hard and at times turbid. The Walkill was found decidedly hard, and discolored by the extensive swamps and peat deposits of the Drowned Lands.

The Fishkill and Wappinger Creeks, the Jansen Kill, the Esopus, Schoharie, Catskill and Rondout Creeks were considered more particularly as direct sources of supply. The Esopus and Rondout Creeks were found the most attractive in quality, by reason of their extreme softness. The drainage areas of all of these mountain streams are sparsely populated, and although they contain many summer hotels and cottages these can be made unobjectionable from a sanitary standpoint by a comparatively small expenditure for sewage disposal in the principal villages and summer colonies.

The drainage areas considered east of the Hudson are also sparsely populated. Their streams have water averaging nearly two and one-half times as hard as the Croton, while the Esopus, Rondout and Schoharie Creeks have water only half as hard as the Croton.

An extended investigation was made to determine the average hardness of the water that would be delivered from large impounding reservoirs on each of these watersheds, for obviously the daily samples taken in summer would show a much higher degree of hardness than the spring flood waters with which the impounding reservoirs will be replenished. Allowing for this, and weighing the average of the weekly samples in proportion to the volume to be stored at the different seasons, it was estimated that the average quality of the water stored in these impounding reservoirs would be as follows:

Reservoir System.	Hardness.	Million Gallons Daily.	Reservoir System.	Hardness.	Million Gallons Daily.
Stormville	102	37	Esopus	20	255
Billings	58	24	Rondout	23	100
Hibernia	91	68	Schoharie	21	171
Clinton Hollow	67	20	Catskill	36	123
Silvernails	107	112		..	...

It is found that combining the Fishkill, Esopus and Rondout waters in the proposed new aqueduct, the average hardness would be 29, while with the Hibernia Reservoir system added to make up the full 500 million gallons per day, the hardness of the whole would be increased to 40, which is practically the same as that of the present Croton supply. In Appendix VI. an estimate is presented of the probable chemical and physical characteristics that the proposed new supply would possess.

Hudson River Water.

This water was made the subject of very full studies during the first few months of the Commission's work, because the proposition to obtain the new supply from the Hudson at a short distance above Poughkeepsie was at that time the most prominent.

The averages of many analyses show that the quality of this Hudson water near the proposed location of the intake would be about the same as that taken from this river between Albany and Troy and filtered for municipal use, and that it can be made at least equally satisfactory by filtration. It was found that the additional pollution which the river receives at Albany is more than offset by dilution from the volume of water that comes in from the tributaries entering below Albany. The average hardness of water taken from the Hudson would be about 46, somewhat less than at Albany, and little more than that of the Croton.

This Commission is of the opinion that by adopting proper precautions, and, also reinforcing the flow in time of drought from large storage reservoirs under the City's control, to be established in the Adirondacks, the water taken from the river near Hyde Park could, by filtration, be rendered palatable and entirely safe for drinking, domestic and industrial use.

Salt Water in the Hudson.

With a view to locating the proposed pumping station for Hudson water at a safe distance above the point to which the tide may carry salt water under extreme conditions of drought and wind, an extended series of observations was made.

The scientific solution of this problem is complicated. It is known that the salt water does sometimes affect the Poughkeepsie supply. An amount of salt, too small to be tasted, may seriously affect the value of the water for steam and industrial purposes, as is seen in the case of the present Ridgewood supply. The present season proved less favorable for finding the limit of the flow of salt water than if there had been less rain, but many valuable data were secured. Many hundred determinations of the amount of chlorine at different depths at points all the way from New York to Albany, and under varying conditions of stream flow, tide and wind, were made. Automatic tide gauges were located at Yonkers, Oscawanna, West Point, Poughkeepsie and Rhinecliff. From a review of these records and from many inquiries of those familiar with the river, it appears that a location near Hyde Park could be made safe in connection with a reinforcement of the Summer flow, but whenever a season of extremely low rainfall, like that of 1883 or 1891 again comes, the present studies should be supplemented by further investigations, with a view to recourse to the Hudson for water supply in the distant future.

Ground Water Supplies.

Analysis previously on record in the Brooklyn Water Department gave nearly all the chemical and bacteriological information that was needed concerning the present quality of the ground water sources of Long Island. Test of samples, taken from some of the thickly populated parts of Brooklyn, were analyzed for comparison and the results are very interesting in showing the amount of pollution that may exist on the surface and not render the water from a driven well unsanitary, even with a coarse gravelly soil. It was found that samples of water which, from chemical analysis, might be considered unsatisfactory, were sterile by bacteriological tests and can safely be used for drinking purposes. This is largely due to the distribution of the sand or gravel which causes a diffused and slow movement of the ground water. Investigations were made to determine the limits at which pollution extended from large amounts of fœcal matter deposited at a depth of 6 or 8 feet below the surface, as in privy vaults, and other experiments have been made to determine the rate of decrease in bacteria from the surface of the ground downward.

Long Island Sources.

It is the opinion of this Commission that the water to be obtained from Long Island should be either ground water, not subject to pollution, or properly filtered surface water.

It is entirely practicable and economical to supply Brooklyn and Queens from the recommended Hill View Reservoir, about three miles north of Jerome Park Reservoir. The details of this system of pipe lines extending across the East River can be readily arranged when necessary. As they were not so important as the questions concerning the sources available for the nearer future, they did not receive special consideration. The Commission desires to urge, however, that one or two connections should be made as soon as practicable between the large mains in Manhattan and those of Queens and Brooklyn, so as to place safeguards against the results of any sudden breakage, or of any dangerous or temporary shortage in either of the boroughs.

This Commission is of the opinion that at present, and for some years to come, the more economical method of increasing the present supply for the Boroughs of Brooklyn and Queens is by adding to it new sources on Long Island. And it is recommended that all further increase should be in the direction of an extension of the ground water sources, because this could be accomplished in less time and at less cost than the collection, storage, and filtration of surface waters not yet utilized. The need of further time and funds made it impracticable to complete surveys and detailed estimates of cost of the necessary works of such additional supplies. The present report is, therefore, limited to an expression of opinion based upon personal examination and careful study of the situation and a thorough investigation of the Island sources.

The source of all underground waters, as well as of surface waters, is the rainfall. It is therefore necessary first, to ascertain the amount which falls upon the territory whence it can be brought to the City, and incidentally also its distribution as to time and place. Secondly, it is necessary to follow the rain water after it has fallen and to find the proportion which is available for the City's use.

The precipitated water and snow divides into several parts. One flows off immediately upon the surface into natural depressions of the land, and thence into brooks and rivers. This run-off increases in proportion as the ground is frozen, as it is wet, and as the rain is intense. Another part is retained for some time by the vegetation and mold, or upon the surface in the form of snow or ice. Another part is evaporated from the plants, from water surfaces and from land surfaces, especially when warm and dry. Still another part percolates into the soil if it is permeable, and is absorbed by the roots or held in the ground by capillarity, to be withdrawn by evaporation from the soil. Finally, one part descends into the ground to impenetrable clays or dense rocks, and until it reaches a plane of saturation below which is accumulated within the interstices of the rocks and soils a large quantity of ground water, which creeps through the pores to the lowest levels, where it can escape as spring water into streams, lakes or the ocean. Each of these parts has been considered, so far as practicable, with reference to the conditions on Long Island.

In order to ascertain whether there was a sufficient quantity of ground water of good quality available for the purposes of a water supply, an investigation was extended over most of the Island. This was begun early in

March. Arrangements were made by which the United States Geological Survey could aid in the work of the Commission by undertaking a study of the geology of the Island, making some of the stream gaugings and measuring the velocity of ground water flow.

The work of the Commission itself comprised observations on rainfall, temperature, wind and relative humidity, studies of evaporation from soil and the amount of percolation, the location of existing wells for ground water observations, sinking new test wells to supplement those already existing for the purpose of determining the character of the soils and rocks in the sub-strata, the gathering of ground water statistics to learn the rate and amount of percolation and of fluctuation of the water table, determining the levels of this water table in wells and measuring the surface water flow.

The investigations were started in the Borough of Queens and County of Nassau, and were later extended into Suffolk County as far as Patchogue and Port Jefferson, with some observations reaching Riverhead. Most of the collected information was plotted, and is contained in Appendix VII.

Meteorological Observations.

Several meteorological stations were already in existence, at some of which observations were made by the United States Weather Bureau and at others by the Brooklyn Water Department. The Commission established five more stations. At Floral Park and Brentwood continuous records were obtained, the former representing the watersheds of the present Brooklyn supply and the latter permitting a comparison of the meteorology of Suffolk County with that of Nassau County. At Oyster Bay, Farmingdale and Manor the stations were equipped with standard rain gauges and thermometers, which were read by special observers.

A compilation of the rainfall records shows an average precipitation for 78 years of 42.56 inches per annum. For the purpose of a reliable supply of water it is necessary, however, to consider not the average but the greatest quantity permanently available. In view of the large storage capacity of water within the interstices of the sandy substrata of Long Island, it is safe to base this supply upon a series of consecutive dry years rather than upon a single dry year. The period of lowest precipitation on record showed for five years, between 1835 and 1839 inclusive, an average of only 35.20 inches per annum. On this basis, it is quite proper to assume 35 inches per annum as the greatest precipitation from which to estimate the amount of ground water which at all times can be abstracted and utilized. From this assumed rainfall it is necessary to deduct the water which runs off on the surface to the ocean, and that which is evaporated and absorbed by vegetation. The remainder is the source of the available ground water. While as much information as time permitted was obtained regarding the stream flow and evaporation, most of the observations made by the Commission had for their object a more direct determination of this available quantity.

Surface Waters.

Long Island, from which the surface water supply is now derived, has near its centre and stretching from west to east, a ridge several hundred feet in height, from which streams run northerly into the Sound and southerly into the Atlantic Ocean. A large part of the Island near the ocean is flat and indented with bays and channels through which the tide ebbs and flows. The shortness of the Island streams makes them small, and the flowing water in their lower portions is maintained almost entirely by the ground water which enters them, the upper portions of the streams being dry except during and shortly after rain storms. The Brooklyn water supply is derived partly from the flow of many of these streams and partly from the ground water, all between Spring Creek and Massapequa.

In order to gain a fair estimate of the amount of water flowing off the surface of the territory under consideration, including that portion of the ground water which isues as springs and supplies the dry weather flow of the streams, gaugings have been made by erecting weirs across some of the characteristic streams, utilizing for this purpose also the existing information of the Brooklyn Water Department as far as practicable. Little stream gauging work had been done except during periods of drought before the present year, when in April and May the United States Geological Survey established ten stations, two in Nassau County and eight along the southern shore of Suffolk County. These measurements were not sufficiently precise or long continued to permit a fair estimate to be made of the surface run-off. The Commission, therefore, made some independent stream flow gaugings, but confined them to six of the most important streams between Freeport and Massapequa.

The Long Island streams are somewhat flashy because they are short and their upper parts are rather steep. Therefore, the few daily observations had been of little use and the Commission established self-recording gauges and weir measurements. Besides these six weir stations, four other stream gauging stations were established, at which daily approximate measurements were made at Jamaica Creek, Seaford Creek, Massapequa Stream and Dixsee's Creek. The watersheds of the streams between East Meadow Brook and Massapequa Stream were studied in some detail to get the drainage areas and the physical surface characteristics.

At present, practically all of the available surface water of Queens and Nassau Counties has been secured and made tributary to the supply. The only larger quantities of surface water left to be secured are in Suffolk County, where at present the law prevents their being taken.

Estimates of the stream flow were made in 1867 by James P. Kirkwood, and in 1875 by Julius W. Adams, which were to the effect that in the dry years it amounted to about 50 per cent. of the minimum rainfall, which however included whatever ground water flow entered the streams. The true surface or flood flow was estimated by Adams at 12 per cent. The studies of the Commission have indicated that the flood flow for a long period of minimum rainfall might be as low as 9 per cent., and that for average years it may be about 16 per cent. The Commission has concluded that the entire visible flow of the streams may be estimated at 35 per cent. of the average annual rainfall and at 23 per cent. for five year periods of minimum rainfall. Assuming a rainfall of 35 inches for a dry period, the flood flow in the streams would correspond to a depth of 3 inches per year and the entire visible stream flow to 8 inches.

The general quality of the surface water now delivered to the Borough of Brooklyn from the easterly half of its present area of supply is similar to that of the usual water-courses from sparsely settled farming country. The water contains a sufficient quantity of organic matter to support a fairly high percentage of bacteria; it has an occasional taste due to the growth of certain organisms, and after rain storms, when the fields are washed by the water running off, it also becomes turbid and dirty. The westerly half of the area contains populous communities, resulting in the pollution of its waters, which is already serious and which will continue to increase. Filter plants have recently been erected at Springfield and Jameco stations to improve the supply from these polluted sources.

In view of what has been stated regarding the quality of the surface waters, this Commission is of the opinion that all such waters supplied to the City should be artificially filtered, and it recommends the immediate construction of suitable plants for that purpose. Such filtered surface waters, as they are softer than the ground waters, will, when mixed with them, moderate the hardness of the latter.

Evaporation.

Evaporation of water proceeds from water and land surfaces and from plants. It increases as the humidity of the air becomes less than that of the soil and as the temperature of the air and soil rises. It is greater on slopes with southern exposure than on land sloping to the north and increases with the movement of air over the surfaces. Evaporation is also dependent upon the character of the soil. It is greater in dense and compact soils, with small pores like clay, than in sands. It is, however, more rapid in the open soils, because there is less resistance to the rising water.

The most powerful preventative of evaporation is the covering of the soil with a material having greater porosity, which reduces the capillary action and, therefore, the ascent of moisture. It is greatly reduced by the formation of any detached crust and also by loosening, plowing or raking of the soils. On cultivated lands where mulching is practiced, the soil moisture is retained much more than in cultivated fallow soils. In forests the evaporation is much less than on cultivated fields. It has also been found that if average soil is saturated with water, but covered by grass or trees, as in a swamp, there is a greater evaporation than from a free water surface.

To get some local data on evaporation from soil, two sets of tanks were placed at Floral Park, one being 2.5 feet and the other 5 feet in depth. In the former the water was kept 2 feet and in the latter 4.5 feet below the surface. The results gained therefrom are given in Appendix VII.

Percolation.

With a given rainfall, the amount of water percolating into the soil will generally depend on the amount of water evaporated, and hold an inverse ratio thereto. It will also depend upon the effective size of the grains, increasing therewith and finally upon the porosity of the soil. If the soil is uncovered or very open, the amount of percolation varies with the rainfall. The time of descent will vary with the size of the pores. In coarse sand it will be rapid and in fine sand slow. In either case, the water, if not intercepted by an impervious material and diverted laterally into an open watercourse, will eventually reach the ground water level.

Sands and gravels, if the grains are fairly uniform in size, have a porosity of about 30 to 45 per cent. of the total volume, the proportion being less when the grains are not uniform in size. Although the porosity of clay ranges from 40 to 70 per cent. the velocity of percolation through it is exceedingly slow because of the fineness of the pores. Only a general estimate can now be made of the average porosity of the soil of Long Island, for although many samples have been taken during the investigations of the Commission, the mechanical analyses by the United States Geological Survey were not completed.

Prof. Charles S. Slichter was detailed by the United States Geological Survey to make certain determinations regarding the velocities of the ground water on the south shore of Long Island, partly to estimate the general flow seaward and partly to study the effect of pumping and the velocity of the ground water near the Brooklyn well stations. These observations were made between East Meadow Brook and Massapequa Stream for comparison with the surface flow to be measured from the same area. They were along the six-mile stretch, having five pumping stations for the Brooklyn water supply and several ponded streams flowing into the conduit at all times. Nine stations were established and at these 12 measurements were secured.

It is generally found that water bearing sand and gravels will readily yield a supply of water amounting to 10 to 30 per cent. of their bulk, according to the conditions above mentioned.

Ground Water.

Ground water free from local pollution or mineral impurities belongs to the best class of waters for city supplies. There are several instances in Europe where it is preferred to filtered river water even when it is more costly. Where the territory is strongly manured for agricultural purposes or is perforated by cesspools and sewers near to the point of taking, there is danger of pollution and of transmitting enteric diseases, which increases with the density of population. Water percolating through soil may partake also of mineral impurities, increasing its hardness or dissolved mineral matter, such as iron or sulphur.

On the other hand, its long journey through porous soil insures to it by this aging a purification, first through the agency of nitrifying bacteria and then by the death of the usual pathogenic bacteria, which is not exceeded by any other known means. Therefore, if taken under proper precautions, it is the most healthful of waters. During percolation and subterranean storage the temperature is equalized to a degree which benefits the water, both in summer and winter.

Ground water should, therefore, not be drawn from too near the surface nor under conditions permitting the inflow of sea water or mineral impurities.

To guard against a local pollution of the water drawn up in the wells it is advisable and customary to acquire a strip of land as wide as practicable along the site whence the water is derived, and to maintain this as a park or in some other suitable way.

The flow of ground water is caused by the action of gravity propelling it through myriads of channels found between the grains of soil and sand. The geological formation of Long Island is favorable to a sustained and ample flow of ground water. The surface soils are mostly sand and gravels, sometimes separated by layers of loam and clay. They extend to such depths that a great storage capacity for water is available. The geological strata, as may be expected, are not uniform. Therefore, those that bear water are not always continuous, vertically or horizontally.

The ground water in a number of places on Long Island, particularly along the south shore, rises to the surface of the ground, causing swamps, but in other places the surface of saturation is found from 50 to 100 feet below it. A survey of the underground conditions of Long Island was the only means of throwing light upon the probable flow, in the absence of practical tests of long duration. The most important observations required by the Commission concerned the quantity of water available from the sub-surface strata.

The elevation of water surface was observed at frequent intervals in 1,045 existing wells; of these, 147 were in the Borough of Queens, 396 in Nassau County and 502 in Suffolk County. In addition to these, 333 two-inch wells were driven for purpose of observation and collection of samples of soil, 1,927 sets of samples having been taken and classified. Of these driven wells 46 were in the Borough of Queens, 249 in Nassau County and 38 in Suffolk County. Forty wells were driven for soil pollution experiments and 104 for underflow measurements by the Slichter method. In addition to these wells, 22 test pits were dug by post hole augurs where the ground water was within five to ten feet of the surface. The observations of the ground water surface were begun on existing wells in March and ended November 1, when 37,042 observations had been taken. The area over which they extended is about 1,000 square miles.

The elevation of the ground water, as found above sea level, causes a flow both toward the Ocean and the Sound. The quantity thus flowing away must be replenished by the rainfall upon the Island. The main question is, therefore, whether or not the quantity of water thus constantly flowing toward the sea is sufficient for the purposes of municipal supply. This depends upon the amount of rain water percolating into the ground and reaching the ground water surface, which has been discussed above. The United States Geological Survey made an examination of surface rocks and soils, also of samples from well borings, and made a report therefrom on the geology of the Island with special reference to ground water questions. The results of the observations and surveys are given in detail in the respective appendices.

Having reached in its vertical descent the ground water surface, which forms the hydraulic slope necessary to cause a flow to some point of discharge, the water flows laterally with a slow but definite velocity. This lateral flow is somewhat like that of a stream, although the frictional resistance of a fillet of water in passing through the pores depends rather upon the size of the pores than upon the distance of the fillet below the surface. The advantage of a line of wells rather than an infiltration gallery lies in the fact that they draw the deeper and more sterile waters, giving those descending from the upper layers a longer time in which to lose any objectionable bacteria.

The oyster industries of a portion of the south shore of Long Island are thought at the present time to require a temporary immersion of the oyster in fresh water immediately prior to marketing, in order to "freshen" or "fatten" them. So far as this Commission can learn, this practice is not general and injures the quality of the oyster. Allowing ground water to flow from the upland into the ocean for this purpose greatly reduces the available volume of the natural waters of Long Island for the supply of the Boroughs of Brooklyn and Queens and other communities.

From the observations made during the present year, it is concluded that the amount of water percolating into the ground and issuing either into the streams or into the ocean directly, is equal to a depth of rainfall of 15 inches per annum. This represents 42 per cent. of the rainfall of a series of dry years.

It is the unqualified judgment of this Commission that the water found available on Long Island is no more in quantity than can be accounted for by the rainfall upon the surface of its own territory and by its local geology. A brief study of the geological formation of the shores of the neighboring mainland is sufficient to justify this conclusion.

It is also the opinion of the Commission that an ample supply of ground water is available on Long Island to justify the material extension of the present supply, and that the surface waters should eventually either be abandoned or filtered before entering the conduits.

Its further opinion is that the ground water should be obtained through the construction of conduits properly located and provided with pumping stations along their course, so as to allow the ground water to flow into them by gravity through appropriate wells placed at one side of them, as frequently as the water yield of the soil in the particular locality will permit. and that their depth should be sufficient to penetrate saturated gravels at least 30 feet below the ground water surface. By this means the Commission believes that all the available ground water will be obtained at less cost than by other means, and a much larger quantity than at present.

The Commission further recommends that studies be made for an extension of the supplies for the Boroughs of Brooklyn and Queens in the manner indicated, that the collecting conduits be located to effect a minimum lowering of the present ground water level by adjusting them as nearly as possible to the present water levels, and that pumping stations be placed at suitable intervals to force the water thus collected into covered reservoirs, whence it would enter the distributing pipe system.

Borough of Richmond.

The Borough of Richmond is at present supplied with ground water from several stations. Some of this water is excessively hard. The quantity is generally limited and an additional supply is urgent. This Commission has approved of a proposition from a private company to furnish, at once, for a period of ten years, a sufficient quantity of filtered water from the State of New Jersey. No other means appears practicable so quickly to supplement the present sources.

A further study should be made to determine whether it would be more economical and desirable to continue this supply for a greater period, or to furnish water from the Borough of Brooklyn through a pipe line across the Narrows.

As soon as practicable sites for both equalizing and distributing reservoirs should be secured as they will soon become necessary in several parts of the borough. The Commission recommends for such a purpose the early selection and purchase of the required property.

Pumping Department.

At the time when this Commission began its work and particularly after the Corporation Counsel had advised that interstate streams should not be considered available, thus ruling out the Housatonic and Ten Mile Rivers, one of the most promising sources appeared to be water taken from the Hudson above Poughkeepsie and filtered. The constant use of filtered Hudson water for more than twenty years by the cities of Poughkeepsie and Hudson and the success of the large recent filters for Hudson water at Albany as well as the extended successful European experience with filtering water much more polluted than the Hudson water, gave proof that this source could be made wholesome in quality, and it was plain that the volume would be ample, particularly after the construction of storage reservoirs in the Adirondacks.

Therefore, while not delaying the investigations for sources of unpolluted upland water lying at an elevation suitable for delivery by gravity, designs were worked upon for taking the Hudson water and pumping it to an elevation suitable for delivery in New York City at the level of the present Croton terminal reservoirs, also other plans for delivering this new supply of water at the high service elevation were studied. The use of Hudson water in the quantity required involved pumps of larger aggregate capacity than are contained in any pumping station yet built. So large a part of the annual cost of this supply was involved in pumping, and the size and cost of the aqueduct depend so largely upon a careful balancing of cost of pumping to an extra height against the saving by the diminished size of an aqueduct having higher velocity and greater friction loss, that these numerous and important problems of pumping were considered by the Commission to require a separate department for their special study. Moreover, among the projects for water from an upland source there were some which contemplated building impounding reservoirs at a lower level than the aqueduct, in order to make a larger drainage area available and pumping the water to the height required; notably, a project for impounding the Fishkill water near Brinckerhoff which, in connection with the high level aqueduct, would have required a large pumping plant.

Therefore, after much preliminary consideration of the pumping question, the Department of Pumping was organized and began work on May 1, 1903. Later, accurate preliminary surveys had demonstrated that reservoir sites existed suitable for impounding the water of the Fishkill and Wappinger Creeks and Jansen Kill, and that the remarkably soft water of the Esopus could be stored by a much higher dam than originally proposed and in a larger reservoir, so that the details of the design of pumps and pumping stations for a Hudson supply became of less immediate importance. At the request of the Commissioner of Water Supply, Gas and Electricity, its energies were directed toward tests of the economy of the present Municipal pumping stations of Manhattan, Queens and Brooklyn, and to studies for their improvement. These studies are reported in some detail in Appendix VIII, and only a brief outline need be presented here.

Pumping from Hudson River.

For the projected Hudson River pumping station, located not far from Hyde Park, there were ultimately to be two independent groups of pumping engines and boilers, separated sufficiently so that an accident in one, as, for example, a boiler explosion, would not interrupt the operation of the other. The two stations were ultimately to contain pumps aggregating 500 million gallons daily capacity, all working under 400 feet lift if a high level supply were adopted in order to give the requisite slope for flow through the 67 mile aqueduct to New York and to provide for head lost in passing through the filters. This would have called for pumping engines of 35,000 pump horse power. The first installation was to be of eight engines, giving about 160 million gallons daily or about one-third of the entire capacity of the new aqueduct. These pumps were to be made in units of 20 million gallons nominal daily capacity, but designed with such ample valve area and water passages that 25 per cent. overload, or extra speed, could at any time be carried in emergency with entire safety and good economy; so that when one engine was shut down for inspection or repair, its neighbors, by being speeded up, could carry on its work. The steam pressure decided upon was 200 pounds per square inch; the duty requirement, 145 million foot pounds per 100 pounds of coal in daily operation; speed for nominal capacity 30 revolutions per minute, or 330 feet piston travel; and the engines, triple expansion crank and fly wheel type. The estimated cost is as follows:

Fire proof pumping stations complete, with foundations suitable for 12 engines of 250 million gallons daily aggregate capacity, each	$536,000
Twelve (12) pumping engines	1,616,000
Engineering, inspection, etc	310,000
Total for each station, 250 million gallons daily	$2,462,000

In comparing the cost of water pumped with the cost of water from a gravity supply, so much depends upon the degree of skill and watchful care exercised by the management that it is difficult to estimate the precise cost per million gallons pumped. Extravagance or indifference of management may, with the best of machinery, double the operating cost; therefore, a brief comparison was made of the actual average yearly cost of pumping in sundry representative large municipal stations.

While it has appeared possible from estimates that under the best pumping station management and with pumps of most nearly perfect design, water could be taken from the Hudson, pumped, filtered and delivered through the high level aqueduct at a total cost little, if any, greater than that of upland water with its expensive reservoirs and larger aqueduct, it must be remembered that mediocrity of management may have much more effect on the efficiency of a pumping plant than upon the efficiency of a reservoir and aqueduct system, and that under most favorable conditions, whatever the saving of cost might be in water pumped from the Hudson and filtered, any possible saving of expense cannot in the judgment of this Commission compensate for the advantages of the upland gravity supply.

Inspection of Present Pumping Stations of New York.

Although the Croton and the Bronx and Byram are gravity supplies, about 20 per cent. of the Croton supply has now to be pumped to supply the buildings on high ground. All of the water used in Queens Borough has to be pumped to its full pressure, and all of the Brooklyn water also has to be pumped and some of it four times over. Greater New York maintains 32 pumping stations, including 86 pumps, and its present daily pumpage is 160 million gallons. Nearly all of the stations have three shifts of enginemen and firemen in the 24 hours, and there are about 400 men on the pumping station payrolls. About 75,000 tons of coal are burned each year, and $12,000 per year expended for oil and petty supplies.

This inspection shows that much of this work has not been done efficiently, and if it were all put under the supervision of an expert of the highest technical skill, he could, if given proper authority, save many times his salary, mainly by a closer watch on the station duty, and by stimulating the stokers and enginemen to keep closer and more intelligent watch upon a daily record of the performance of their machines and the consumption of coal, oil and supplies. Efforts toward improvements of this kind had already been made by Mr. N. S. Hill, Jr., Chief Engineer, before this Commission began its operations, and he has co-operated cordially in this work.

Improvements Recommended at Pumping Stations in Borough of Manhattan.

The One Hundred and Seventy-ninth Street Pumping Station is the principal pumping station connected with the Croton system and contains pumps with a nominal daily capacity of 58 million gallons, two of which, Nos. 5 and 6, have been in process of installation during the past year and are not entirely complete. The four pumps previously in use are of excellent design and are capable of better economy and of pumping more water than heretofore. A test of these pumps on May 8 showed excessive loss of action, caused principally by water valves adrift, which amounted to 60 per cent. on pump No. 2 and 65 per cent on pump No. 6. After replacing these valves and making simple repairs, this slippage was reduced to about 4 per cent.

A short time prior to these tests the Chief Engineer had observed the unsatisfactory performance of these pumps and had instituted a search for the cause, which was revealed so conclusively by the test of May 8. The tests and examinations also showed that parts of the steam valve gear were much worn and that the larger bearings were in need of adjustment. Indicator diagrams showed a poor distribution of steam and consequent impairment of efficiency. The receivers were found in a leaky condition and by cleaning the condensers the vacuum was increased one and one-half inches. The repairs found necessary were quickly made and were comparatively expensive.

The organization of the One Hundred and Seventy-ninth Street Station in the number of men employed was found to compare favorably with that at similar stations in other cities and the daily rate of wages was found to be about the same as those prevailing for similar work on large pumping engines elsewhere. The excessive cost of pumping was due to inefficient management.

The Ninety-eighth Street Station contains pumps aggregating 25 million gallons daily, nominal capacity. Engines Nos. 1 and 2 have been in service

23 years, and they appear to be hardly worth the expense of repairing, particularly in view of their being of a design not giving good economy, even when in thorough repair. The No. 3 high duty engine at the Ninety-eighth Street Station is of modern design and while well adapted for use in emergencies, it can best be shut down and the pumping concentrated at One Hundred and Seventy-ninth Street, as will be later explained.

The High Bridge Station contains pumps of 11 million gallons nominal daily capacity. These pumps are of design so uneconomical in operation in comparison with the modern pumping engines at One Hundred and Seventy-ninth street, that it is best to abandon their use, withdraw the men, and do this pumping also by the engines at One Hundred and Seventy-ninth street.

During May, June, July and August, 1903, the average daily pumpage at these stations was 30,400,000 gallons at One Hundred and Seventy-ninth street; 20,400,000 gallons at Ninety-eighth street, and 1,500,000 gallons at High Bridge; a total of 52,300,000 gallons. The nominal daily capacity of the One Hundred and Seventy-ninth street Station is 58,000,000 gallons, and an examination of the machinery shows that it can be prudently run at a speed, to deliver about 64,000,000 gallons daily, which would give a surplus of about 11,700,000 gallons, or about 20 per cent. above the average total daily consumption of the past season. The centralizating at this station of all the pumping is thus found to be practicable for the immediate future. The existing mains and gate valves permit this arrangement.

The high duty pump at the Ninety-eighth Street Station should be maintained idle, but ready for any emergency, with one or more boilers under steam and a minimum force of men in readiness.

By this centralization of the pumping there would be a large saving in the use of coal, due mainly to the better and more economic design of the engines at One Hundred and Seventy-ninth street.

The average cost per million gallons pumped one hundred feet high for all these stations during four months of the past season, after the tests and repairs at One Hundred and Seventy-ninth street had begun, but before they were finished, averaged $6.27. After repair work now in progress is completed a saving will be found, and under good management a skillful firing, the design of the engines and boilers makes it appear possible to pump in regular daily work at an expense per million gallons 100 feet high of not exceeding $4.00. This would be a saving of 34 per cent., as compared with the cost for June, July and August, 1903; or instead of $11,000 per month the cost should be about $7,000 per month, saving nearly $48,000 per year. The saving in comparison with the condition prior to beginning the tests and repairs in May, 1903, would be larger, for immediately prior to these tests and repairs it was taking six pumps to do the work subsequently performed by four.

New Jerome Park Station.

At this station, now under construction, slight changes were recommended, comprising the adding of an economizer and a superheater and the use of air pumps and feed pumps driven from the main engine. These would materially increase the duty in regular operation.

Pumping Station in Queens Borough.

There are in this borough five pumping stations operated by the City, one in Flushing, one in Bayside, one at Whitestone, and three in Long Island City, of which No. 2 has been out of commission for the past year because of a boiler explosion.

During the months of May, June, July and August, 1903, these averaged a daily pumpage from driven wells of about 3.6 million gallons under an average total lift of 176 feet. The total pumping expenses during that period were $18,945, making the average cost of pumping 1 million gallons 1 foot high $0.24, including only the cost of coal, attendance, ordinary repairs and supplies, and not including any allowance for interest, depreciation, sinking fund or extraordinary repairs.

The cost in small stations like these must always greatly exceed that in large stations, mainly because of the labor cost being relatively so much larger; but a comparison with the results achieved by small pumps under fairly comparable conditions in certain other cities indicate that this cost is unnecessarily high.

An inspection showed that all of these stations in Queens Borough, with the exception of those at Bayside and Flushing, contained antiquated machinery, some of it erected 29 years ago, still in daily use. The Bayside and Flushing Stations each contain one engine of modern design, which has been run alternately with the older and less economical engine.

The Chief Engineer, Mr. N. S. Hill, Jr., has already begun the renovation and repair of these plants, and proposes to replace the older engines in the larger stations, Long Island No. 1, Bayside and Flushing, by modern high duty engines. This should result in saving more than 40 per cent. of the fuel at these three stations, amounting on the basis of present rate of pumping to $6,250 per year. Beyond the replacement of old pumps by new in the larger stations, there are few important changes that can be recommended until the future source of supply for this growing borough has been more fully determined.

Pumping Stations in Borough of Brooklyn.

This Department has co-operated with Mr. I. M. de Varona, Chief Engineer, in the investigation of methods for securing greater economy in the operation of the numerous low lift driven well plants. It appears that this can be best attained by operating the several plants by motors with electricity, generated at a power house which it is recommended should be established in connection with the Millburn Pumping Station. The electric transmission lines can be placed on the strip of land owned by the City in which the conduit runs.

The Pumping Department has also co-operated with Mr. de Varona in the preparation of plans and specifications for the Gravesend Station; upon designs for improving the economy of the proposed pumping station for the infiltration galleries at Wantagh, and has advised concerning the type of engine and layout of a plant for the new high service pumping engines at Ridgewood.

With regard to centralizing the pumping and lessening the cost of lifting the water from the present driven well stations into the conduit, nine sites, lying between Spring Creek and Massapequa, have been selected by Mr. de Varona for future operations, all of which, together will yield, by his estimate, 113 million gallons per 24 hours. The location of these may depend somewhat upon the success of, and experience derived from the first infiltration gallery which is now in process of construction near Wantagh under Mr. De Varona's design and supervision.

The present driven well pumping plants are nearly all of a crude, temporary character. Most of them were built in a hurry to meet a temporary shortage of water, and the type of pump and engine is excessively wasteful of fuel. Thus the cost of pumping probably averages three times that which is necessary for scattered plants of this kind equipped with modern high grade machinery.

The Commission estimates that with centrifugal pumps of the latest design, electrically driven from a central power station, the cost need not exceed 8½ cents per million gallons raised 1 foot high, whereas in 1896, it averaged 27 cents with the present plants. The intermittent services has increased the cost per million gallons pumped, but in the future as ground water is given preference over surface water, the economy will further increase with steadiness in operation.

A portion of the Brooklyn water is pumped and repumped four times:

1st. From the driven wells, a total lift, averaging 30 feet into the aqueduct leading to Millburn, at a cost of about 27 cents per million gallons 1 foot high.

2d. By the pumps at Millburn it is lifted about 50 feet, at a cost of 6½ cents to flow through the 48-inch pipes to Ridgewood;

3d. It is all lifted about 175 feet by the Ridgewood pumps, at a cost of about 5 cents.

4th. About 9 million gallons per day lifted an average of 94 feet to the high service reservoir and tower at Mt. Prospect, at a cost of about 11 cents per million gallons 1 foot high.

While a portion may thus be lifted four times, nearly half of the whole is only lifted once, namely, by the pumps at Ridgewood.

The Commission has estimated that a new system of pumping the ground water at the nine stations between Spring Creek and Massapequa by electrically driven pumps, as described above, and having an aggregate capacity of 113 million gallons daily, can be provided for $332,000, while a first installment of pumps capable of delivering 72 million gallons daily, but with pumping stations of full size, would cost $282,000.

The estimated saving in fuel, supplies and other expenses in pumping an average of 46 million gallons per day against a total head averaging 30 feet, as compared with the cost at the rates actually incurred in the year 1896, would be about $96,900 per year, or about 30 per cent. per annum on the proposed expenditure.

The power plant at Millburn and the pumping plants at Merrick, Wantagh and Massapequa could be erected ready for use within one year from signing of contract, and the remaining stations could all be ready for operation in six months more.

Pumping Plant for the Wantagh Infiltration Gallery.

It was noted that under the contract recently made for this work the pumping plant to be provided by the contractor was designed for temporary use, or for a year pending the test of capacity and efficiency of the gallery system, and that it was of the same uneconomical class as the existing pumps, with the pumping station a frame building of a temporary character. Therefore, it was recommended by this Commission that the specifications be so changed as to call for the latest design in centrifugal pumps of high efficiency, with provision for an electric motor, to be attached at any future time as a substitute for the steam engine. It was further pointed out that, by the addition of condensers to the temporary engines, about 25 per cent. of the coal could be saved, and that the permanent fireproof pumping station might as well be built now as at a later date, thus saving the cost of the temporary wooden structure.

Gravesend and New Utrecht Pumping Plants.

The advantage of consolidating these plants was mentioned by Mr. de Varona in his quarterly report for September 30, 1902, and an appropriation of $100,000 was made later in that year for this work. A draft of specifications was submitted to this Commission in July, 1903, and returned in August with a recommendation for a triple expansion crank and flywheel engine capable of highest economy for daily use, with provision of a cheaper and simpler pump in the same station for emergencies. The cost of the latter would be about the same as for moving the present compound direct acting engine from the present station to the new station, while this triple expansion auxiliary would take only about half the fuel for pumping the same quantity of water.

The average pumpage at this station is taken at 6 million gallons daily, and by centralizing this pumping for New Utrecht and Gravesend, and doing it with a new engine of the best class, it is estimated the annual cost for coal, labor and supplies, need be only about $16,000 per year, instead of the cost of about $27,764 in 1902 for pumping an average of 4.3 million gallons. The change and consolidation will thus permit pumping about 35 per cent. more water while expending $11,700 less per year.

Millburn Pumping Station.

This contains engines of a total nominal daily capacity of from 75 to 80 million gallons and an average of about 45 million gallons daily has been pumped during the past year under an average head of about 50 feet, at an average cost of 6½ cents per million gallons 1 foot high. By using the high duty engines installed during the past year to the greatest extent practicable it is expected that the cost per million gallons at this station can be reduced 20 per cent. as compared with previous years.

This Commission has suggested that a further saving could be made by providing more efficient means for furnishing dry steam to the engines and for heating the feed water.

In general this station was found to be in a satisfactory condition and with an excellent prospect of making a favorable record during the coming year by means of its new engines.

Ridgewood Pumping Station.

The old station contained pumps having an aggregate nominal capacity of 90 million gallons daily, and the new station contains pumps of 57.5 million gallons. All deliver into the Ridgewood reservoir at an elevation of 170 feet above tide. The expense of pumping and for repairs at these stations appears unduly large in comparison with the best examples found in other cities. The cost of boiler repairs also appears to have been excessive and was found in such notable contrast to the low cost of repairs at the Millburn station on the same type of boiler that explanation was looked for in the quality of boiler feed water used.

The Ridgewood water receives a considerable percentage of chlorine and other deleterious matter from certain of the driven wells west of Millburn which lie so near the seashore that brackish water flows in when they are heavily drawn upon. If the resulting excessive corrosion may be, as appears probable, mainly attributed to this inflow, it furnishes most striking evidence that additional expense may be justified for securing a pure, soft water when balancing one source against another, or in seeking additional water east of Millburn to replace that from the objectionable wells. Inasmuch as a 48-inch main direct from Millburn brings the same kind of water which acts so favorably in the Millburn boilers, into the Ridgewood station, it is recommended that this be used exclusively for feeding its steam boilers.

The cost per million gallons of pumping at Ridgewood was reduced about 28 per cent. in 1899 in comparison with the years preceding, by the introduction of modern engines that replaced some of the old beam engines, but further economies can be readily obtained. The cost of pumping appears to have been steadily increasing for three years past at the new Ridgewood station, having been \$.066 in 1899, \$.076 in 1900 and \$.080 in 1901 per million gallons 1 foot high. By adding two new triple expansion engines each of 20 million gallons nominal daily capacity and substituting these for four of the old vertical compound engines now in daily use at the so-called New Ridgewood station, and by sundry other economies at Ridgewood, it appears possible to reduce the average cost to \$.045 per million gallons 1 foot high, including interest and sinking fund charges, or from the present cost of about \$173,000 per year down to about \$110,000 per year, thus saving about \$63,000 annually.

It is estimated that these two new high duty low service engines would cost complete with foundations and all accessories \$355,000.

Proposed Consolidation of Mt. Prospect Pumping Station with Ridgewood Station.

The two old beam engines of 9 million gallons combined capacity daily and 70 feet lift now used on the high service reservoir, are not economical and cannot be made so.

The two engines of 8 million gallons combined capacity daily and 162 feet lift on the extra high or "Tower service" are doing as well as can be expected for direct acting engines of this type.

The Mt. Prospect station as a whole is uneconomical and its pumping engines should be replaced by engines of the best modern type or consolidated with the Ridgewood plant. The latter plan appears to be the better arrangement. Mr. de Varona in his report for 1902 estimated that

12 million gallons daily will soon be required for this service, and estimated that a large annual saving in cost of operation could be made by either new pumps at Mt. Prospect or consolidation at Ridgewood, with preference for the latter.

From the studies of the Commission it appears that a more favorable arrangement can be made than that proposed in the report of 1902, and that the best plan will be to utilize the present new Ridgewood station for the accommodation of this future high service plant, putting in two new engines of the most eceonomical type each of 15 million gallons daily capacity to supersede the Mt. Prospect station, and gradually to replace the present five vertical compound low service engines each of 10 million capacity by new and more economical engines of the vertical triple expansion crank and fly wheel type each of 20,000,000 gallons dally capacity. Two of these new engines could pump the 40 million gallons daily of low service water now pumped at this station and, as already stated, save about $63,000 per year in the cost of the Ridgewood low service pumping. Adding to this the yearly saving in operating cost by pumping the Mt. Prospect high service water by the proposed substitution of two new and economical engines located at Ridgewood, which was estimated by Mr. de Varona at $40,610 per year, it appears that about $103,000 per year can be saved in the expense of pumping the water for the high and low service supplies.

It is estimated that the cost of the Mt. Prospect substitution should not exceed $360,000, which added to the $355,000 estimated for the changes in the Ridgewood low service pumps, gives a total estimated expenditure of $715,000.

The saving as estimated above would pay about 14½ per cent. annual interest on this expenditure, and by working out the details carefully and with an efficient operation of the plant equal to that which can to-day be found in several large municipal plants, a further large saving can be made in cost of labor, oil, supplies and ordinary repairs.

*Proposed Cross River Reservoir.**

Early in the year, the Commissioner of Water Supply, Gas and Electricity requested this Commission to examine plans for an impounding reservoir, proposed to be built in the Croton Watershed at Cross River, and to report its opinion upon the advisability of beginning the construction immediately.

On consideration of all of the circumstances, it was found that while this reservoir may at some future time be useful as an adjunct to the Croton system, it does not appear to the Commission advisable to undertake its construction in the near future.

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* One member of the Commission does not wholly concur in the conclusions of this section.

It would require several years to construct, and, therefore, could not be in use much sooner than the large new supply proposed, and with this large supply once in use there would be no necessity for the Cross River Reservoir for many years. It therefore appears better to devote the sum required for this reservoir to the new supply. Moreover, the water from Cross River will be soon stored in the large reservoir formed by the new Croton Dam.

The Hudson River and Lake George.

The waters of the upper Hudson, meaning those secured from the Adirondack portion of the Hudson River watershed, lying above Hadley, at the junction of the Sacandaga and the Hudson, have frequently been considered as possible sources of future water supply for the City of New York. The area of the Adirondack Watershed available for this purpose is about 2,650 square miles. If the yield of this area be assumed at 750,000 gallons per square mile per day, the total available supply from this source would be about 2,000 million gallons daily.

After making all necessary deductions for feeding the Champlain Canal and for industrial purposes other than water power, it is apparent that a quantity largely in excess of 500 million gallons daily could be taken for the supply of the City of New York. In this plan, it would be necessary to convey the water by aqueduct from some point in the drainage area above Hadley to New York City, a distance of about 185 miles. The high cost of this project prohibits its execution.

If the water of the Hudson River is to be used for an additional supply for The City of New York, it would be much more economical and equally satisfactory from a sanitary point of view to take it from some point near Hyde Park, raise it by pumping to a reservoir and filter site at a suitable elevation on the high ground east of the river, filter it and conduct it to New York through an aqueduct of the required capacity. The efficiency with which it is feasible to operate filters at the present time would make the quality of the water entirely satisfactory. This constitutes, by far, the most practicable and economical plan of taking water from the Hudson River for purposes of additional supply. Indeed, under this plan, the waters of the Mohawk River and its tributaries are also equally available with those of the upper Hudson, as well as those of the other tributaries above the intake.

At the inception of the work of this Commission this plan of additional supply appeared to offer material advantages and it was seriously studied, but, as investigations progressed, the high level gravity supply recommended was found to be preferable.

When in the future it becomes necessary to resort to the Hudson River for a source of additional supply, storage reservoirs must be built in the Adirondacks to impound flood waters, to be released during the dry portion of the year as compensation for the amount drawn out for the City's supply. If this were not done the diminished flow in the river would induce a further up-flow of the diluted sea water under tidal influence.

The lowest discharge of the Hudson River at Poughkeepsie is about 1,500 million gallons per day, while the ordinary minimum flow probably varies between that amount and 2,000 million gallons per day. The abstraction of 500 million gallons per day by pumping from the low-water discharge of the river would, therefore, materially increase the up-flow of the salt water, which it would be necessary to neutralize by a compensating release from the fresh water storage in the Adirondacks.

It has not been possible for the Commission to make surveys, examinations and estimates to determine quantitatively the elements of this problem of the Adirondack storage and pumping from the river, but it may be safely stated that the Adirondack portion of the watershed of the Hudson River, including the drainage areas of the Sacandaga River, Schroon River and the Hudson above Hadley, afford sites for storage reservoirs having an aggregate capacity of upwards of 300,000 million gallons. This amount of storage would be sufficient to add more than 2,500 million gallons per day to the flow of the Hudson at Poughkeepsie in dry seasons. Under this system of compensation it would be feasible to keep the extreme point of up-flow of dilute sea water probably below Poughkeepsie.

In the distant future, when the capacity of the gravity water supplies recommended by the Commission for first development are exhausted, it will probably be advisable to resort to pumping and filtering the Hudson River water in accordance with this outline plan. The availability and advantages of the recommended gravity supplies are so great, however, that the Commission considered it advisable to direct its chief efforts toward completing plans for this development rather than diverting more of its funds and forces to securing details of the Hudson River plan, which will be needed only after a long period of years. The Commission, therefore, has no recommendation to make regarding the pumping and filtration of the Hudson River water, but it desires to point out the great resources in reserve of that plan for the future supply of the City. Indeed, the combined capacity of the gravity supplies recommended and of the Hudson for remote development is so great that they may be considered as constituting a practically unlimited supply for the future.

Lake George has also been advocated, both alone and in combination with adjacent watersheds on the north, for additional supply. Its elevation is too low for a satisfactory gravity supply, and its drainage area is only about 230 square miles. Its yield is consequently too small to justify the necessary cost of securing it.

Millburn Reservoir—Brooklyn Supply.

This reservoir was recommended in 1885 and built in 1893 for the storage of surface water. As tests have shown that it does not hold water it has not yet been used.

At the request of the Commissioner of Water Supply, Gas and Electricity, specifications for work intended to make this reservoir tight, at a cost estimated at about $500,000, were reviewed. After full consideration, this Commission is of the opinion that the utility of the reservoir to the Brooklyn water supply system is not sufficient to justify any such expenditure.

Some investigations were therefore made to determine if it could be made water tight at a much smaller expenditure by the introduction of turbid water and silting up of the leaks. Numerous borings were made in the bed of the reservoir and samples of the so-called layer of puddle taken for mechanical analysis and tests made of its permeability. This material was found so improperly placed, of such irregular and insufficient thickness and of such poor quality, that it has not been thought wise to attempt this experiment.

Inasmuch as the future development of the Long Island supply will be in the direction of ground water, rather than surface water, and as these ground waters require storage in covered reservoirs, there appears to be no sufficient reason to justify the expenditure of further large sums of money to make this reservoir tight. It is not equal for storage purposes to the natural storage capacity for ground water of the sandy substrata of the Island.

The Commission is therefore of the opinion that as better water in sufficient quantity can be obtained by the further developing of the ground water supplies of Long Island or by connection with Manhattan, that the Millburn Reservoir should be abandoned for the purpose for which it was built.

Increase of Population of New York.

The estimate of future population of a great city like New York is attended with some uncertainty, but it is usually made by adding a constant percentage to the population estimated at the end of each of a series of assumed consecutive short periods, such as ten years. This produces an increase in geometrical ratio, which may be consideral sufficiently accurate for at least two or three decades. In the present case, the Commission has attempted only to ascertain the population of The City of New York in 1925 or 1930, as is shown in Appendix X. The statistics employed for this purpose are those found in the report of "NEW YORK CITY'S WATER SUPPLY" by John R. Freeman, 1900, and those received from the Department of Health of the City in October of the current year. In 1890 the population of those communities now consolidated in The City of New York was as follows:

Manhattan and The Bronx.	Brooklyn.	Queens.	Richmond.
1,612,599	840,857	86,502	51,805

In the year 1900 the population in the different boroughs of the consolidated City reached the following amounts:

Manhattan.	The Bronx.	Brooklyn.	Queens.	Richmond.
1,851,187	202,092	1,169,796	153,734	67,166

With the rates of growth exhibited during the past 13 years, it is estimated that the probable population of the five boroughs of the City will be about as follows in 1925:

Manhattan.	The Bronx.	Brooklyn.	Queens.	Richmond.
2,130,000	675,000	2,705,000	680,000	130,000

Under this approximate estimate, the population of the entire City would be about 6,320,000 in 1925.

If there be assumed for purposes of estimate a consumption of 150 gallons per head of population per day at that time, the amounts consumed in the different boroughs would be:

Manhattan.	The Bronx.	Brooklyn.	Queens.	Richmond.
Gallons. 319,500,000	Gallons. 101,250,000	Gallons. 405,750,000	Gallons. 102,000,000	Gallons. 19,500,000

The total of these estimated quantities for the entire City would be 948 million gallons per day.

The increase in consumption, per head of population, with the lapse of time has been the subject of much study among civil engineers. It is a matter of practically universal observation that the use of water for legitimate purposes encourages a still greater use, but there are no data available at the present time on which quantitative conclusions may be based. The introduction and enforcement of regulations directed toward the reduction of waste and the use of other available means to accomplish that end, may be depended upon to reduce the per capita consumption in The City of New York, as has been set forth in another place in this report; but it is impossible to state definitely what that reduction may be. The general experience in other cities where the increase of per capita daily consumption has been studied, leads the Commission to believe that in the estimate for the future requirements of the city a less quantity than 150 gallons per head per day twenty-five years hence should not be taken. That amount, therefore, has been used in the computations on which the Commission's conclusions are based.

The Feasibility of Developing a Temporary Supply.

The Commission gave careful consideration to the feasibility of finding some temporary additional supply at moderate cost, pending the completion of the permanent additional supply, but was forced to the conclusion expressed in the report of September 17, 1903, viz., that

" no possible quickly available and near source could be found, or any-
" thing that would be worth the trouble or expense of development as
" an interim supply to make good the present excess of consumption in
" Manhattan and The Bronx over the recorded actual yield of the
" present watersheds in a year of extreme drought."

Summary of Costs.

The works recommended to be constructed first comprise a section of the Hill View Reservoir of 600 million gallons capacity, the main aqueduct of 500 million gallons daily capacity from that reservoir to Stormville Reservoir, a section of the Stormville filters of 50 million gallons daily capacity, the twin aqueduct, one channel of 400 million gallons and the other of 250 million gallons daily capacity from the Stormville Reservoir to the Billings Reservoir and these two reservoirs. This construction will afford an additional supply of 60 million gallons per day. Concurrently with the preceding construction, the aqueduct of 400 million 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 four to 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:

Hill View, covered reservoir, first section of 600 million gallons capacity..........	$9,059,000	
Stormville filter plant, first installation of 50 million gallons daily capacity........	3,581,000	
Stormville reservoir, 10,000 million gallons capacity	2,503,000	
Billings reservoir, 6,800 million gallons capacity	1,806,000	
Ashokan reservoir, 66,500 million gallons capacity	11,734,000	
Total		$28,683,000

High Level Aqueducts.

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.................	9,075,000	
		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 aditional supply of nearly 320 million gallons daily.

It is estimated that the complete construction of reservoirs, filters and aqueducts for the full additional supply of 500 million gallons per day may be required by 1925. The cost of the remaining construction in excess of that already provided for will be as follows:

Reservoirs.

Hill View reservoir completed to 2,030 million gallons in 1925	*$13,168,000	
Stormville filters completed to 500 million gallons daily capacity in 1925	*14,646,000	
Hibernia reservoir, 30,500 million gallons capacity	9,308,000	
Silvernails reservoir, 17,200 million gallons capacity	5,530,000	
Total		*$42,652,000

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 million gallons daily capacity	1,573,000	
Aqueduct from Hibernia to Silvernails, 220 million to 330 million gallons daily capacity	1,276,000	
		8,728,000
Total cost of additional construction is		*$51,380,000

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 million gallons per day will be the sum of the two preceeding totals:

Total cost of entire work............................*$111,478,000

*Through a misunderstanding these figures were incorrectly stated in the published synopsis of the Report, the total cost being given there as $98,839,000, instead of $111,478,000.

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 the latter 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.

Damages to Water Rights.

The services of Messrs. Dean & Main, of Boston, were secured for the Commission to inspect and report upon the water rights along Fishkill and Wappinger Creeks and the Jansen Kill, with a view to making an approximate estimate of the damage to those rights which would be caused by the proposed diversion of water for the additional supply of The City of New York. Such an estimate must necessarily be approximate only and subject to revision. The entire damage on Fishkill and Wappinger Creeks was estimated not to exceed about $1,250,000, and it may fall below $1,000,000; this sum being about equally divided between the two streams.

The entire damage to water rights on the Jansen Kill, resulting from proposed diversion of water for the City's use, is small and may run from about $50,000 to $100,000.

No detailed approximate estimate was made of damages which might result to water rights on Esopus Creek, as both funds and time were lacking; but informal estimates were made by members of the engineering force of the Commission. It is believed that these damages will not exceed $400,000 to $450,000 on this stream.

Further examinations of this character must be made in detail before the final estimates for damages to water rights can be reached for the streams on either side of the Hudson.

RECAPITULATION.

The Commission has endeavored to make its investigations comprehensive, embracing a study of the present supply and of practicable sources of future supply not excluded by the instructions of the Corporation Counsel as to interstate waters.

The general sanitary conditions of the water at present supplied to all boroughs is found to be not entirely satisfactory, although the typhoid death rate of New York and Brooklyn is lower than in most large American cities. The supply in general is found to be carefully safeguarded from the standpoint of health, although occasionally turbid and rarely malodorous.

It is recommended that works be immediately begun for the filtration of the Croton supply and that all the new supplies be filtered. It is also recommended that the reservoirs in Central Park be cleaned and that they be covered as soon as the Croton supply is filtered.

The waste of water has been investigated and found largely due to defective plumbing and fixtures. The leakage from street mains is found to be less than heretofore supposed. This problem of the amount of distribution of the water waste is an extremely difficult one and it is recommended that these investigations be continued and extended by permanently districting the city for this purpose and ascertaining the inflow and outflow for each district, and that the cause of the large night flow be more fully investigated.

The Commission recommends further for the prevention of waste that the house-to-house inspection be continued and extended, that the rate of consumption in representative buildings be studied, that more stringent plumbing regulations be enforced and that meters be more generally applied. It is strongly of the opinion that notwithstanding the greatest possible reduction of waste a large additional supply of water is imperative.

It is found that all boroughs of the City of New York are in need of an increased supply of water. The present supply is already drawn upon to an extent that might lead to a dangerous shortage in a year of drought.

A study of the growth in population and the increase in per capita use of water causes the Commission to recommend that works be immediately begun on an additional supply, capable of gradual development, first of about 60 million gallons per day, but capable of ultimate development to 500 million gallons per day, the principal aqueduct being built of the full capacity at first.

The sources recommended for immediate development are the upper Fishkill and the Esopus creeks, the latter to be by means of a much larger dam than heretofore proposed, creating a storage reservoir of nearly 70,000 million gallons capacity. All these new works are to be at an elevation such that the water can be delivered by gravity at a large terminal reservoir near the city limits at an elevation of 295 feet above tide.

The upper Fishkill and the Esopus creeks can supply more than 500 million gallons per day. The aqueducts are planned so that they can in future years, be readily supplemented from the headwaters of the Rondout and Wappinger creeks and the Jansen Kill.

The least time required for building the new work, limited by the long tunnels through the mountains east of Peekskill, is estimated at about five years, and as soon as the aqueduct from Billings into the Croton watershed is completed, 60 million gallons of water daily can be added to the Croton supply and brought into the city through the old Croton aqueduct.

For Brooklyn and Queens, an immediate development of the ground water sources of Queens and Nassau County 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 million 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.

The high pressure from the proposed new aqueduct will eliminate the cost of pumping the high service supply for Manhattan and The Bronx, and will afford a supply for special fire mains, thus affording much better protection against fire than any salt water fire system.

The important pumping stations of the several boroughs have been examined and their condition reported. Recommendations are made which, if adopted, will annually save large sums of money.

An additional supply of about 60 million gallons daily can be secured from the Fishkill watershed within five years from the time of beginning the work, at a cost of about $39,000,000. An additional supply of nearly 320 million gallons daily may be secured from the watersheds of the Fishkill and Esopus Creeks by a further expenditure of about $21,000,000, making a total of about $60,000,000. The latter construction may be completed to such an extent as to draw on the Esopus water within the same period, of about five years.

The entire additional supply of 500 million gallons per day can be secured at a cost of about $111,500,000. This final construction need not be completed before 1925.

ACKNOWLEDGMENTS.

The Commission desires to express its hearty appreciation of the professional skill, sound judgment, zeal and energy of the Department Engineers in the prosecution of the various fields of work assigned to them; and it also desires to express its appreciation of the industry and thoroughness displayed by the field and office forces in the discharge of their duties throughout the work of the Commission. It is probably seldom that such an unprecedentedly large amount of work has been done so satisfactorily in such a limited time, and the Commission takes pleasure in expressing its unqualified commendation of the manner in which its forces have performed their duties.

Respectfully presented,

WM. H. BURR,
RUDOLPH HERING,
JOHN R. FREEMAN.

APPENDIX I.

Eastern Aqueduct and Reservoir Department.

Appendix I.

Eastern Aqueduct and Reservoir Department.

E. G. Hopson, *Department Engineer.*

This appendix covers a description of and estimates for the proposed works for collecting a Gravity High Level Additional Supply on the east side of the Hudson River, and the aqueducts required to convey it to a point near the city limits; also certain aqueducts to convey waters from the sources on the west side of the Hudson River to the same point; and a brief statement of investigations made in connection with a low level supply and aqueduct system.

The designs for the various works have been based upon two general projects of supply development, which have been styled Projects No. 1 and No. 2. These projects are frequently referred to in this Appendix, and their definitions are as follows:

Project No. 1.

This project entails the successive construction of the Stormville Reservoir, the Billings Reservoir, the Hibernia Reservoir, the Clinton Hollow Reservoir and the Silvernails Reservoir, either singly or in groups, as the future needs of the City demand; and when this entire eastern supply has been exhausted, it proposes a further extension of the system to the Ashokan Reservoir by an aqueduct from the Clinton Hollow Reservoir, and ultimately a further connection with the Rondout Creek; in short, this project contemplates the development of the eastern sources first, and subsequently the western sources.

Project No. 2.

This project entails the successive construction of the Stormville Reservoir, the Billings Reservoir, the Ashokan Reservoir and the Rondout Reservoirs; and after the exhaustion of these sources, the ultimate construction of the Hibernia and the Silvernails reservoirs; or, in other words, the development of the western sources prior to that of the eastern sources. The Commission recommends the adoption of this project.

The development of the Fishkill Creek would, for reasons of expediency, be a necessary precedent to both projects, as an emergency supply to meet possible shortages.

Thus, under both projects, the details of construction are identical between Hill View Reservoir and the Billings Reservoir, including both reservoirs, the main aqueduct, and the filtering plant, excepting that the aqueduct between Billings Reservoir and the filters would, under Project No. 2, require to be built with two independent conduits for the purpose of keeping the water from the western sources separate from those of the eastern sources until both have passed through the filters.

Supply.

The supplies that have been considered as suitable and available are:

On the East Side of the Hudson River—

	Drainage Area.
The Fishkill Creek	81 sq. miles.
The Wappinger Creek	90 to 116 "
The Roeliff Jansen Kill	149 to 173 "
Total	320 to 370 sq. miles.

On the West Side of the Hudson River—

	Drainage Area.
The Esopus Creek	255 sq. miles.
The Rondout Creek	129 "
Total	384 sq. miles.

The detailed description of the watersheds on the east side and their proposed development are given in the following pages:

The detailed description of the watersheds on the west side of the Hudson River and their proposed development are given Appendix II.

The supplies derived from the eastern sources are as follows:

Supply in Gallons Per Day.

Fishkill Creek—			
From Stormville Reservoir	37,000,000		
From Billings Reservoir	24,000,000		
Wappinger Creek—			
From Hibernia Reservoir	68,000,000		
From Clinton Hollow Reservoir	20,000,000	to	23,000,000
Roeliff Jansen Kill—			
From Silvernails Reservoir	112,000,000	to	130,000,000
Totals	261,000,000	to	282,000,000

Sources of Supply East of Hudson River.

The drainage areas on the east of the Hudson river available for a gravity supply for high service, or, in other words, for delivery near the city limits, at about elevation 295, fall within circumscribed limits.

It is self-evident that no water supply may be obtained at the necessary elevation from any territory south of the Croton Watershed much in excess of that required for the future needs of the small communities thereon.

Southerly Limit of Available Watersheds.

The southerly limit of available drainage areas is, however, more sharply defined by the location of a suitable site for the filtering plant. This site has been found in the vicinity of Stormville, in Dutchess County, about a mile southerly from the upper Fishkill Creek. The desirability of filtering the entire additional supply being recognized as an established fact, it is obvious that water that has not undergone this process may not enter the aqueduct below the filtering plant. This fact rules out of consideration any tributaries from the Hudson River, between the Croton River and the Fishkill Creek. Of these tributaries, the only one that could under other circumstances be available for part of the High Level Supply, is the Peekskill Creek; the others are too remote from the main aqueduct line to be economical possibilities.

Peekskill Creek.

A site for a dam on the Peekskill Creek may be found about a mile southwest of Tompkins Corners—judging from surface indications and surveys made in that vicinity. From the reservoir thus created, a supply could be drawn directly into the High Level Aqueduct.

The area of the watershed above this dam is 15 square miles. This watershed is very satisfactory from a sanitary point of view, being well wooded, of considerable elevation and very sparsely inhabited. The supply that could be derived here is about 750,000 to 800,000 gallons per square mile of watershed, or about 12,000,000 gallons per day in all.

Objections to Peekskill Creek.

The cost of development of so small an area, however, will be very high as compared with the development of larger areas, even under the most favorable conditions of construction. The Peekskill Creek is, moreover, the present water supply of the town of Peekskill, and it might prove to be impossible or extremely difficult to obtain any of its water without legal complications out of proportion to the value of the stream.

Easterly Limit of Available Watersheds.

The easterly limit of research is approximately fixed by the State lines of Connecticut and Massachusetts, by reason of the expressed opinion of the Corporation Counsel as to the legal inadvisability of attempting to divert waters flowing from New York into adjacent States. Hence the available territory for exploitation consists of a comparatively narrow strip between the Hudson River and the State line, extending northerly from the town of Fishkill. This area is entirely drained by tributaries entering the east side of the Hudson.

FISHKILL CREEK DRAINAGE AREA.

The most southerly tributary on the east side of the Hudson River available for diversion for a gravity supply above the filtering plant, is the Fishkill Creek. The lowest points at which diversion may be made are near the villages of Stormville and Billings, on two of the main feeders of the creek.

Area.

The drainage areas above the points of diversion are as follows:

Above the Stormville Dam..........................	49 sq. miles.
Above the Billings Dam...........................	32 "

Stormville Area.

Geological Features.

The general geological structure of the Stormville area, as taken from the United States Geological Survey map and partially checked by field observation, is as follows:

Sedimentary Rocks.

Era.	Groups.	Area in Square Miles.
Silurian.......	Hudson River metamorphosed (slates and mica schists).......	9
	Cambro-Silurian metamorphosed (crystalline limestone).......	25
Cambrian........	Georgia (quartzite and sand rock)	2
Pre-Cambrian ...	Westchester (gneiss and granite)............................	13
	Total	49

Elevations.

The maximum elevation of the area is....................	1,400 feet.
The minimum elevation of the area is.....................	300 "
The average elevation of the area is......................	510 "

Description.

The bottom lands are generally cleared and cultivated. The uplands are to a very large extent wooded. The population is sparse, a considerable proportion being located on the site of the proposed reservoir. There are practically no swamps on the watershed.

Billings Area.

Geological Features.

The geological structure of the Billings area as taken from the United States Geological Survey map, partially checked by field observations, may be classified as belonging to Hudson River group of metamorphic slates and schists. The slate or shale is the predominating rock, and outcrops are very frequent.

Elevations.

The maximum elevation of the area is....................	1,400 feet.
The minimum elevation of the area is.....................	320 "
The average elevation of the area is......................	580 "

Description.

The population is scanty, and engaged wholly in agriculture. The uplands are well wooded, and the hill slopes in general steep and rocky. Practically no swamps exist in this area, nor any source of pollution worthy of especial note.

WAPPINGER CREEK DRAINAGE AREA.

Area.

The Wappinger Creek drains the territory immediately north of the Fishkill Watershed and west of the Ten Mile River Watershed. The points selected as most suitable for dam sites are at Hibernia and Clinton Hollow. The drainage areas above these points are:

Above Hibernia Dam................................	90 sq. miles.
Above Clinton Hollow Dam............................	26 " "

Hibernia Area.

Geological Features.

The main geological features of this area, as taken from the United States Survey map, partially verified by field observations, are as follows:

Sedimentary Rocks.

Era.	Groups.	Area in Square Miles.
Silurian	Hudson River metamorphosed (slates and mica schists)	70
	Cambro-Silurian (limestone)	14
Cambrian	Cambrian (quartzite and red sand rock)	1
	Georgia (Potsdam limestone)	3
Pre-Cambrian	Westchester (gneiss and granite)	2
	Total	90

Elevations.

The maximum elevation of the area is	1,440	feet.
The minimum elevation of the area is	265	"
The average elevation of the area is	490	"

Description.

The surface in general is hilly. The trend of the valleys is almost invariably in a north and south direction; the upper portions of the hill slopes are often abrupt, rocky and well wooded; the lower lands are as a rule well cultivated.

Population.

The chief centres of population are Millbrook, Stanfordville and Bangall. Millbrook is the most considerable of these, and has a permanent population of perhaps 1,000 and a summer population probably not exceeding 1,500. Stanfordville falls entirely within the reservoir limits.

With the exception of these three centres, the population on the drainage area is scanty, and almost entirely engaged in agricultural pursuits. The only source of pollution that might be considered as a possible menace is the village of Millbrook.

Clinton Hollow Area.

Geological Features.

The geological structure of this area as taken from the United States Geological Survey map, partially verified by field observations, is as follows:

Sedimentary Rocks.

Era.	Groups.	Area in Square Miles.
Silurian	Hudson River (shales and sandstone)........................	21
	Cambro-Silurian (limestone)................................	2
Cambrian.......	Cambrian (Potsdam limestone)............................	3
	Total..	26

Elevations.

The maximum elevation of the area is.................... 920 feet.
The minimum elevation of the area is...................... 300 "
The average elevation of the area is....................... 450 "

Description.

The surface of this area is in general decidedly hilly. The slopes are sharp, and rock outcrops are abundant. The lower portions of the area are under cultivation, the uplands being often wooded.

Excepting in the vicinity of the two small ponds that fall within the limits of the proposed reservoir, there is no swamp land worthy of especial mention, or likely to cause trouble.

ROELIFF JANSEN KILL DRAINAGE AREA.

Area.

A point selected as the most suitable for diverting the Roeliff Jansen Kill into the upper portion of the Hibernia area is near Silvernails station on the Central New England R. R., immediately below the junction of the main stream with Shekomeko Creek.

The area tributary to this point is 149 square miles.

Geological Features.

The geological character of this area as taken from the United States Geological Survey map, partially verified by field observations, is as follows:

Sedimentary Rocks.

Era.	Groups.	Area in Square Miles.
Silurian	Cambro-Silurian metamorphosed (crystalline limestone)	53
	Cambro-Silurian (limestone)	4
	Hudson river metamorphosed (slates and mica schists)	91
Cambrian	Cambrian (quartzite and red sand rock)	1
	Total	149

Elevations.

The maximum elevation of the area is...................... 2,624 feet.
The minimum elevation of the area is...................... 380 "
The average elevation of the area is...................... 670 "

Description.

The larger portion of this area is very hilly, and in parts decidedly mountainous. Mt. Washington in Western Massachusetts forms a portion of the easterly divide. The area of the drainage from Massachusetts is 16 square miles.

Some of the central portions of the area are flat and swampy, but by far the greater proportion of the whole is dry, well wooded and rocky. The largest centre of population in this area is the village of Pine Plains, with a total of about 500.

It is possible that the construction of the reservoir will almost entirely wipe out this village.

Outside of Pine Plains and a few other smaller villages, the population is scanty, the soil being in general poor and rocky, unsuitable for high cultivation.

KINDERHOOK CREEK AREA.

Possible Diversion.

To the northwest of the area drained by the Roeliff Jansen Kill, the upper part of the valley of Taghkanic Creek lies at sufficient elevation, and the formation of the land is such that the drainage from 48 square miles of territory may be diverted at no unreasonable expense into the valley of the Roeliff Jansen Kill.

The means for creating this diversion would be a dam at New Forge on this creek, and the formation of a reservoir on the extensive flat lands immediately above this point. This reservoir is disproportionately large in area to the size of the watershed, and the floor would consist of swampy land, the draft would be through an open canal and tunnel terminating near West Copake, a few miles above the Silvernails reservoir.

Condition of Drainage Area.

The general conditions of this watershed are very similar to those of the adjacent watershed of the Roeliff Jansen Kill. The land is in general rocky and hilly, shale rock being the predominant formation, and in all probability the quality of the water of the Taghkanic Creek is very satisfactory, as the population is scanty and there is little likelihood of there being any serious cause of pollution.

Objections.

The objection to considering this area as a possible source to additional supply is that of the excessive cost of its development, which would be caused almost wholly by the heavy damages for water diversion from riparian owners on Kinderhook Creek.

The total supply likely to be derived from this area would not be more than 36 million gallons per day, and the damages for diverting even so small a portion of the Kinderhook Creek would probably be excessive, and entirely disproportionate to the value of the benefits received.

OTHER SOURCES TO THE NORTH.

There are no rivers or streams north of the Roeliff Jansen Kill and the Taghkanic Creek that may be considered as possibilities for diversion into the High Level Aqueduct. Those streams which are at sufficient elevation are either too small, or their diversion may only be effected by excessively long aqueducts through difficult country.

STORAGE AND DEPLETION.

All storage capacities of reservoirs have been designed on the basis of the records of the Sudbury River in Massachusetts, for reasons described in Appendix IV.

These records show a remarkable period of drought from 1879 to 1884, which was only partially experienced on the Croton Watershed at that time. The storage has been designed to tide over a similar period of drought on these watersheds, and provide for an average daily draft of 750,000 gallons per square mile of watershed.

The Sudbury records, which extend back to 1875, and the Croton records that reach back to 1868, do not give any parallel case; nor do the rainfall records that extend back to 1818 indicate that similar dry conditions occurred during almost the whole of last century. Hence it may be inferred that the exhaustion or entire depletion of the storage proposed would not have occurred with these drafts during the whole of the past century.

The reservoirs under a constant daily draft of 750,000 gallons per square mile of watershed, will be kept below ordinary High Water for periods varying with the amount of evaporation on the watersheds. Thus, it has been calculated that with no evaportion taking place, the longest time during which any reservoir will be kept below High Water Line is 1 year 9¼ months, and with 10 per cent. of water surface on the watershed 1 year 10½ months. All the watersheds under consideration have less than 10 per cent. of water surface, except that of Clinton Hollow Reservoir.

The storage for each of the watersheds has been computed at

169,000,000	gal. per sq. mile	of watershed of	0 per cent.	Water surface
175,000,000	"	"	1 per cent.	"
180,000,000	"	"	2 per cent.	"
185,000,000	"	"	3 per cent.	"
190,000,000	"	"	4 per cent.	"
195,000,000	"	"	5 per cent.	"
200,000,000	"	"	6 per cent.	"

—except in the case of the Clinton Hollow Reservoir, for which a storage of 520,000,000 gallons per square mile of watershed was used.

Description of Reservoir Surveys and Estimates.

All of the reservoirs covered by this Appendix have been surveyed, and plotted on a scale of 400 feet to the inch. These surveys included complete topography, and location of roads, railroad and buildings. The average distance between shots is probably about 300 feet. Contours were drawn at five feet intervals and the capacities of the reservoirs were compiled from the planimetered areas of these contours.

Detailed surveys and plans on a scale of 100 feet to the inch were made of all dam sites.

All estimates have been worked from the large scale plans, except in the case of part of the Clinton Hollow Reservoir.

Real Estate.

In preparing real estate estimates a careful census was made of population and property within the taking line, and the exact taxable assessments were obtained from the town records, as far as possible.

The engineer's estimated cash value was obtained by the carefully weighed judgment of Mr. W. M. Stodder, Assistant Engineer, who personally conducted the census, visited every house and interviewed the residents, and obtained a great mass of confirmatory evidence as to the general accuracy of his valuation; this evidence consisting of last selling prices and opinions of local real estate experts and other similar information.

All of the real estate data has been compiled on large sheets specially prepared for the purpose.

The general results obtained give the following rates of taxation and cash value for the different locations:

Reservoir.	Per Acre.			
	Assessed Valuation.	Estimated Cash Value.	Assessed Valuation for Entire Town.	Cost as Given in Estimate.
Stormville	$39 97	$47 34	E. Fishkill.............$34 23	......
....	......	......	Beekman.............. 35 90	$200
Billings...........	24 84	30 19	Lagrange...... ...... 34 19	150
Silvernails.	31 81	38 48	....	150
Hibernia	......	59 18	....	250
Clinton Hollow ...	......	30 00	....	150

It will be noticed that the value of real estate has been estimated at from 400 per cent. to 500 per cent. of the estimated cash value of the properties.

Reimbursement to Towns.

A sum equal to one-half of the assessed valuation of the lands taken has been set aside to meet any claims that the various towns might make on account of "loss of taxable property." This sum, at 3 per cent. interest, is sufficient to provide a yearly revenue about equal to that obtained from the reservoir lands by the different towns.

Sanitary Protection of Watersheds.

The amounts that have been estimated under this head are intended to provide for the abatement of all serious pollution on the watersheds, which would be classed as capital expenditures.

Watersheds.

The watershed areas were carefully checked on the United States Geological maps, and the entire divide line has been perambulated by a trained man, so that knowledge on this point is exact and definite.

Roads.

All new highways have been projected on the large scale maps and have been estimated on the following bases:

Classification.	Cost Per Foot.	Description.
Class A....	$8 50	First class marginal roads, macadam surface 18 feet wide, very heavy construction on steep and broken side hill country, inclusive of all ordinary special structures, and with rip-rap shore protection, retaining walls, graded approaches, and a certain amount of landscape work near villages.
Class B.....	7 00	First class marginal road, similar to Class A, but with no landscape work, retaining walls or graded approaches.
Class C.....	5 50	Side hill work, frequent rip-rap protection, macadam surface, all ordinary special structures included.
Class D.....	4 50	In general not a marginal road, including all special structures and macadam surface 15 feet wide.
Class E.....	4 00	Light work, fairly level country, includes special structures and 15 foot macadam surface.
Class F.....	3 50	Regrading and resurfacing with macadam existing roads, no extensive alteration to present gradient.

Railroads.

In working estimates of railroad relocation, the following averages have been used for different classes:

Classification.	Cost Per Foot.	Description.
Class 1......	$7 50	Good average work in rolling country, including all grading, culverts and tracks.
Class 2......	9 00	Heavy side hill work, including all grading, culverts and track.
Class 3......	11 00	Same as Class 2, but for especially steep side hill country.
Class 4......	37 00	Deep cuts at tunnel portals, including all grading, retaining walls and track.
Class 4½....	15 to 57	Rip-rapped embankment at reservoir crossings, including all grading and track.
Class 5......	92 00	Single track tunnels (partly lined).
Class 6......	120 00	For steel viaducts (complete).

Diversion of the Fishkill Creek.

STORMVILLE DAM.

Dimensions and Description.

The proposed dam on the Fishkill creek, near Stormville, is mainly of the standard type of earth dams, with masonry core wall and overfall. The main dimensions are as follows:

Maximum height from high water line to surface of ground is.	66	feet.
Maximum height from high water line to lowest bed rock is about	104	"
Length of overfall at high water line is	400	"
Length of the earth section is	2,990	"
Length of the entire dam is	3,390	"

It is proposed to face the water slope with heavy rock paving and to build the overfall of solid masonry on the bed rock. The waste channel will be, to a large extent, blasted out of the rocky side hill. The wasteway is designed to carry a freshet flow equal to 6 inches of water on the entire drainage area in twenty-four hours, with 3 feet depth of water flowing over the crest. The extreme capacity of the overflow, however, will be greatly in excess of this.

Outlets.

At the southerly end of the overfall, the gatehouse will control the draft from the reservoir, the ordinary draft being conducted through two 48-inch pipes into the main conduit.

Two other 48-inch pipes at Elev. 300 at the bottom of the reservoir will be used to empty the reservoir in cases of emergency, and to control the flow of the stream during construction.

Dikes.

A small dike of the same general cross section as the earth portion of the main dam will be required near the present railroad station at Stormville, in order to close the gap through which the New York, New Haven and Hartford Railroad passes. This dike will have the following dimensions:

Length at high water line	535	feet.
Maximum height of flow line above surface of earth	23	"
Maximum height of flow line above bed rock, about	41	"

Another small dike will be required about a mile and a half northeast of the main dam, to close the gap in the hills surrounding the reservoir near Sylvan Lake. This dike will be of the same section as the one previously described.

Its dimensions will be as follows:

Maximum length of High Water Line....................	765 feet.
Maximum height of High Water Line above surface of ground	19 "
Maximum height of High Water Line above bed rock about..	30 "

Borings.

A line of wash drill borings has been taken along the centre of the proposed dam and dike at Stormville and through the intervening knoll or drumlin, and from these borings the general depth of the bed rock and the nature of the overlaying strata have been carefully determined, so far as their limited scope would permit.

The bed rock consists of a metamorphic limestone bluish in color, and firm and hard in texture. Its beds are almost vertical, and the true contour of the rock below the covering of drift is probably extremely irregular. The overlying drift is, as a general rule, a firm and compact hardpan. This hardpan, below a depth of a few feet from the surface, is of a blue-gray tint, is rich in clay or finely divided rock flour, and is without doubt impervious to the percolation of water.

These conditions were found for practically the whole length of the main dam. The borings were taken at intervals of 100 feet in the deeper portions and 200 feet in other parts, and wash drill samples were taken at 5-foot vertical intervals. In the large knoll or hill to the north of Stormville, which forms part of the west side of the reservoir, fears were at one time entertained that the strata might not prove of sufficient watertight qualities to form an efficient barrier.

In taking borings at this point, dry samples were collected wherever possible at intervals of 10 feet in depth. These dry samples were obtained by punching a hollow tube into the earth at the bottom of the casing pipe, until a sufficient sample was forced into the hollow of the tube and retained there. These dry samples are an extremely valuable check on the ordinary wash samples, and demonstrate conclusively the exact nature of the strata. The general results obtained show that this drumlin consists of a hard, compact, bolder clay, blue-gray in color, overlying the limestone formation. The color of this bolder clay is a consideration of much importance, its bluish tint indicating the absence of oxidation which invariably accompanies the percolation of ground water.

On the knoll to the south of Stormville, the ledge outcrops frequently at the summit. Borings taken at the northern extremity, however, show that there are possibilities of finding porous strata at that end of the knoll; but there is no question as to the general fitness of this hill to form part of the barrier.

The number of borings taken at this reservoir is............	28	
The greatest depth penetrated being.........................	75	feet.

Lack of time and means alone prevented a more extended investigation at this site than has been taken. Enough, however, has been done to show the entire feasibility of building this dam for a reasonable sum and with sure prospects of success.

Before construction is undertaken here, a much more detailed study should be made than has been possible with the limited time available, and it is recommended that the entire site be covered with wash drill borings taken at the corners of squares of 100 feet on a side, laid out on a comprehensive plan. This plan should embrace the entire main dam site, the two dikes and the drumlins north and south of Stormville.

STORMVILLE RESERVOIR.

Area and Elevations.

The proposed reservoir covers 1,694 acres at the High Water Line, elevation 364. This land is almost entirely cleared and under cultivation, and with one small exception free from swamps.

The elevation of the lowest full draft is.................. 341 feet.

Capacity.

The capacity of the reservoir below Elevation 341....	6,440,000	gallons.
The capacity of the reservoir above Elevation 341....	10,094,000	"
Total capacity	16,534,000	"

The average depth of water in the reservoir will be 39.4 feet below ordinary High Water.

Taking Line.

An approximate line of taking has been laid on the plan that embraces a total area of 2,985 acres. This line as laid out provides wide margins to the reservoir, more than will be actually required for purposes of construction alone, but arranged with a view to future complete control of the shores and approaches, and also the satisfactory adjustment of real estate settlements.

Statistics.

The population permanently residing within the taking line is....	310
The number of summer boarders and occasional residents is....	70
" horses and cattle is....	686
" occupied dwelling houses is....	89
" unoccupied dwelling houses is....	7
" factories, shops and stores is....	19
" barns, stables, sheds, etc., is....	221
" acres of arable land....	2,725
" acres of woodland....	50
" acres of pasture....	210
Total acreage....	2,985

Valuation.

The taxable value of the realty within the taking line at the last town assessment is....	$119,310
The engineers' estimate of the present cash value is....	141,308

The reservoir lies within the towns of Beekman and East Fishkill, Dutchess County. Both these towns have been steadily declining in valuation and population during the past few years, as shown by the following table:

Date.	Beekman.			East Fishkill.		
	Real.	Personal.	Total.	Real.	Personal.	Total.
1894	$743,850	$52,900	$796,750	$1,265,446	$44,650	$1,310,096
1895	741.822	48,900	790,722	1,252,970	38,650	1,291,620
1896	687,798	49,300	737,098	1,175,206	38,650	1,213,856
1897	672,273	58,350	730,623	1,169,631	50,550	1,220,181
1898	645,967	56,540	702,417	1,140.391	44,650	1,185,041
1899	635.532	28,540	664.072	1,119,585	42.950	1,162,535
1900	635,532	25.570	661,102	1,119,585	35.750	1,155,335
1901	634,532	35.880	670,412	1,119.585	32,550	1,152,135
1902	629,532	34,680	664,212	1,119,585	39,550	1.159,135

Population East Fishkill and Beekman.

The population of East Fishkill in 1890 was..................	2,175
The population of East Fishkill in 1900 was..................	1,970
The population of Beekman in 1890 was.....................	1,113
The population of Beekman in 1900 was.....................	1,071

Roads.

Twentv-six thousand feet or about 4.9 miles of existing roads are within the reservoir limits, or must be discontinued through the reservoir construction. These roads are in general poorly graded and surfaced.

It is proposed to build 47,550 feet or 9 miles of well graded, surfaced and fenced roads to take the place of those that must be discontinued; this length is inclusive of existing roads that will be rebuilt and resurfaced.

Railroads.

Seven thousand one hundred feet or 1.34 miles of the New York, New Haven & Hartford R. R. will require to be rebuilt at a higher level. It has been estimated that a new roadbed parallel to the present roadbed, and as close as possible to it, will be built; the gradients of the new line being the same as, or better than those of the present line.

The slopes of the railroad enbankment subject to wave action in the reservoir will be protected by rip-rap.

Removal of Soil and Shallow Flowage Treatment.

It has been the practice in many communities wholly or partially to remove soil from reservoir bottoms in public water supplies. Massachusetts has set a strong example in this respect, and the contention has been made with apparently good reason that the improvement in quality of the water stored in a stripped reservoir is worth the money spent on the stripping. Some recent developments, however, have cast doubt on this contention.

The City of Boston has during recent years caused all its reservoirs to be cleared of soil, the standard adopted being that all soil having 3 per cent. or more of organic constituents should be removed or covered with sand or gravel.

The records of the biological analyses of water derived from certain stripped reservoirs for a number of years after their construction showed a marked advantage in the lessened number of organisms as compared with unstripped reservoirs. This advantage was maintained for a number of years, but recently a marked increase in organisms has been developing in these same reservoirs, and their present condition is such that it will not be possible to show any appreciable advantage of the stripped reservoirs on this account.

The New York practice has been to leave the soil in place, and under the proposed scheme of additional water supply, which embraces a thorough and complete sand filtration of all waters, it would seem to be inadvisable to spend large sums of money for purposes of soil removal.

It is believed that little more should be done than to complete certain local improvements, such as covering with sand the surface of any peat or muck areas (especially where the reservoir is shallow), and possibly the removal of soil from a few shallow places, and the filling in of other shallow places with the excavated material, and protecting these fills with sand or gravel beaches. The principle to be observed in all these operations should be the elimination of all sheltered, shallow nooks or backwaters where organic life would have a specially favorable opportunity to multiply.

It has been estimated that a daily draft of not less than 750,000 gallons per square mile of watershed may be safely reckoned upon from the areas on the east side of the Hudson River; with this draft the records of the Croton and Sudbury Rivers show that the level of the water in any reservoir will occasionally be kept below High Water mark for periods as long as about two years, and in this connection it is a matter of consideration whether the removal of soil from the margins likely to be exposed during this interval would not be effective in preventing to a large extent the growth of vegetation. It is a matter of grave doubt whether the results of stripping even these margins are worth the expenditure, excepting in the special cases previously alluded to.

All these matters are open questions on which the best authorities disagree, and for purposes of these designs and estimates the following rules have been adopted, as being safe and giving an outside cost:

Strip all soil from margins between the levels of 3 feet above High Water and 5 feet below the minimum draft line wherever the natural slope of the ground is flatter than 1 vertical to 10 horizontal.

Cover the surface of all deep muck holes and swamps with gravel and sand.

Fill all shallow margins and back-waters with earth, and face the water-sides of these fills with coarse sand or gravel beaches.

Following out these general principles, the total area to be stripped of soil will be 482 acres or 28 per cent. of the whole area. The average depth of this stripping will probably run to about 10 inches.

The total quantity of earth removed will be 645,000 cubic yards. This material will require hauling an average distance of 1,200 feet, in order to be desposited in the shallow places on the margins. The shallow flowage fills will require for protection 50,000 cubic yards of sand or gravel for beaches.

Cemeteries.

There are two small cemeteries a little above the proposed flow line of the reservoir; they are very small, however, and not likely to cause trouble.

BILLINGS DAM.

Dimensions and Description.

This dam consists of two unequal sections of earth dam on either side of a knoll nearly in the middle of the main valley.

The dimensions are as follows:

Length at High Water Line..................	700 feet and 1,490 feet.
Maximum height flow line above surface of ground	60 "
Maximum height flow line above surface of bed rock	About 100 "

The general design of the dam is similar to that of the Stormville Dam, being of the standard type of earth dams, with masonry core wall and paved water slope.

It may be found possible with the general scheme of reservoir development under consideration to connect the Billings and Hibernia reservoirs by an open canal which would under ordinary conditions carry the drafts from Hibernia Reservoir into Billings Reservoir, but during floods would act as a waste channel and discharge in the opposite direction. In this event an overflow and waste channel may be omitted from the design of the Billings Dam, and the earthen section carried entirely across the valley. This will be a valuable feature in the design if found practicable, as the depth of the drift below the dam here makes a wasteway a somewhat expensive undertaking, and the general principle of keeping a waste channel as remote as possible from the dam is a good one, and worthy of being followed wherever possible.

The reasons that would call for the construction of a waste channel at the Billings Dam are:

1. The possibility that the connection between Billings Reservoir and Hibernia Reservoir may be by means of a tunnel instead of an open cut, in which case the tunnel would not be of a sufficient capacity to carry the freshet flows.

2. The consideration that the construction of the Hibernia Reservoir

might be at a date so remote that it would not be economical to anticipate its construction by building the open cut at the same time as that of the Billings Reservoir construction.

Borings.

Borings to determine the location of the ledge rock and the nature of the overlying strata are in process at this dam site.

General Indications.

It has been assumed that the proposed construction is an economic possibility at this site; the data to support this view, however, is somewhat meagre.

The surface indications are not conclusive in many respects; the ledge rock does not outcrop so frequently as to render its location obvious. On the northern side hill the rock is a distinct shale; on the southern side hill the slopes are very abrupt, terminating in a bluff of some crystalline rock. Large masses of rock detached from this bluff have formed a steep foot slope from the bluffs to the brook. Immediately north of the brook and distant about 200 feet is an outcrop of shale, and there are indications of possibilities of other outcrops near the top of the large knoll in the middle of the valley.

There is a strong possibility, however, that the ledge may only be found at great depth on parts of this site in spite of the favorable indications just alluded to.

The cost of building a core wall to rock, even at considerable depths, will not, however, form any great proportion of the total cost of this reservoir, and it has been considered as being perfectly practicable and safe to omit carrying the core wall to rock if the latter is at very great depth, providing the overlying earth is found to be of an impervious nature.

The hardpan that has been found in the Stormville valley about six miles distant, and which, from general surface indications, may be expected to be found in this valley and other adjacent valleys, is a very compact bolder clay, extremely hard, of almost the consistency of cement concrete.

The strata overlying the rock here, so far as could be observed at certain favorable points, and from the wash drill samples of the few borings already taken, is of a decidedly clayey nature, and the brook bed is in parts entirely in clay. While the general indications are by no means as clear and conclusive as could be wished, they are sufficient to afford grounds for reasonable expectation of good results in the structure proposed.

The great desirability of a dam at this point as forming an important unit in the general scheme of the eastern supply system, renders it profitable to spend a comparatively large sum of money at this place, even if the results of the boring operations now in process should develop more undesirable features than are at present anticipated.

The estimate of dam construction gives the cost of the dam built with a masonry overfall and wasteway, with sufficient allowance made in both cases to cover the contingency of finding bed rock at unexpected depth.

BILLINGS RESERVOIR.

General Description.

Ordinary High Water Line will be at elevation...	372.5	
Area within this flow line will be................	969	acres.
Mean depth of water will be...................	25.0	feet.
Elevation at lowest full draft...................	343	feet.
Capacity of reservoir below Elevation 343.......	1,200,000,000	gallons.
Capacity of reservoir above Elevation 343........	6,826,000,000	"
Total capacity	8,026,000,000	"

This reservoir is long and narrow in shape, the floor is level and side hills are steep and often rocky. The country rock is a shale, firm and compact in its natural condition, but a rock which weathers and disintegrates freely when exposed.

There is very little swamp or peaty land in this reservoir and the surface soil is generally thin. The area is clear of woods, and mostly under cultivation or pasturage.

Statistics.

The population permanently residing within the taking line is...	78
The number of summer boarders and occasional residents is......	82
" horses and cattle is..........................	272
" occupied dwelling houses is....................	30
" unoccupied dwelling houses is.................	3
" factories, shops and stores is..................	4
" barns, stables, sheds, etc., is..................	128
" acres of arable land is........................	1,600
" acres of woodland is..........................	380
" acres of pasture is...........................	435
Total acreage	2,415

Valuation.

The area within the proposed taking line is............ 2,415 acres.
The taxable value of all property inside the taking line at the last assessment was.......................... $59,989
The estimated cash value is.......................... 72,909

The entire reservoir lies in the town of Lagrange, Dutchess County. The taxable valuation and population of the town has been steadily declining for the past few years, as shown in the following table:

TOWN OF LAGRANGE.

Year.	Valuation.		
	Real.	Personal.	Total.
1890	$1,042,507	$99,650	$1,142,157
1891	1,075,983	105,959	1,181,942
1892	1,055,983	108,250	1,164,233
1893	1,001,783	83,950	1,085,733
1894	1,001,351	85,300	1,086,651
1895	994,358	76,300	1,070,658
1896	934,007	72,300	1,006,307
1897	929,082	87,600	1,016,682
1898	905,855	78,750	984,605
1899	878,139	68,525	946,664
1900	878,139	45,325	923,464
1901	877,139	52,475	929,614
1902	877,139	43,025	920,164

Population of Lagrange.

The population of the town of Lagrange in 1890 was 1,463; in 1900, 1,304.

Roads.

Forty thousand feet or 7.6 miles of public highways fall within the reservoir limits or must be discontinued through reservoir construction. These roads are the usual type of back country roads, poorly graded and surfaced.

It is proposed to build 54,900 feet or 10.4 miles of well-graded and surfaced roads in place of those which will be discontinued; of this length 17,600 feet or 5½ miles will consist of regrading and resurfacing existing roads.

Railroads.

No discontinuance of any railroad lines will be required, but for a short distance it will be necessary to protect the embankments of the N. D. & C. R. R. from wash by rip-rapping the slopes of embankments. A new culvert will also be required to take care of the flow of Jackson Creek at the railroad.

Removal of Soil and Shallow Flowage Treatment.

The same general principles regarding soil removal and shallow flowage treatment have been adopted at this reservoir as at the Stormville Reservoir for purposes of this estimate.

The area of land to be stripped will be.............	482 acres.
The approximate quantity of soil excavated from this area will be.................................	466,000 cu. yards.
The average haul of this material will be............	7,000 feet.

With the flow line at the elevation proposed the upper parts of this reservoir will be quite shallow, and the desirability of performing the whole or a large part of the work of soil removal will be greater at this reservoir than in some of the others.

23,300 cubic yards of sand and gravel will be required for beaches to protect the shallow flowage banks, and for covering swampy lands to an average depth of one foot.

The stripped area is 36 per cent. of the entire area.

Jackson Creek.

A necessary appurtenance to the Billings Dam and Reservoir is a small diverting dam, reservoir and channel on a brook called Jackson Creek, about 8,000 feet east of Billings Station, whereby the drainage of 7 square miles of territory may be carried into the brook channel entering Billings Reservoir near Billings Station.

The length of this small dam at High Water Line is about....	530 feet.
The height of the Water Line above surface of ground is.....	24 "
The height of the Water Line above surface of rock is about...	40 "

The small reservoir thus formed will have an area of 19 acres at High Water Line, elevation 431. The waste will flow through a channel 5,900 feet long to a controlling and regulating dam, over which it will fall into the present channel of the creek that leads down into the Billings Reservoir.

The excavated canal will have a maximum depth of 23 feet, and the general depth of the cut will be about 11 feet.

The section of the canal is as follows:

Width of bottom is....................................	20 feet.
Slopes 1 vertical to 1¼ horizontal, paved to a height of 2 feet above High Water Line............................	
Ordinary depth of water................................	10 "
Section area of waterway................................	325 sq. feet.

This channel is designed to carry 1,000 cubic feet per second during freshets with a velocity of about 3 feet per second. This will take care of all but floods of extraordinary amounts, for safety against which an overflow channel has been designed at the dam.

The area of land required for the reservoir on Jackson Creek is. 84 acres.

Diversion of the Wappinger Creek.

HIBERNIA DAM.

Dimensions and Description.

This dam is situated immediately below the two main branches of the creek at Hibernia, Dutchess County.

The elevation of the ordinary high water line is............	372.5 feet.
The length of the dam at high water line is................	6,640 "
The maximum height of flow line above surface of ground is.	132.5 "
The maximum height of flow line above bed rock probably not more than..................................	148 "

This dam has been designed as a combination earth and masonry dam. The earth section is of the standard type previously described for the Stormville and Billings dams, but with heavier paving on the water side.

The dimensions of the earth section are as follows:

Total length at high water line..........................	3,340 feet.
Maximum height of flow line above surface of ground is.....	78 "
Maximum height of flow line above surface of rock is........	85 "

The masonry section of the dam has the following dimensions:

Length	3,300	feet.
Maximum height high water line above surface of bed rock about	148	"
Height of top of dam above ordinary high water is........	5	"
Thickness of dam at high water level is..................	25.28	"

The masonry section has been designed on lines very similar to those used on the Wachusett Dam, in Massachusetts, with, however, certain modifications.

The main reason for using the Wachusett design is that that section is an unusually heavy one, and estimates based on that design will be at least conservative.

The material used in the wall of the dam is heavy rubble laid in Portland cement, or cyclopean rubble. The outside facing on both sides will be ashlar, laid with close joints.

The two wings at the ends of the earth sections will be of the same material.

It has been estimated that ledge rock will be excavated to an average depth of 10 feet over the entire bottom of the masonry dam to secure a good footing.

Quarries.

Suitable material for the heart masonry of the dam may probably be found at Stissing Mountain, a distance of 10 miles northerly from the dam. The stone in this mountain is apparently a coarse-grained granite, which will probably be suitable for rubble and easily worked. The stone for the ashlar and dimension work will probably require to be brought from a greater distance.

Stissing Mountain appears to be the nearest point to the dam whence stone of the right quality can be obtained. The quarry and dam both lie on the same railroad, and it will be possible to deliver stone at the dam site at a low cost.

Foundations.

The bed rock outcrops for almost the entire length of the dam, so that its nature and elevation may be positively determined without the necessity of any borings for the purposes of this investigation.

The site is a depression or gap in the long rocky hill forming the western shore of the proposed reservoir, but the general geological structure continues unbroken across the site.

The rock is a shale, with beds lying almost vertically, and the general line of strike almost parallel with the axis of the dam. This rock, when undisturbed, seems to have remarkably durable qualities. As an instance of this it was noticed that at a number of outcroppings the surface of the rock is very sharply striated by ancient glacial action. These scratches and grooves have been preserved practically unchanged since the glacial epoch. This fact forms unimpeachable evidence of the durable qualities of the rock.

It was noticed, however, that wherever this rock has been cut into, as at the railroad excavation on the north side of the creek, the ragged and broken surfaces have weathered and disintegrated with rapidity. No doubt this fact is largely due to the shattering action of the high explosives used on the railroad work.

There is no doubt that this rock, when treated with care and preserved from exposure, will form an extremely satisfactory foundation for a dam, its compactness and the inclination of the cleavage planes being guarantees of safety from sub-surface percolation, and its closeness to the surface of the ground being a factor of great economic importance. This rock is, however, entirely unfit for use as masonry in the dam, or even for paving on slopes, where exposed to any considerable wave action.

Wasteway.

The wasteway will be 600 feet long, with stone crest at 1 foot and 2 feet below ordinary high water, and a capacity of discharge, with the reservoir at Elevation 374.5, equal to 6 inches on the entire watershed delivered in twenty-four hours.

If this wasteway be required to carry waste overflows from the Billings area in addition to those from the Hibernia area, the total length of overflow will be proportionately longer. This modification of the design may be made at a later period if found to be desirable, without appreciably increasing the cost of the dam.

Dikes.

A small dike will be required near Willow Brook Station, on the P. and E. R. R., at a point about 2 miles north of the main dam.

The length at high water line will be about..................	270 feet.
Maximum height of flow line above surface of ground will be..	4 "

It has been estimated that this dike will be built wholly of soil stripped from the adjacent shallow parts of the reservoir and deposited in an embankment with flat back slopes and without any core wall. The water side will be faced with paving, and the highway relocated to cross on the top of the dike.

A small dike will be required at a point about 1,100 feet south of the main dam, and its dimensions are as follows:

Length at high water line	35 feet.
Maximum height from high water line to surface of ground	5 "
Maximum height from high water line to surface of ledge	6 "

HIBERNIA RESERVOIR.

Description.

The elevation of the proposed flow line for this reservoir is	372.5 feet.
The elevation of the point of lowest draft from which the full supply can be drawn is	349 "

The capacity of the reservoir above Elev. 349 is	30,000,000,000 gallons.
The capacity of the reservoir below Elev. 349 is	42,000,000,000 "
Total capacity	72,000,000,000 gallons.

The area within the ordinary high water line is	4,350 acres.
The average depth below ordinary high water line is	50.8 feet.

The villages of Stanfordville, Washington Hollow, and part of Bangall fall within the reservoir limits.

The general shape of this reservoir is that of a wide valley with a general north and south direction, fairly level floor, and steep and rocky side hills. The surface of the ground is almost wholly cleared and fairly well cultivated.

The maximum length of the proposed reservoir is	9.3 miles.
The maximum width of the proposed reservoir is	1.3 "

Roads.

The total length of public highways that must be discontinued through this reservoir construction is 144,500 feet, or 27.4 miles.

To take the place of these discontinued highways it is estimated that the following new construction will be required:

New roads	38,100 feet.	7.2 miles.
Reconstruction of existing roads	20,070 "	3.8 "
Total	58,170 feet.	11.0 miles.

Railroad Relocation.

A portion of the Central New England R. R. and the P. and E. R. R. location fall within the limits of the reservoir. It is proposed to relocate these railroads entirely to the west of the reservoir, whence they will return to their present location in the vicinity of Stissing.

Length of lines to be discontinued is as follows:

Central New England R. R.	52,500 feet.	9.94 miles.
Poughkeepsie and Eastern R. R.	34,300 "	6.49 "
Total	86,800 feet.	16.43 miles.

C. N. E. R. R.

The proposed new location of the C. N. E. R. R. will start from the present Hibernia Station and follow a course indicated in the plan via Clinton Hollow, Upton Lake and Market to Stissing, crossing the P. and E. R. R. by an overgrade crossing north of Upton Lake. The total length of the proposed new location is 59,000 feet, or 11.2 miles.

P. and E. R. R.

The proposed new location of the P. and E. R. R. is parallel with the above described route of the C. N. E. R. R. from Upton Lake to Stissing. The total length of the proposed new construction for this road is 32,600 feet or 6.2 miles.

General.

All railroad relocation work has been estimated on a very liberal basis, with ample allowance for all special structures, bridges, viaducts, right-of-way, etc.

Removal of Soil and Shallow Flowage Treatment.

Under the same principle of soil stripping and shallow flowage elimination that has been used in previous reservoir estimates, the total area of lands to be stripped is 532 acres, or 12 per cent. of the whole area.

The material to be excavated from this area will total 712,000 cubic yards. This material will require hauling for an average distance of 1,200 feet.

The sand and gravel required for beaches and shore protection will be 39,000 cubic yards.

The general shape of the reservoir does not require a large amount of special treatment for shallow flowage, except in the shallow arm in the vicinity of Willow Brook, and the northern extremity, near Stissing and Stanfordville.

Cemeteries.

There are two cemeteries, one wholly and the other partially inside the reservoir limits. The former is a very small private yard; the latter is also small, and the removal of the bodies will form an insignificant factor in the work of the reservoir.

Real Estate.

It has not been found practicable, with the time and means available, to make a close examination of the real estate problems involved in this reservoir construction, or to take a careful census of the population.

The land as a whole consists of good average farming land. The houses and buildings are in general in good condition, well up to and perhaps above the average of country districts.

The agricultural population is appreciably increased by summer boarders during July, August and September, the boarding business probably being a considerable factor in the income of the average farmer.

The village of Stanfordville, which is by far the largest community which will be affected, has a population of about 300 or 400.

Buildings within Proposed Area.

Dwelling houses	244
Other buildings of all kinds, about	600

Population.

By using the same ratio of inhabitants per house in this reservoir as was found in the Silvernails, Stormville and Billings reservoirs, the total population inside the taking line is 800.

This reservoir falls within the three towns of Pleasant Valley, Washington and Stanford, in Dutchess County.

The population of these three towns at the 1890 and 1900 census was as follows:

	1890.	1900.
Pleasant Valley	1,531	1,483
Washington (not including Millbrook)	2,073	1,960
Stanford	1,859	1,624

In all three of the towns the population has been steadily declining, and, with the exception of the temporary increase due to summer boarders, the decline will probably continue.

Valuation.

The value of real estate per acre for this reservoir has been set at 25 per cent. more than that for the Stormville Reservoir.

CLINTON HOLLOW DEVELOPMENT.

The general design of reservoir development under which this project was considered embraces these four alternative schemes:

(1) The introduction of water from the sources on the west side of the Hudson into this reservoir through an aqueduct discharging at a point near Milan (under Project No. 1).

(2) The introduction of water from the Roeliff Jansen Kill through a tunnel from Jackson Corners into the upper end of the reservoir.

(3) The introduction of both of the above waters into this reservoir.

(4) The development of the Clinton Hollow Reservoir alone on a basis of from 750,000, to 850,000 gallons of daily yield per square mile of watershed.

It is obvious that either one of these projects calls for a study of considerable elaboration and extensive surveys, in order to determine even approximately the economical development.

For instance, if a large supply from the western sources be introduced, this watershed may be developed to a much higher limit than has been considered advisable in other watersheds, possibly as high as 900,000 gallons per square mile of watershed per day. In this case the supply from the western sources would be used to prevent the water level from being kept below high water line for too great periods.

In the case of Proposition No. 2, this reservoir would form an integral part of the development of the Roeliff Jansen Kill Watershed, a considerable portion of the required storage for the latter watershed being afforded by this reservoir.

The actual value of the Clinton Hollow development is, however, more apparent in the case of Proposition No. 1 than in the other cases, and the following estimates and designs are based on that proposition alone.

CLINTON HOLLOW DAM.

A favorable site for a dam exists about 2,000 feet north of the small mill dam at Clinton Hollow village.

Dimensions and Description.

The dimensions of the proposed structure are as follows:

Length at high water line	930 feet.
Maximum height of flow line above surface of ground	89 "
Maximum height of flow line above bed rock, about	107 "
Elevation of flow line	387 "

This dam is estimated to be of the standard earth type, with masonry core wall and paved water slope. A gatehouse controlling a 48-inch outlet will serve to drain the reservoir in emergencies and take care of the brook water during construction.

Overfall.

A low portion of the hills surrounding the reservoir about 2,600 feet northwest of the dam affords a favorable site for a wasteway. Unfortunately, the ledge does not come to the surface at this point, but indications are that it will be found at no great depth.

A masonry overfall and paved channel have been estimated on, the length of the overflow being 200 feet and designed to discharge a quantity equal to 6 inches on the watershed in one day, with a depth over the crest of 3 feet.

Site of Main Dam.

The rock at this site is a crystalline limestone, appearing capable of forming a satisfactory foundation. The outcrops are at the west side of the brook and at several points on the steep westerly side hill.

No outcrops are visible on the east side of the brook on the dam line, but, judging from general contours and such outcrops as are found at points not very remote from the dam, it is fair to infer that rock will be found at no unusual depth below the surface.

The estimates have allowed for an average depth of 30 feet from the surface of the ground to the rock on the east side of the brook. The drift at this point is apparently hardpan.

CLINTON HOLLOW RESERVOIR.

Description.

The area of this reservoir at the level of the proposed flow line at Elev. 387 is...............	2,157 acres.
The mean depth of the water below Elev. 387......	26.2 feet.
The elevation of lowest maximum draft is........	360 "

The capacity of the reservoir above Elev. 360 is...	13,900,000,000 gallons.
The capacity of the reservoir below Elev. 360 is....	4,500,000,000 "
Total capacity	18,400,000,000 "

The maximum length of the reservoir from the dam to the upper extremity north of Milan is......	6.7 miles.
The maximum width is........................	0.8 "

The greater portion of the area is cleared, hard, dry land under cultivation or pasturage, the exceptions being a small area of swamp adjacent to two ponds within the reservoir limits, and in the upper reaches of the reservoir near Milan.

Rock outcrops are abundant within this area so far as observed, the rock being crystalline limestone.

Roads.

The length of the new highway construction estimated to take the place of those discontinued under the new conditions is about 15 miles.

Soil Stripping and Shallow Flowage Treatment.

The area from which soil will be excavated is about..	464 acres.
Soil excavated from reservoir and deposited in shallow flowage banks, about....................	620,000 cu. yards.
The average length of haul for above, about.........	2,000 feet.
Sand and gravel used in forming beaches, about.....	20,000 cu. yards.

NOTE.—The estimate of work on the Clinton Hollow Reservoir is largely based on the United States Geological Survey map, the surveys of the reservoir not having been wholly plotted. These surveys have all been made and are available for use at any time when opportunity is found to plot the notes. The Geological map was checked as far as possible and the estimates prepared from it; they cannot, however, be considered other than close approximations.

Diversion of the Roeliff Jansen Kill.

DAM AT SILVERNAILS.

Dimensions and Description.

This dam is situated immediately below the junction of the Roeliff Jansen Kill with the Shekomeko Creek.

Its main dimensions are as follows:

Elevation of proposed High Water Line is..............	465 feet.
Length of High Water Line............................	1,600 "
Maximum height from flow line to bed rock...............	115 "

The section of the dam as proposed will be entirely a masonry one, mostly of the standard type provisionally adopted for estimating purposes.

This standard section extends for a total length of 1,000 feet.

The northerly end of the dam for a length of 600 feet will be built at a lower level than the main portion, and of a different section, being intended to act as a spillway. The level of the crest of the spillway will be 1 foot below high water line for a length of 300 feet, 4 feet below for 200 feet, and 5 feet below for a length of 100 feet.

A deep channel cut out of the rocky side hill will carry the waste into the river bed below the dam. The gatehouse situated between the overflow channel and the river bed will control three 48-inch outlet pipes, which will serve as an emergency outlet from the reservoir, and to control the flow of the river during construction.

Quarry.

The stone for the rubble heart of the dam may be obtained at the same quarry as that suggested for the Hibernia Dam, namely Stissing Mountain. The distance by railroad from this dam to the proposed quarry is 3½ miles.

It is probable that the stone for the ashlar and dimension stone work will require to be brought from a longer distance.

Foundation.

The rock crops out or is very close to the surface from the northerly end of the dam to the south side of the creek.

All the rock in this vicinity is a distinct shale, the cleavage planes of which are inclined at an angle of about 40 degrees from the vertical, the general direction of the strike being almost parallel with the axis of the dam.

This rock when not exposed to weathering influences is compact and firm, and free from visible fissures and seams likely to cause trouble from percolation under the dam. The feasibility of building a dam at this site economically and with entire success is unquestionable. Sufficient data as to the exact location of the bed rock on the south side hill, however, has not been obtained to render the estimate of cost a definite one.

The southerly side hill is covered with a deposit of drift, which has been estimated about 40 feet in depth. The ledge outcrops on the southerly side hill nearest to the creek that have been discovered so far are at a distance of 1,600 feet south of the creek.

Allowance has been made in the estimate for an average cut of 40 feet through the earth on the south side of the creek. In addition there has been estimated an average cut of 10 feet in ledge over the entire base of the dam in order to secure a tight footing and remove all weathered and seamy rock.

Cut-off.

About 1,200 feet north of the dam between the rocky hill forming the north abutment and the main range of hills beyond, a sandy plain exists which is probably the remains of an ancient lake bed.

The elevation of this plain is about 28 feet above proposed High Water.

It is probable that this entire plain consists of very porous sand or gravel, and that considerable leakage from the proposed reservoir might take place if some means are not taken to build a cut-off.

It has been estimated that a trench with side slopes of 1 to 1 will be excavated here, and a core wall of Portland Cement Concrete will be built in the trench from the bed rock to the level of the High Water Line, and the trench afterwards refilled.

The length of this cut-off is about	1,150 feet.
The maximum depth at which bed rock is likely to be encountered (judging from surface indications), about	80 "

It is quite possible, however, that borings at this point may materially modify these ideas, and perhaps prove the fact that a cut-off is unnecessary.

SILVERNAILS RESERVOIR.

Description.

The area within the proposed High Water Line is	2,014	acres.
The average depth with the reservoir at High Water Line is	39.4	feet.
The elevation of the lowest full draft from this reservoir has been assumed to be elevation...	430	"
The elevation of the ordinary High Water Line has been taken at	465	"
The available storage between elevation 430 and elevation 465 is	17,200,000,000	gallons.
The unavailable storage below elevation 430 is....	8,600,000,000	"
The total capacity of the reservoir is..	25,800,000,000	gallons.

The elevation of the lowest full draft and the High Water Line have been assumed more or less arbitrarily.

Both of these elevations should be finally established only after careful computations and estimates of their true economic position.

It is obvious that the lower the draft line is made the higher will be the cost of the outlet channel near Pine Plains. It is also obvious that the higher the ordinary flow line is established, the more difficult will it be to save any portion of the village of Pine Plains, or to control economically the outlet.

On the other hand, it is plain that the more storage that can be obtained in this reservoir, the more economically may the reservoirs at Hibernia and Billings be built.

These elevations were assumed not as a result of computations, but as an approximation derived from a careful weighing of the interests involved.

The exact determination of these two elevations is not possible at the present time, as the complete solution of the problem requires the extension of the surveys for a reservoir westerly down the main valley to a point a mile west of Jackson Corners, and the consideration of an alternative outlet from a reservoir with a dam at this point, the outlet being through a tunnel into the Clinton Hollow Reservoir.

For the purposes of the present estimate it has been found necessary to defer the elaborate computation that would be required to settle all these points in a final manner, and make the above arbitrary assumption of these elevations in full knowledge of the fact that their final determination will not be radically different from the assumptions made, and that the general result obtained will be very near the truth.

Soil Stripping and Shallow Flowage Treatment.

The general shape of the valley is favorable for the proposed construction. The floor of the reservoir is level, and the side slopes are decidedly abrupt and rocky, and very little shallow flowage exists excepting at the upper extremities near Ancram and Pine Plains.

The same rules that have been adopted in soil excavation and shallow flowage treatment for other reservoirs have also been used here.

The results found are as follows:

The area of land from which soil will be excavated is.	433 acres,
	or 22 per cent. of the whole area.
The quantity of soil to be excavated is..............	580,000 cu. yards.
The average haul of material excavated is...........	1,600 feet.
The amount of gravel and sand to be used for beaches and swamp improvement is....................	19,000 cu. yards.

Cemeteries.

There are three cemeteries that either fall within the limits of the reservoir or are on the margins.

One is in Pine Plains and is by far the largest of the three; the graves are numerous at this point. The other two are insignificant in size and in the number of graves.

The entire matter of moving the bodies from these grave yards is of but little comparative cost.

Roads.

The existing highways to be discontinued through the construction of the reservoir consists of 57,900 feet or 11 miles of poorly graded, rough, hilly country roads.

To take the place of these roads under the new conditions there have been laid out and estimated 66,165 feet or 12.6 miles of well built, graded and fenced highways.

Railroad Relocation.

45,000 feet or 8.5 miles of the main line of the Central New England R. R. and 13,600 feet or 2.6 miles of the Silvernails branch of the Central New England R. R. falls within the reservoir limits, or will require to be discontinued.

For a distance of 1,700 feet the embankment slopes of the Poughkeepsie & Eastern R. R. will be required to be protected with rip-rap from the wave wash.

It is proposed to build the following new road beds to take the place of those which will be discontinued:

A line leaving the present Silvernails branch C. N. E. R. R. at a point about 1½ miles east of Jackson Corners and taking a general south-easterly direction to the present station at Pine Plains.

The line would involve the construction of a tunnel 5,800 feet long. and its total length is 21,800 feet or 4.1 miles.

A line starting from the present station on the C. N. E. R. R. at Pine Plains and following a general northeasterly direction to a point about 2 miles southwest of Ancram lead mines; thence due north to the present location north of Ancram. This line would require the construction of a tunnel 6,600 feet long. The total length of the new line is 43,300 feet or 8.2 miles.

Real Estate.

A provisional taking line has been laid out with a view to securing complete control of all margins and approaches to the reservoir, and to aid in making real estate settlements on a liberal basis. This taking line includes the greater part of the village of Pine Plains, also the villages of Ancram and Gallatinville.

The total area within this taking line is 5,321 acres.

Outside of the villages the reservoir site is mostly a poor quality of farming land, the greater portion of the whole being pasture land. The buildings do not come up to the average of prosperous agricultural communities.

The following summary of statistics collected for this area will give a clear idea of the situation:

Statistics.

Population permanently residing inside taking line	496
Number of summer boarders and occasional residents	80
" horses and cattle	614
" occupied dwelling houses	140
" unoccupied dwelling houses	1
" factories, shops and stores	27
" barns, stables and sheds	289
" acres of arable land	4,227
" acres of woodland	318
" acres of pasturage	776
" acres inside the taking line	5,321

Valuation.

The taxable value of all real estate inside taking line at the time of last assessment was	$169,261
The estimated cash value is	204,752
Value of property used in estimate, 400 per cent. of estimated cash value or $150 per acre	798,150

Population of Gallatin, Pine Plains and Ancram.

The population of these three towns has during recent years been declining as shown below :

	1890.	1900.
Pine Plains	1,308	1,263
Gallatin	1,016	823
Ancram	1,332	1,238

COMPARATIVE COST OF STORAGE IN RESERVOIRS.

Reservoirs.	Capacity Million Gallons.	Cost.	Approximate Cost per Million Gallons.
Framingham Reservoir No. 3	1,080	$379,000	$351*
Ashland Reservoir	1,400	787,000	562*
Sudbury "	7,400	2,002,000	271*
Hopkinton "	1,530	860,000	562*
Wachusett "	63,067	6,500,000	103*
Bog Brook "	4,145	855,000	207
Titicus "	7,167	1,200,000	170
Stormville "	10,094	1,840,000	182†
Billings "	6.826	1,217,000	178†
Silvernails "	17,200	4,647,000	270†
Hibernia "	30,292	6,891,000	227†
Clinton Hollow Reservoir	13,900	1,051,000	75†

NOTE.—Costs of reservoirs do not include real estate, and have been approximated from the best available data.

HIGH LEVEL AQUEDUCT LINE.

Preliminary Line of High Level Aqueduct.

The High Level Aqueduct, as originally designed, was a structure starting from a point on the Hudson River, a few miles north of Poughkeepsie,

* Soil entirely or almost entirely removed from bottom.
† Estimated.

called Greer Point, and running in a generally southerly direction through Dutchess, Putnam and Westchester counties to a terminal reservoir near the city line at Yonkers; the supply being pumped from the Hudson River and filtered. The elevation of the terminal reservoir was to be 300 feet above the sea level.

In running this preliminary line a traverse was carefully chained for its entire length, excepting through the mountainous and broken country between Tompkins' Corners and Hortontown, where measurements were taken by stadia methods. This traverse was staked at every 100 feet, and levels were taken at each stake and intermediary points, wherever necessary.

Careful lines of benches were run to check the traverse at intervals of about a mile wherever possible, or at points where roads cross the line of aqueduct, and all levels were tied with the bench levels of the New Croton Aqueduct and the United States Coast and Geodetic Survey. All angular work in this traverse was carefully performed and connected by directly measured lines or triangulated connections with the triangulation stations of the United States Coast and Geodetic Survey.

By using these triangulation points as a base, the line has been adjusted and checked so that it has been possible to lay out the whole system by rectangular co-ordinates and establish the geodetic position of every point.

The measurement of the base line traverse was kept within a limit of accuracy of about 1 in 500, but by means of the frequent checks and ties that were made with the geodetic triangulation points, the line has been so adjusted that the possible limit of actual error in its entire length will probably fall within a maximum of 1 in 2,500.

Using this measured and leveled traverse as a base, side topography was taken by means of hand levels, and contours were plotted. This topography was used only for a preliminary study of the location, and for making such preliminary estimates of cost as were submitted from time to time during the year.

Later in the season, as the general scheme of supply was developed from investigations and surveys made in other quarters, the advantage of a gravity supply from the watersheds on the east and west sides of the Hudson River became apparent, and the necessity arose of modifying the original aqueduct design in accordance with the changed conditions, and laying out a line on the basis of final location.

Final Deduction of Governing Elevations and Gradients.

The determination of the elevations of governing points and the gradients of aqueduct line were obtained by an exhaustive study of the relative costs of the distributing reservoir at Hill View, the cost of aqueduct work at various gradients, the cost of the filter plant at Stormville, and the Stormville Reservoir, the Billings Reservoir and the Hibernia Reservoir, built at different elevations.

All of the designs of these structures enter intimately into the general study of elevations and gradients, and are interdependent. A final determination was reached which placed the elevations as follows:

Hill View Reservoir, ordinary high water line	295.0
Stormville filters, maximum flow line below filters	331.0
Stormville filters, maximum flow line above filters	340.0

The gradients of the aqueduct are as follows:

For all cut and cover work and tunnels, a gradient of	.0001156
For all steel pipe work, a gradient of	.00046

—with an additional .2 of a foot added at each siphon for loss of head at entry and exit.

These elevations and gradients only refer to the aqueduct between Hill View Reservoir and Billings Reservoir.

The gradients of the aqueduct between the Billings Reservoir and the Ashokan Reservoir have been taken as follows:

For cut and cover aqueduct and tunnels	.0002
For steel pipe siphon	.0015

Final Location.

These fundamental points being determined, the next step was carefully to retrace in the field the entire line, and to take good, close topography over a strip of country of sufficient width to afford full opportunity to make a close study of the nature of the location, to show all rocks, streams, swamps, buildings, roads and railroads within reasonable distance, and to tie all of this work to the base line already previously located.

Numerous alternate lines that showed possibilities of a better location were followed and carefully surveyed, and the entire work was plotted on a scale of 200 feet to the inch. This plotting has required five large rolled sheets, each 30 feet in length, or a total of 150 feet of mounted paper, and on these sheets the whole location has been carefully mapped and inked.

With this plan completed it has been possible to lay out a final location, which is shown by a green line on the plans. This location is the result of a careful study of the relative economy and advantages of the shortest possible route combined with the avoidance of natural obstacles difficult and expensive to surmount.

A profile of the entire line was projected from the contour plan, and the estimate of quantities was worked from the profile.

The work of estimating was done by the method of centre line cut and fills, corrections being applied to all side-hill work for the increase in quantities caused by the slopes. The quantity for every 100 feet of the line has been gone into in detail, giving the exact amount of masonry, earth and rock excavation, borrowed earth, overhaul, etc., and all culverts, bridges, steel pipes, blow-offs, siphon chambers, manholes, farm crossings, road and railroad crossings, and all special structures have been estimated.

The methods used in this work are strictly comparable with those used in preliminary estimates for location of the Nashua and Weston aqueducts, and although the scope of the work on this aqueduct has been enormously greater than on both those aqueducts combined, and the time and means available have been much less, the results obtained are, for all practical purposes of preliminary lay-out, of equal value to the more costly work performed in the location of the other two aqueducts.

The general location of this line is undoubtedly satisfactory, and the estimates of cost are close approximations to the truth. It is unnecessary to state that all the problems of location are not finally settled by this survey; in many instances it was found as the work of location advanced that a great number of promising schemes developed which offered almost sure prospects of a better location; but these places are in general mere local modifications of the line. Although it will be necessary to follow up these alternate routes before construction is started, yet at this juncture it was found necessary to pass them by through lack of means and time to complete their study.

Experience in previous work of this class shows that these minor modifications are generally best settled immediately before construction, when opportunity and means exist for a final threshing out of details.

The estimate as it stands is on a definite line carefully examined for its entire length with liberal allowances made for unit prices of work. This aqueduct can undoubtedly be built for the sum estimated, and the inevitable tendency of all future modifications will be to shorten the length of the line by substituting certain tunnels for portions of the cut and cover aqueduct, and to reduce the cost. The final location of the aqueduct extends from Hill View Reservoir to Billings Reservoir, a total distance of 300,800 feet.

North of Billings Reservoir the surveys were continued for a total length of 19,000 feet to a point near Rochdale Mills, about 2 miles south of Pleasant Valley on the Wappinger Creek. This line is part of the location of the 400 million gallon aqueduct between Billings Reservoir and the Ashokan Reservoir on the Esopus. No final location has been worked out in detail north of the Billings Reservoir.

The part of the line between Rochdale and the Ashokan Reservoir has been carefully examined on the ground and reconnoitered for its entire length, and the location laid on the Geological Survey maps.

The length of this line has been carefully checked and corrected for the increase of cost due to curvature of line, and estimates of cost for the different classes of work have been reduced to a basis comparable with the finally located line south of Billings.

Value of Estimate of Aqueduct North of Billings Reservoir.

The value of a preliminary estimate prepared in this way is out of all proportion to the amount of work spent in its preparation, and there is no doubt as to a small percentage of error in the general results obtained.

Value of Estimate North of Billings Reservoir.

As an example of the accuracy of this class of estimate, that of the main aqueduct south of Billings Reservoir, submitted September 1, which was compiled in this way, was as follows:

Aqueduct from Hill View Reservoir to Stormville Reservoir—	
Cut and Cover Aqueduct, 218,700 feet, at $53	$11,591,000
Tunnel, 66,400 feet, at $77.75	5,162,600
Steel pipe (3-10-foot pipe), 16,280 feet, at $120	1,953,600
Real Estate	401,700
Aqueduct from Stormville Reservoir to Billings Reservoir—	
Cut and Cover Aqueduct, 28,000 feet, at $50.20	1,405,600
Tunnel, 7,100 feet, at $74	525,400
Real Estate	48,000
Total	$21,087,900

FINAL ESTIMATE OF SAME WORK.

Aqueduct from Hill View Reservoir to Billings Reservoir—	
Cut and Cover work, 187,100 feet, cost	$9,215,760
Average cost per foot, $49.26.	
Tunnel, 100,000 feet, cost	9,110,900
Average cost per foot, $91.11.	
Steel pipe (1/10-foot pipe), 13,700 feet, cost	726,750
Average cost per foot, $53.05.	
Real estate	492,130
	$19,545,540
To make a fair comparison with the preliminary estimate add:	
By-pass through filter, 6,000 feet	300,000
2 lines of 10-foot steel pipe, 13,700 feet	1,370,000
	$21,215,540

It will be seen that the difference in totals between these estimates is very little, although the details are quite dissimilar.

The gradients and sizes of the final aqueduct design are different from those of the preliminary.

	PRELIMINARY ESTIMATE.	FINAL ESTIMATE.
Cut and cover work—Gradient	.000135	.000115
Cut and cover work—Average inside diameter	18.0	18.75
Average cost per foot	$53 00	$49 26
Tunnel work - Gradient	.00021	.000115
Tunnel work—Average inside diameter	15.6	17.0
Average cost per foot	$77 75	$91 11
Steel pipe-work gradients	.0004	.00046
Diameter	10.0	10.0
Average cost per foot	$40 00	$53 05

The Cut and Cover work was found to be actually less in cost than computed in the preliminary estimate, although the section was slightly increased.

The tunnel work was found to be $13.36 more per foot on account of the increased size of section, and to provide for extra expensive work in the long tunnel north of Tompkins' Corners.

The steel pipe work was found to be $13.05 per foot more, almost wholly on account of the costly steel pipe bridge crossing of the Croton River, which had not been provided for in the preliminary estimate.

Yet in spite of the final modifications of better location, shorter line, and substitution of tunnel work for cut and cover in many places, the estimates of the entire line agree within $127,640, or within a limit of accuracy of less than 1 per cent. of the entire cost.

Division of High Level Aqueduct.

For general purposes of convenience, the aqueduct has been divided into four great divisions as follows:

The First Division extends from Hill View Reservoir to the south side of the Croton River.

The Second Division extends from the south side of Croton River to the north end of the long tunnel near Hortontown.

The Third Division extends from the north end of the long tunnel to the east side of the Hudson River.

The Fourth Division extends from the east side of the Hudson River to the western extremity of the line.

Sections.

The finally located line for ease in handling has been further sub-divided into sections of approximately a mile in length, so arranged that the different classes of work are segregated as much as possible. These sections form convenient units for classification and pricing, and are also suitable sub-divisions for individual contracts whenever the work may be put under construction.

Adjustment of Prices.

The unit prices used in this estimate have been adjusted to suit the particular requirements of each section, due allowance being made for the nature of the material to be excavated, the difficulties of handling and the length of haul, and the accessibility of the work from the nearest highways or railroads.

Right of Way.

The standard minimum width of aqueduct right-of-way is 100 feet, with extra width in spceial cases as required for high embankments, deep cuts and special structures, and allowance for the small parcels of land which inevitably must be taken to secure amicable settlements with land-owners. It is estimated that the average width of the right-of-way will be 140 fee.

The value of the lands through which the aqueduct passes varies from a few cases of fair residential properties worth from 10 cents to 15 cents per square foot to rocky hillsides of a market value not exceeding $5 to $10 per acre. The prices of real estate even in farming districts vary somewhat in a ratio governed by the distance and accessibility to the city; much of the land in the vicinity of the city being held for future developments at a high price.

The average cost of land in Westchester County is decidedly more than in any of the counties to the north. The following rates of value have been assigned to the aqueduct right-of-way for cut and cover work and steel pipe work:

COST OF AQUEDUCT RIGHT OF WAY.

STATION.	COST OF LAND PER ACRE.	COST PER LINEAR FOOT OF AQUEDUCT.
10 - 150	$930 00	$3 00
150—770	775 00	2 50
770—1580	620 00	2 00
1580—End	465 00	1 50

The cost of land for tunnels has been taken at one-half the price per linear foot of other work.

FINALLY LOCATED LINE.

(South of Billings Reservoir.)

The various classes of work are as follows:

Cut and Cover Masonry Aqueduct	187,100	feet
Tunnel	100,000	"
Steel pipe siphons	13,700	"
Total length bet. Hill View Res. and Billings Res.	300,800	"

—(exclusive of by-pass through the filters at Stormville.)

CUT AND COVER PORTIONS SOUTH OF BILLINGS RESERVOIR.

The general design of the sections is in accordance with the considerations and conclusions set forth in Appendix III., with the following dimensions:

The maximum inside height	18.5	feet.
The maximum inside width	19.0	"
The depth of water at maximum flow line	17.6	"
Wetted perimeter	53.1	"
The maximum inside area	280.7	sq. feet.
The area of waterway at maximum flow line	276.3	"
Hydraulic mean radius	5.2	"

Capacity.

The coefficient C used in computing capacity in the formula, *Velocity* $= C \sqrt{radius \times slope}$, is for new clean aqueduct, 146, and for aqueduct foul and slime-coated under ordinary conditions of use, 128.

The actual carrying capacity of the aqueduct is based on the latter conditions.

The capacity of the aqueduct in gallons per 24 hours, and velocity of flow are as follows :

Depth.	Clean Aqueduct.		Foul Aqueduct.	
	Velocity.	Discharge.	Velocity.	Discharge.
18 5........	3.68	614,000,000	2.96	538,000,000
17.6......	3.58	640,000,000	3.14	561,000,000
14.8........	3.38	586,000,000	4.23	514,000,000

Description of Section.

The Cut and Cover portions are designed to be wholly of concrete masonry.

It is proposed for purposes of estimate to introduce complete vertical joints through the entire structure at intervals of about 50 feet, to minimize any danger from temperature or shrinkage cracks, these joints being filled with metal water-stops to prevent leakage.

ASSUMPTIONS AS BASIS OF ESTIMATES OF COST.

The main bulk of the side walls and invert are of Portland cement concrete, mixed in proportion of 1 cement to 10 of other material.

A side lining of 6 inches of Portland cement concrete in proportion of about 1 to 5 to be deposited at the same time as the side walls are built.

An arch of Portland cement concrete in proportions of 1 cement to 7 of other materials.

A heavy surfacing of Portland cement mortar applied in two coats to the surface of the invert.

The reasons given for the adoption of this section are as follows:

(1) The entire Portland concrete type offers promise of greater permanency and strength than the combination types of aqueduct that have been hitherto built.

(2) This type is the most economical to construct.

(3) This type may be built almost wholiy by common labor and hence construction is least likely to be interrupted by strikes or labor troubles.

Much work was done in investigating the adaptability of a concrete-steel aqueduct section, but not sufficient to reach final conclusions. This investigation should be completed before actual construction is begun.

Types of Masonry Sections.

The varying conditions of work encountered on the line have required the following specially designed types of masonry sections, each with its own special modifications to suit local peculiarities.

The quantities of masonry for each of the types are as follows:

Classes of Masonry.	Type A (dry earth).	Type B (wet earth).	Type C (embankment).	Type D (rock).
Concrete 1 to 10	3.80 cu. yd.	5.38 cu. yd.	4.49 cu. yd.	1.89 cu. yd.
" 1 " 7	1.28 "	1.54 "	1.28 "	1.28 "
" 1 " 5	0.36 "	0.36 "	0.36 "	0.36 "
Gramolithic Surfacing	2.40 sq. yd.	2.40 sq. yd.	2.40 sq. yd.	2.40 sq. yd.

Grading.

In the grading estimates it has been provided that all earth hauled to distances exceeding 1,500 feet shall be classed as borrowed earth and paid for at an additional rate.

An average of two-thirds of the bulk of the masonry is estimated as obtained from material excavated in the trench.

All embankments will be faced with a thickness of about 1½ feet of loam, which will be obtained from the surface of the aqueduct excavation, placed in separate spoil banks, and rehandled.

All embankments under masonry will be built in 3-inch layers, wetted and rolled with grooved rollers to a level of 1 foot above the invert, afterward being re-excavated to the true grade line of the invert.

All boulders exceeding ½ cubic yard in volume will be paid for as rock excavation.

In special cases where the aqueduct passes through valuable estates and residential property, the trenches will be entirely refilled to their original level and sodded.

All roads crossing the aqueduct will be rebuilt or relocated, if necessary, at gradients not exceeding 4 in 100 wherever possible, nor exceeding the present gradients of the roads.

Earth excavation is estimated to a bottom width 2 feet greater than the masonry section and as if excavated with side slopes of 1 to 1.

Earth embankments will have a top width of 15 feet, with side slopes of 1¾ horizontal to 1 vertical.

Culverts.

The minimum size of culverts used is a 20-inch vitrified pipe.

Culverts have been estimated for, wherever necessary, of the size required, and at maximum intervals of not more than about 2,000 feet. All sizes up to 30-inch diameter are vitrified pipe laid in Portland concrete.

The sizes of the openings allowed for in the estimate have been liberal.

Cut and Cover Portion North of Billings Dam.

Description.

This portion of the work has been laid out with gradient of 1 in 5,000, and has been estimated for 300 and 400 million gallons capacities per day.

Dimensions.

The dimensions and capacities of the structure are:

	For 300 Million Gallon Aqueduct.	For 400 Million Gallon Aqueduct.
Maximum inside height	13.42 feet	15.17 feet
" " width	14.00 "	15.67 "
Depth at maximum flow line	12.72 "	14.37 "
Total inside section area	147.5 square feet	187.0 square feet
Inside section area below maximum flow line	145.0 " "	183.8 " "
Wetted perimeter " " " "	38.9 feet	43.7 feet
Hydraulic mean radius " " " "	3.720 feet	4.206 feet
Maximum capacity in mil. gals. per day (foul aq.).	330	441

Quantities.

The quantities in the dry earth type of each of these aqueducts are:

	For 300 Million Gallon Aqueduct.	For 400 Million Gallon Aqueduct.
Earth excavation	10.1 cubic yards	12.2 cubic yards
" borrow	2.5 " "	2.7 " "
Concrete masonry 1-10	2.31 " "	2.68 " "
" " 1-7	0.84 " "	0.99 " "
" " 1-5	0.26 " "	0.30 " "
Granolithic	1.8 square yards	2.0 square yards

Cost.

The cost of an ideal section of these aqueducts is $27.48 and $32.15 per foot respectively. This cost has been increased 30 per cent. to bring it to the cost of completed work. This ratio has been well established by previous work of a similar character south of Billings Reservoir.

TUNNELS.

The portions of the aqueduct south of Billings Reservoir that are in tunnel have a total length of 100,000 feet.

Description.

The general design of the tunnel sections is shown in Appendix III.

The general principle followed as far as possible in the design is that of a tunnel with concrete side lining and invert, but without an arch wherever the rock is of sufficient firmness and durability to stand without support.

It was found to be cheaper to build a tunnel with concrete side lining even in firm rock than without, for hydraulic considerations alone.

The design is such that an arch may be added subsequently, without any modification of the remainder of the section, if conditions should require one.

The following four types of tunnel have been considered in the estimates:

Class of Work.	Type 1. For Firm Rock (Side Walls and Invert Only).	Type 2. For Doubtful Rock (Side Walls Invert and Arch).	Type 3. For Unsound Rock (Side Walls and Invert with Heavy Timbered Arch).	Type 4. For Earth (Horseshoe Shape with Heavy Timbered Arch).
Tunnel excavation heading	3.50 cu. yd.	3.50 cu. yd.	3.50 cu. yd.	Quantities uncertain. The cost of this type has been taken at 25% more than Type 3.
" " bench	8.71 "	8.71 "	10.03 "	
Concrete 1 to 10	2.14 "	2.14 "	2.21 "	
" 1 to 7	....	0.82 "	1.36 "	

In estimating the cost of tunnels the following assumptions have been made of the lengths of the different classes of work that are likely to be encountered.

In the majority of cases surface indications were so clear that the nature of the rock and earth was easily ascertained.

Station.	Nature of Rock.	Lengths in Feet.			
		Type 1.	Type 2.	Type 3.	Type 4.
429 to 453	Mica-schist and earth.......	.....	1,200	600	600
982+50 to 1002	Mica-schist and gneiss......	600	950	400	....
1062 to 1142+50	Mica-schist and earth.......	1,000	5,050	1,000	1,000
1212 to 1230+50	Mica-schist................	.....	1,400	450	....
1336 to 1367+50	Granite or gneiss	2,000	750	400	....
1376 to 1388	Mica-schist................	.....	900	300	....
1391+50 to 1402+50	Mica-schist................	.....	850	250	....
1406+50 to 1446	Mica-schist and earth.......	.....	2,750	900	300
1462+50 to 1489	Mica-schist or diorite.......	800	1,400	450	....
1576 to 1766	Gneiss, earth and granite....	11,000	4,000	2,000	2,000
1951+50 to 2409	Gneiss....................	28,550	11,500	5,700	....
2844 to 2929	Shale.....................	.....	6,400	2,100	....
2947 to 2951+50	Shale.....................	.....	300	150	....
	Totals.................	43,950	37,450	14,700	3,900

The lined tunnel through rock will have the following dimensions:

Maximum inside height..............................	18.50 feet.
Maximum inside width..............................	16.50 "
Area of maximum waterway..........................	279.3 sq. feet.
Area of waterway at depth of 17.6..................	273.5 "
Wetted perimeter at depth of 17.6..................	52.3 "
Hydraulic mean radius at depth of 17.6.............	5.23 "

NOTE.—17.6 feet is the depth of the maximum flow of the cut and cover section.

Capacity.

The coefficient C used in computing the velocity with the above values of R. is 128 for foul aqueduct, the same as that used for cut and cover sections.

The reasons for this selection may be summed up as follows:

It is expected that this tunnel, when clean, will have a coefficient of flow of about 135, as compared with a coefficient of 146 for the clean cut and cover aqueduct.

" The superior hydraulic qualities of the cut and cover work are due to the greater facilities for performing first-class masonry work in open trench in the light of day.

"It has been found that the impairment of flow is much greater in the smoothly surfaced cut and cover sections than in the rougher tunnel sections, and the ultimate results of fouling will be that both sections will probably be reduced to the same conditions of efficiency.

The capacity of the lined tunnel is as follows:

When Flowing at Depth of	Velocity (Feet per Second.)	Discharge (Gals. per 24 Hours.)
14.8 ft. (8/10 full depth)	3.22	485,000,000
17.6 " (Approx. max. capacity)	3.07	543,000,000
18.5 " Full	2.92	527,000,000

TUNNELS NORTH OF BILLINGS RESERVOIR.

Location and Description.

The location, length and description of these tunnels are as follows:

Station.	Length.	Description.
3738 to 3780+30	4,230	Tunnel through mica-schist and shale.
3909 to 3938	2,900	" " " " "
4724 to 4901	17,700	Tunnel through North River blue stone.

Dimensions and Capacity.

The tunnels have been estimated for capacities of 300,000,000 and 400,000,000 gallons per day; the dimensions and capacities are as follows:

	300 m. g. aq.		400 m. g. aq.	
Max. inside height	13.42 feet.		15.17 feet.	
" " width	12.25 "		13.17 "	
Area of max. waterway	150.4 sq. feet.		185.0 sq. feet.	
" waterway (maximum capacity)	147.0 "	*	180.4 "	†
Wetted Perimeter "	38.3 feet.	*	42.2 feet.	†
Hydraulic Mean Radius "	3.83	*	4.275	†
Capacity in mil. gals. per day "	338	*	436	†

* At depth of 12.72 ft. (max. capacity). † At depth of 14.37 ft. (max. capacity).

Quantities.

The quantities in these tunnels per foot are:

	300 m. g. aq.	400 m. g. aq.
Tunnel excavation, Heading	3.5 c. y.	3.5 c. y.
" " Bench	3.5 "	4.9 "
Concrete Lining, invert and side walls	1.58 "	1.81 "
" " Arch	0.58 "	0.58 "

Steel Pipes.

AQUEDUCT SOUTH OF BILLINGS RESERVOIR.

The steel pipe work required for inverted siphons between Hill View Reservoir and Billings Reservoir is as follows:

Station.	Location.	Length.
76 to 151+50	Bryn Mawr	7,550 feet.
251 to 259+50	Near Scarsdale	850 "
521 to 523+50	" Elmsford	1,250 "
769+50 to 789	" Neperan	1,950 "
1292 to 1313	At Croton Lake	2,100 "
	Total	13,700 feet.

Manufacture.

The methods of building the large diameter pipe that will be required may be divided into two classes:

(1) Shop construction, including all work of cutting, punching, riveting, coating and testing, the completed pipe to be shipped to the field in convenient lengths of about 30 feet, and there laid in place and riveted together.

In this class of work the limiting size of pipe will necessarily be the largest that can be shipped by rail. This size has been found to be 10 feet in diameter, in lengths of about 30 feet.

(2) Field construction, in which the whole or a very large part of the work of building the pipe is performed in the field, the parts being assembled and riveted in the trench.

In this case it is possible to perform a large portion of the work at the shops; such as cutting painting and punching the plates, and also perhaps a considerable part of the riveting. The coating in this case must be performed in the trench and applied as a paint to the cold steel.

With this method of construction the pipe may be built with much larger diameters than in the first case, and the cost of freight will be materially reduced.

Comparison of the Two Methods.

The economy of the field-built pipe is apparently high. Two lines of 11.7-foot diameter pipe would be sufficient to carry the same quantity as three lines of 10-foot diameter pipe, both with the adopted gradient of .00046.

The saving in the cost of metal, manufacture and grading is markedly in favor of the two large pipes over the three smaller pipes, but in spite of the apparent economy it has been considered expedient to give the preference to the shop-built pipe for the following reason:

The advantage of dipping the pipe vertically when free from rust and scale into a hot bath of asphalt coating is so great a factor in increasing the life of the pipe that it has been considered sufficient to outweigh the particular economic advantages of the pipe built in the field.

Cost of Shop-built Pipes.

With the choice then restricted to the different sizes of shop-built pipes, the most economic arrangement and size of this class of pipe is shown in the following tabulation:

Tabulation of Costs and Loss of Head for 500 Million Gallon Aqueducts.

No. of Lines of Pipe.	Diameter in Feet.	Cost per Foot.	Friction Head in 10,000 ft.
3	8	$87	13
3	9	106	7
3	9½	116	5½
3	10	127	4
4	8	114	7½
4	9	139	4
4	9½	152	3
4	10	165	2½
5	7	124	9½
5	8	142	5
5	9	173	2½
5	9.5	192	2
5	10	206	1½

In preparing the above tabulation of costs, the pipes are estimated to be of sufficient thickness for heads up to 150 feet. The ultimate tensile strength of steel has been taken at 60,000 pounds per square inch, with a factor of safety of 5.

An extra allowance of ⅛ of an inch thickness has been allowed to provide for the future possible corrosion.

Thickness and Weight.

The thickness of plate for 10-foot diameter pipe under different heads, and the corresponding weights per foot of finished pipe are as follows:

Pipe built in alternate large and small courses with lap-joints for thicknesses less than ¾-inch, and with projecting rivet-heads.

Thickness.	For use under Heads up to	Finished Weight per Foot.
½ inch	145 feet.	712 pounds
$\frac{9}{16}$ inch	168 "	801 "
⅝ inch	191 "	890 "
$\frac{11}{16}$ inch	217 "	979 "
¾ inch	240 "	1120 "

Cost of Steel.

The cost of steel plate suitable for these pipes has during the past eleven years varied between 1.08 cents per pound and 3 cents per pound, for plates delivered at the water front in New York or Philadelphia.

The actual fluctuations during the past eleven years are as follows:

Cost of Steel Plates at Tide Water, Philadelphia and New York, in cents per lb.

Year.	Maximum.	Minimum.	Average.
1893	1.85	1.45	1.70
1894	1.42	1.20	1.29
1895	1.95	1.20	1.49
1896	1.45	1.23	1.36
1897	1.20	1.08	1.15
1898	1.27	1.08	1.19
1899	3.00	1.35	2.35
1900	2.38	1.21	1.69
1901	1.78	1.55	1.71
1902	2.10	1.78	1.94
1903	2.10	1.78	1.86
Average for 11 years			1.61

The present price of steel plate is about 1.08 cents. In view of the fact that lower prices are likely to prevail in the immediate future and that the average during the past eleven years has been only 1.61 cents, and that during that period it rose but once above 2 cents for a longer period than twelve months, it appears safe and reasonable to allow a price of 2 cents per pound for plates at New York or Philadelphia. This price has been used in the estimates.

In the foregoing estimate of costs of finished pipe the cost of grading has been included, and the entire cost of a completed pipe has been compounded and reduced to a present value on the basis of 3 per cent. compound interest, assuming that each separate pipe would only be built when the future increase of consumption called for its construction.

In this matter of compounding and reducing to a present value, the advantage will lie with the smaller diameter pipes of which so large a proportion of cost may be deferred.

It will be seen that, in spite of this fact, the advantage in economy lies distinctly with the larger diameters.

Feasibility of Building 10-Foot Pipes.

With reference to the feasibility of building a pipe of this diameter, it may be noted that large quantities of 18-foot diameter pipe ⅝ inch thick were recently laid at Niagara Falls for penstocks, and that no trouble has been found through distortion of this pipe. The crown of the pipe was observed to settle less than 1 inch after a filling of 4 feet of earth was completed over the top of the pipe.

In the case of this 18-foot pipe there were four longitudinal seams, and the pipe was painted with carbonizing coating in the trench.

The chief difficulty to be met with in the case of the proposed 10-foot shop-built pipe is the danger of injury to the coating in handling the pipe in the trench.

It has been found to be quite feasible to handle pipe of 7½ feet diameter in lengths of 30 feet and weighing 8 tons per length without injury to the coating, and from the experience gained in this matter it has been judged to be easily within the limits of reason to reckon upon being able to handle this pipe in lengths of 30 feet, weighing 10½ tons, and place it in the trench without material injury.

It is obvious that the process of hauling and skidding must be performed with especially designed apparatus, and the refilling must be done with care, and all large stones kept from contact with the pipes.

This pipe has been estimated to be built up of alternate large and small courses, with two longitudinal double riveted seams.

The coefficient of flow for this style of pipe with projecting rivet heads has been taken as 105.

It is probable that in the spring of 1904 extremely valuable data will be available for more complete study of the flow of water through these pipes, from the gaugings that will be taken of the flow through the new 90-inch pipe of the Weston Aqueduct.

Countersunk Rivets.

There is no doubt that a pipe could be built with circular butt joints and with countersunk rivet heads on the inside that would have a much superior hydraulic surface to the one estimated on.

By using this method of construction, the coefficient of flow will no doubt be much increased, in which case the inside diameter may be reduced materially for the same delivery and at the same gradient.

It has been alleged by a prominent firm of pipe builders that countersinking the rivets would add nearly 50 per cent. to the cost of riveting, and that it would be much more difficult to make tight work.

The question of a choice between these two methods of pipe building is worthy of a careful study, and the solution may be that in any future contracts for pipes of this class, both styles of pipe will be specified and alternative tenders received from contractors.

Cost of Pipe.

The cost of building these pipes at the shops in lengths of about 30 feet, dipping each length vertically into an asphalt coating, inspecting, testing, transporting and setting in place in the trench, have been estimated at an average of 3 cents per pound; adding the cost of the plates at 2 cents per pound will give a total of 5 cents per pound for the finished pipe in place.

This price has been carefully checked by a comparison with the cost of this class of work on a 7½-foot pipe for Weston Aqudeuct.

The contract price of that pipe per pound and the current price of steel plate at the time that contract was awarded are as follows:

WESTON AQUEDUCT 7½-FOOT STEEL PIPE.

Weight of finished pipe, per foot	500 pounds.
Cost of steel plate, per pound	1.8 cents.
Cost of manufacturing, transporting, testing and setting in place	2.2 "
Total cost per pound of finished pipe	4.0 cents.

The location of all the proposed steel pipes is within short hauling distance of railroads, and the roads are in a fairly satisfactory condition, so that the cost of hauling will be a small proportion of the entire cost, hence there is every reason to suppose that the cost of this work will fall well within the limits of the estimate.

CAST-IRON PIPE SIPHONS.

The crossings of the Hudson River, the Esopus and Rondout creeks have been estimated as being made by means of 60-inch cast-iron pipe, each one having a capacity of about 100 million gallons per day, with a hydraulic gradient of about 5 in 1,000.

This pipe will be laid either in tunnel under the river or in a trench dredged out of the river bed.

Perhaps it should be stated that the fact that this class of pipe has been successfully laid in other places under similar conditions was an important factor in determining the selection of cast-iron pipe for this estimate. The cost of this work was taken well on the safe side, viz., $50 per foot for each pipe laid.

It is probable that a more exhaustive study of the problem of these crossings will establish the fact that a steel pipe of large diameter and with a concrete jacket may be used to better advantage and at less cost than the cast-iron pipe.

Cast-iron pipe has also been estimated as being used in crossing the flood plains of the Rondout and Esopus creeks. The reasons are that it will probably be found advantageous to lay the pipes here below the surface of the ground and with a concrete jacket to avoid any possible danger of flotation of the pipe when empty.

TWIN AQUEDUCT BETWEEN STORMVILLE FILTERS AND BILLINGS RESERVOIR.

In order to keep the waters from the western sources separate from those of the eastern sources until they have passed through the filters at Stormville, it may be necessary to build an aqueduct with two separate conduits here.

The design adopted is for a conduit of 400 million gallons capacity to carry the western waters, and one of 250 million gallons for the eastern supply.

Although it may be found possible to defer the building of the second conduit and thus obtain the advantages accruing from deferred payments, yet for structural reasons it is desirable to build both aqueducts as one structure, and it is also more economical to do so by obtaining the full advantage of cheapest design of masonry and a minimum of grading work.

The cost of building these conduits at the same time, or at an interval of several years, is as follows:

Cost of 400 million gallon aqueduct, including such portions of the 250 million gallon aqueduct as are on embankments, and all of the same that are in tunnel, and real estate...	$2,893,374
Subsequent cost of building remaining portions of the 250 million gallon aqueduct..............................	899,292
	$3,792,666
The cost of building the 400 million gallon conduit and 250 million gallon conduit as one structure and at the same time (including real estate)........................	3,584,171
Economy of latter over former design.................	$208,495

Another especial advantage that the latter design presents is that the Billings Reservoir may be constructed at an early date, and its waters brought down to the Stormville Filters separately. In view of the fact that damages for water diversion of the Fishkill Creek must be paid in full at the time the Stormville Dam is built, this is a matter worthy of recognition.

Dimensions and Capacity.

The dimensions and capacity of the proposed aqueduct are as follows:

Cut and Cover Portions.

	400 Mil. Gal. Conduit.	250 Mil. Gal. Conduit.
Maximum inside height........................	16.75 feet.	14.0 feet.
Maximum inside width........................	17.17 feet.	14.33 feet.
Maximum inside area........................	227.5 sq. feet.	159.5 sq. feet.
Inside area below maximum flow line............	224.9 sq. feet.	156.1 sq. feet.
Wetted perimeter below maximum flow line......	48.0 feet.	40.3 feet.
Hydraulic mean radius below maximum flow line..	4.68 feet.	3.87 feet.
Maximum capacity in gallons per day...........	433,000,000	273,000,000
Capacity at ⅞ full depth per day................	398,000,000	252,000,000

Tunnel Portions.

	400 Mil. Gal. Conduit.	250 Mil. Gal. Conduit.
Maximum inside height........................	17.0 feet.	15.1 feet.
Maximum inside width........................	16.0 feet.	12.2 feet.
Maximum inside area........................	247.3 sq. feet.	167.6 sq. feet.
Inside area below maximum flow line............	239.4 sq. feet.	164.5 sq. feet.
Wetted perimeter below maximum flow line......	57.8 feet.	48.3 feet.
Hydraulic mean radius below maximum flow line..	4.14 feet.	3.41 feet.
Maximum capacity in gallons per day...........	433,000,000	270,000,000

Quantities.

The quantities in the ideal sections are:

Cut and Cover Portion, Twin Aqueduct.

Earth Excavation	19.6	cubic yards per linear foot.
Earth Borrow	4.2	" "
Portland Cement Concrete, 1 to 10	4.49	" "
Portland Cement Concrete, 1 to 7	1.84	" "
Portland Cement Concrete, 1 to 5	.65	" "
Granolithic Surfacing	3.94	sq. yards per linear foot.

Twin Tunnel (Arched Lined).

Tunnel Excavation—Heading	3.5	cubic yards per linear foot.
Tunnel Excavation—Bench	13.6	" "
Portland Concrete, Lining 1 to 10	3.63	" "
Portland Concrete, Lining 1 to 7	1.43	" "

The cost of the ideal section of Cut and Cover work for the twin aqueduct is $55.04 per foot.

The cost of the ideal section of Cut and Cover work for the single conduit of 500 million gallons capacity is $41.85 per foot.

The actual cost of the latter for this portion of the line was found to be 117 per cent. of the ideal cost, or $48.94 per foot.

Using the same rate of increase, the actual cost of completed work on the twin aqueduct will be $64.40 per foot.

The actual cost of the twin tunnel is $118.45 per foot, which has been increased to $122 per foot, to allow for the cost of shafts.

Aqueduct Between Billings Reservoir and Hibernia Reservoir.

PROJECT NO. 1.

Under Project No. 1 this aqueduct would require a capacity of 500 million gallons per day, less the supply from the Stormville Reservoir and the Billings Reservoir.

The main aqueduct between Billings Reservoir and Stormville Reservoir has been designed to be of the full size, in order that it may be possible to shut off the Stormville supply at any time if required, in which case it will not be reasonable to consider any reduction in the size of the Billings-Hibernia Aqueduct on account of the Stormville supply.

The reduction on account of the Billings Reservoir will be 24 million gallons per day, so that the net capacity of the Hibernia-Billings Aqueduct should be 500,000,000—24,000,000, or 476,000,000 gallons per day.

Tunnel.

18,400 feet of this aqueduct will consist of a tunnel, which will be wholly through shale rock and will operate under a pressure of about 30 feet head, when the two reservoirs are at High Water Line.

This tunnel has been estimated to be of the same gradient and dimensions as the tunnels on the main line of the aqueduct, although it may subsequently be found preferable to make the tunnel section of the horseshoe type, and of a somewhat smaller diameter. The reduction in cost on account of these modifications, however, will not be material.

A gate chamber will be required at each end of this tunnel to control the flow in cases of emergency, or for repairs, but under ordinary working conditions the flow through this tunnel will be entirely self regulated.

Open Cut.

The open cut is estimated to be excavated with side slopes of 3 horizontal to 1 vertical, except the lower 12 feet, which will have paved slopes of 1¼ horizontal to 1 vertical.

There is no doubt that a large part of this open cut work will be through rock. The estimate, however, has been based on a cut in earth, which is as costly as if the excavation were fully in rock on account of the larger quantities of excavation and the extra paving required for earth work.

Other Possibilities.

There is a possibility that the open cut may be extended for the entire distance between these two reservoirs, by deepening a narrow gorge through which the drainage from Tyrrell Lake flows, and thus substituting open cut work for tunnel work.

This gorge has been surveyed and found to be of an average width of about 200 feet at the bottom, with steep rocky sides and a deep swampy bottom. The maximum cut that would be required is about 70 feet.

While the project of an open cut through this gorge does not at first glance appear as tempting as a tunnel proposition, yet there are strong reasons why it would be more advantageous than the latter.

With an open canal, the need for an overflow and wasteway at the Billings Reservoir might be entirely avoided, the surplus from that drainage area backing up through this canal into the Hibernia Reservoir and wasting at Hibernia Dam.

This would be especially advantageous, as the Billings Dam site does not afford a particularly favorable site for a good wasteway.

This open cut proposition should be thoroughly investigated before a tunnel is built at this point, and careful soundings of the depth of the much and the surface of the bed rock in the gorge should be taken; but in the absence of more definite knowledge, it has been assumed that the tunnel proposition is the better of the two schemes.

UNDER PROJECT NO. 2.

Under Project No. 2, this aqueduct would require a capacity equal to the supplies from the Wappinger and Jansen Kill areas. These supplies are from 200 million gallons to 220 million gallons for a yearly average, but it will be necessary to provide for extra heavy drafts during periods when other supplies are shut off; for this purpose the capacity has been taken at about 300 million gallons per day.

This tunnel will have a gradient of 1 in 5,000, and its dimensions are as follows:

Maximum height, 12 feet 2 inches; maximum width, 13 feet 2 inches; area of inside section, 134.31 square feet; wetted perimeter, 42.03; hydraulic mean radius, 3.20.

If at any time it should be found necessary to obtain the entire supply of 500 million gallons from the Billings Reservoir this tunnel will, at a hydraulic gradient of .0006, be able to pass that quantity through; or, in other words, 500 million gallons per day will flow through this tunnel when the level of the Hibernia Reservoir stands 11 feet higher than the level of the Billings Reservoir, with an average velocity of 5.76 feet per second.

The length of open cut and tunnel are the same under both projects. The reasons for or against an open cut as a substitute for the tunnel apply equally under Project No. 2 as in the case of Project No. 1.

AQUEDUCT FROM SILVERNAILS RESERVOIR TO HIBERNIA RESERVOIR.

General.

As previously described under the heading "Silvernails Reservoir," this design for an outlet from Silvernails Reservoir may be ultimately abandoned in favor of one leading into the Clinton Hollow Reservoir, but under present limitations it was necessary to lay out this line definitely and make an accurate estimate of the most reasonable location. Several alternative routes were projected on the large scale plan of the plain south of Pine Plains, and this route was selected as having more promise of economy than the others.

To locate this route finally it will be necessary to enlarge upon the present surveys considerably, and to take borings and test pits at certain important points; however, it is highly probable that the chosen route which lies through Mud Pond and Stissing Pond, will be found to be the best line for an outlet through this plain, and any further knowledge will tend to show that the aqueduct may be built for lower costs than estimated.

Hydraulic Properties.

The aqueduct is mostly an open canal, with a bottom width of 10 feet and paved side slopes of 1¼ horizontal to 1 vertical, to a total height of 10 feet above the bottom. The ordinary depth of water will be 7 feet, and the gradients are such that with this depth the capacity will be 220 million gallons per day, with a velocity of 2.5 feet per second.

With the water flowing at the level of the top of the paving, the capacity will be 330 million gallons per day, and under these conditions the tunnel would have to be run under a slight head. This, however, would only occur during emergency drafts from the Silvernails Reservoir.

Above the level of the top of the paving there is a berme of 4 feet on each side, and the slopes above are 2 horizontal to 1 vertical, and are faced with 1 foot depth of loam and sodded.

The tunnel is 3,050 feet in length, mostly through limestone rock. The dimensions are:

The maximum inside height..............................	10 feet.
The maximum width......................................	12 "

It is expected that this tunnel will require arching for its entire length.

There are two regulating dams on the line of this aqueduct to hold up the water and retard velocity.

Right-of-way has been allowed for on a liberal basis, as has also all special structures such as gates and gatehouses, highway and railroad crossings, etc.

The estimate of cost for the canal has been based on excavation wholly in earth. No doubt these conditions will be encountered for the greater part of the length, but a rock section has been designed of the same capacity and slope as the earth section. The width of the channel in rock excavation will be about 20 feet at the bottom. The cost of the channel in rock is not appreciably greater than in earth on account of the large saving in grading and paving quantities in the former over the latter section.

AQUEDUCT FROM HIBERNIA RESERVOIR TO CLINTON HOLLOW RESERVOIR.

This aqueduct is only considered in connection with the development of Project No. 1, and has been estimated as being of the full size of 500 million gallons capacity to enable a full draft to be made temporarily from this source if it should be found necessary to shut off the other supplies. The dimension and slope of the aqueduct may be considered as being about the same as that of the main high level line, for the purpose of this estimate.

The tunnel is wholly through firm and solid shale rock which will undoubtedly require a light arch for its entire length. It is probable that little timber support, if any, will be required here. The average cost of this tunnel has been taken the same as that of the main line in corresponding work.

AQUEDUCT FROM CLINTON HOLLOW RESERVOIR TO ASHOKAN RESERVOIR.

This aqueduct is a possibility under Project No. 1, and offers advantages over any other line of aqueduct to the Ashokan Reservoir from the point of view of economy, as it is the shortest possible route between the eastern and western supplies. The following estimates are made on the basis of an aqueduct of 300 and 400 million gallons per day capacity. The dimensions of the structure are as follows:

	300 Mil. Gal. Aqueduct.	400 Mil. Gal. Aqueduct.	Gradients.
Cut and Cover Aqueduct—			
Inside height	13.5 feet.	15.1 feet.	.0002
Inside width	14.0 "	15.6 "	.0002
Tunnels—			
Inside height	13.5 "	15.1 "	.0002
Inside width	12.3 "	13.2 "	.0002
Steel Pipe Siphons—			
Diameter of double line of pipe	7.25 "	8.2 "	.0015
Cast-iron Pipe—			
Number of lines of 60-inch pipe	3	4	.005

Hudson River Crossing.

The crossing of the Hudson River is at a point near East Kingston. The method of crossing proposed is by lines of 60-inch cast-iron pipe, laid in lengths of 48 and 60 feet at a time, by means of divers in a dredged trench in the river bed, or by tunnel under the river. The depth of the river is here about 35 feet.

Esopus Creek.

It is proposed to use cast-iron pipes for the portion of the aqueduct that passes through the flood plain of the Esopus Creek for a distance of 4,500 feet.

This aqueduct line has been carefully examined for its entire length and the nature of the ground noted. The country is favorable for the construction proposed, and it is safe to say that a detailed estimate would show totals of cost lower than those submitted.

Station.	Classification of Work.				
	Cut and Cover, Feet.	Tunnel, Feet.	Steel Pipe, Feet.	Cast-iron Pipe, Feet.	
0– 95	......	9,500	......	......	Clinton Hollow.
95–137	4,200	......	......	.	
137–409	.....	......	27,200	......	
409–451	......	......	......	4,200	Hudson River.
451–565	......	......	11,400	......	
565–610	......	......	......	4.500	Esopus Creek
610–655	......	......	4,500	......	
655–787	......	13,200	......	......	
787–829	......	......	4,200	......	
829–866	......	3,700	......	......	Ashokan Reservoir.
Totals	4,200	26,400	47,300	8,700	

Aqueduct Sections.

The designs of the aqueduct sections for cut and cover and tunnel work are the same as those for the aqueduct from Billings Reservoir to the Ashokan Reservoir.

Reservoirs.

STORMVILLE RESERVOIR—ESTIMATE OF COST.

Main Dam and Two Small Dikes.

Earth Excavation—	
Stripping dam base, 31,700 cubic yards, at 25 cents	$7,925
Trench for core wall, 30,830 cubic yards, at $1	30,830
Wing wall, waste weir, gatehouse, channel, etc., 29,070 cubic yards, at 35 cents	10,175
Rock Excavation—	
Core wall trench, 8,830 cubic yards, at $2.50	22,075
Wing walls, waste weir, etc., 54,530 cubic yards, at $1.50	81,795
Embankment, 686,750 cubic yards, at 40 cents	274,700
Soil dressing, 25,296 cubic yards, at 50 cents	12,648
Gravel facing, 64,620 cubic yards, at 50 cents	32,310
Paving on slopes, 26,200 cubic yards, at $2.25	58,950
Sodding, 9,760 square yards, at 30 cents	2,928
Walk, 3,100 lineal feet, at $1	3,100
Masonry—	
Concrete, 41,180 cubic yards, at $6.70	275,906
Rubble, 20,640 cubic yards, at $5	103,200
Ashlar, 1,770 cubic yards, at $10	17,700
Dimension stone, 686 cubic yards, at $40	27,440
Brick, 373 cubic yards, at $15	5,595
Face work of rubble, 1,030 square yards, at $1.50	1,545
Coping, 627 feet, at $3	1,881
Gate House—	
Superstructure,	20,000
Gates and hoists, nine, 3½ by 5 feet, at $1,500	13,500
Stop-plank grooves, 572 feet, at $3.50	2,002
Stop-planks, 260 feet, at $3	780
Stop-plank lifter,	1,000
Floor plates, 620 square feet, at $1.35	837
Ladder, 433 feet, at $2	866

Pipes—		
48-inch B, 560 feet, at $10	$5,600	
10-inch gauge, 76 feet, at $1.50	114	
Specials, 7 tons, at $60	420	
Connection chamber	6,500	
Landscape work, including keeper's house, stables, shops, etc	20,000	
	$1,042,322	
10 per cent. for engineering and contingencies,. .	104,232	
		$1,146,554

Relocation of Highways.

New Roads—		
10,200 feet, Class C, at $5.50	$56,100	
15,500 feet, Class D, at $4.50	69,750	
4.700 feet, Class E, at $4	18,800	
16,400 feet, Class F, at $3.50	57,400	
750 feet, embankment type, at $15	11,250	
2 arch culverts	20,000	
	$233,300	
10 per cent for engineering and contingencies	23,300	
		256,630

Relocation of Railroads.

Raising level of N. Y., N. H. and H. R. R.—		
1,500 feet of embankment, at $15	$22,500	
3,400 feet of embankment, at $23	78,200	
2,200 feet of embankment, at $11	24,200	
1,800 feet of rip-rap, at $10	18,000	
2,000 feet sidings, at $3	6,000	
1 highway crossing	5,000	
New passenger station at Stormville	5,000	
New freight station at Stormville,	2,000	
	$160,900	
10 per cent. for engineering and contingencies	16,090	
Interference with traffic, etc	30,000	
		206,990

Removal of Soil.

Excavating 645,000 cubic yards of soil, and depositing it in embankments (average haul, 1,200 feet), at 25 cents	$161,250	
Excavating 50,000 cubic yards of sand and gravel for beaches, at 30 cents	15,000	
Removing bodies from two small cemeteries to new site, including cost of new site	20,000	
	$196,250	
10 per cent. for engineering and contingencies	19,625	
		$215,875

Real Estate.

Total area inside taking line, 2,985 acres, at $200 (including all buildings, etc.)	597,000
Reimbursement to towns of Beekman and East Fishkill for taxable property taken	60,000
Sanitary protection of watershed	20,000
Grand total	$2,503,049

BILLINGS RESERVOIR—ESTIMATE OF COST.

Dam.

Earth Excavation—	
Stripping dam base, 13,045 cubic yards, at 25 cents	$3,261
Trench for core wall, 21,605 cubic yards, at $1	21,605
Wing walls, waste weir, gatehouse, channels, etc., 74,540 cubic yards, at 35 cents	26,089
Rock Excavation—	
Core wall trench, 2,657 cubic yards, at $2.50	6,643
Wing walls, waste weir, etc., 29,170 cubic yards, at $1.50	43,755
Embankment, 244,950 cubic yards, at 40 cents	97,980
Soil dressing, 10,320 cubic yards, at 50 cents	5,160
Gravel facing, 26,900 cubic yards, at 50 cents	13,450
Slope paving, 12,490 cubic yards, at $2.25	28,103
Sodding, 3,360 square yards, at 30 cents	1,098
Walk, 2,525 feet, at $1	2,525

Masonry—		
Concrete, 20,870 cubic yards, at $7	$146,090	
Rubble, 23,520 cubic yards, at $5.50	129,360	
Ashlar, 1,408 cubic yards, at $10	14,080	
Dimension stone, 613 cubic yards, at $40	24,520	
Brick, 450 cubic yards, at $15	6,750	
Face work of rubble, 1,105 square yards, at $1.50	1,658	
Coping, 515 feet, at $3	1,545	
Gate House—		
Superstructure	25,000	
Gates and hoists, nine, at $1,500	13,500	
Stop-plank grooves, 602 feet, at $3.50	2,107	
Stop-planks, 420 feet, at $3	1,260	
Stop-plank lifter	1,000	
Floor plates, 690 square feet, at $1.35	932	
Ladder, 480 feet, at $2	960	
Pipes—		
60-inch B, 489 feet, at $15	7,335	
48-inch B, 16 feet, at $10	160	
10-inch gauge, 71 feet, at $1.50	107	
Specials, 26 tons, at $60	1,560	
Connection chamber	22,000	
Landscape work, including keeper's house, stables, shops, etc	20,000	
	$669,593	
10 per cent. for engineering and contingencies	66,959	
		$736,552

Relocation of Highways.

New Roads—		
3,800 feet, Class C, at $5.50	$20,900	
32,400 feet, Class D, at $4.50	145,800	
17,600 feet, Class F, at $3.50	61,600	
1,000 feet, embankment type, at $7	7,000	
1 arch culvert	20,000	
	$255,300	
10 per cent. for engineering and contingencies	25,530	
		280,830

Railroad Alteration.		
1 arch culvert under N. D. and C. R. R.	$15,000	
Removal of Soil.		
Excavating 466,000 cubic yards of soil and hauling same 7,000 feet to shallow flowage bank, at 35 cents	163,100	
Excavating 23,000 cubic yards of sand and gravel for beaches, at 30 cents	6,900	
	$170,000	
10 per cent. for engineering and contingencies.	17,000	
		$187,000
Real Estate.		
Total area inside taking line, 2,415 acres, at $1.50 (including all buildings, etc.)		362,250
Reimbursement to town of Lagrange for taxable property taken		30,000
Sanitary protection of watershed..............................		20,000
Diversion of Jackson Creek.		
Entire cost of small dam and reservoir on Jackson Creek	$60,000	
Channel—		
Earth excavation, 77,240 cubic yards, at 30 cents	23,172	
Loaming slopes, 1,470 cubic yards, at 40 cents	688	
Rip-rapping slopes, 4,590 cubic yards, at $2..	9,180	
1 highway bridge and approaches..........	10,000	
1 highway bridge and approaches..........	7,000	
1 highway bridge and approaches...........	3,000	
Regulating dam	20,000	
	$133,040	
10 per cent. for engineering and contingencies	13,304	
		146,344
Real Estate—Jackson Creek.		
Total area inside the taking line, 84 acres, at $150...........		12,600
Reimbursement to town of Lagrange......................		10,000
Sanitary protection of watershed........................		5,000
Grand total		$1,805,576

HIBERNIA RESERVOIR—ESTIMATE OF COST.

Dam.

Earth Excavation—	
Stripping dam base, 49,197 cubic yards, at 25 cents	$12,299
Trench for core wall, 3,670 cubic yards, at $1.	3,670
Wing walls, waste weir, gatehouse, channels, etc., 50,531 cubic yards, at 35 cents	17,686
Rock Excavation—	
Trench for core wall, 6,285 cubic yards, at $2.50	15,713
Wing walls, waste weir, gatehouse, etc., 155,679 cubic yards, at $1.50	233,519
Embankment, 1,127,664 cubic yards, at 40 cents	451,066
Soil dressing, 28,315 cubic yards, at 50 cents	14,157
Gravel facing, 75,200 cubic yards, at 50 cents.	37,600
Paving on slopes, 25,278 cubic yards, at $2.25	56,876
Sodding, 7,800 square yards, at 30 cents	2,340
Walk, 3,485 feet, at $1	3,485
Masonry—	
Concrete, 35,454 cubic yards, at $6.70	237,542
Rubble, 530,260 cubic yards, at $5	2,651,300
Ashlar, 29,500 cubic yards, at $10	295,000
Dimension stone, 3,850 cubic yards, at $40	154,000
Brick, 800 cubic yards, at $15	12,000
Face work of rubble, 3,800 square yards, at $1.50	5,700
Coping, 910 feet, at $3	2,730
Gate House—	
Superstructure	15,000
Gates and hoists, six, 3½ by 5 feet, at $1,700.	10,200
Stop-plank grooves, 822 feet, at $3.50	2,877
Stop-planks, 406 feet, at $3	1,218
Stop-plank lifter	1,000
Floor plates, 270 square feet, at $1.35	365
Ladders, 822 feet, at $2	1,644

Pipes—		
48-inch B, 246 feet, at $10	$2,460	
10-inch gauge, 142 feet, at $1.50	213	
Specials, 6 tons, at $60	360	
Iron railing, 5,365 feet, at $1.50	8,048	
Landscape work, including keeper's house, stables, shops, etc.	25,000	
Small dike south of the dam	1,700	
Small dike at Willow Bridge	2,000	
	$4,278,768	
10 per cent. for engineering and contingencies	427,877	
		$4,706,645

Relocation of Highways.

New Roads—		
25,000 feet, Class C, at $5.50	$137,500	
57,600 feet, Class D, at $4.50	259,200	
4,200 feet, Class E, at $4	16,800	
20,600 feet, Class F, at $3.50	72,100	
800 feet, embankment type, at $15	12,000	
500 feet, embankment type, at $20	10,000	
1,500 feet, embankment type, at $45	67,500	
1 arch culvert	10,000	
1 arch culvert	15,000	
1 arch culvert	40,000	
	$640,000	
10 per cent. for engineering and contingencies	64,010	
		704,110

Relocation of Railroads.

C. N. E. R. R.

New Roadbed, Right of Way and Track—		
18,500 feet, of Class 1, at $7.50	$138,750	
4,900 feet, of Class 2, at $9	44,100	
25,300 feet, Class 3, at $11	278,300	
400 feet, Class 6, at $120	48,000	
3,000 feet, sidings, at $3	9,000	
59,000 feet telegraph line, at $1	59,000	
10 highway crossings, at $5,000	50,000	

New station at Hibernia.............	$3,000	
New station at Market................	2,000	
New station at Stissing................	4,000	
	$636,150	
10 per cent. for engineering and contingencies	63,615	
Interference with traffic, etc.,......................	50,000	
		$749,765

P. & E. R. R.

New Roadbed, Track and Right of Way—

18,000 feet, Class 1, at $7.50...........	$135,000	
3,800 feet, Class 2, at $9...............	34,200	
10,800 feet, Class 3, at $11............	118,800	
2,000 feet sidings, at $3................	6,000	
32,000 feet telegraph line, at $1.........	32,000	
8 highway crossings, at $5,000.........	40,000	
New station at Market................	2,000	
New station at Stissing................	4,000	
	$372,000	
10 per cent. for engineering and contingencies	37,200	
Interference with traffic, etc..................	30,000	
		439,200

Removal of Soil.

Excavating 712,000 cubic yards of soil from reservoir, and hauling same for an average distance of 1,200 feet, at 25 cents..................	$178,000	
Excavating 39,000 cubic yards of sand and gravel for beaches, at 30 cents..................	11,700	
Removing bodies from two small cemeteries, and providing new cemeteries.................	30,000	
	$219,700	
10 per cent. for engineering and contingencies	21,970	
		241,670

Real Estate.

Total area inside taking line, 9,125 acres, at $250 (inclusive of all buildings, etc.)................................	2,281,250

Reimbursement to towns of Washington, Pleasant Valley, Stanford and Clinton for value of taxable property flooded	$135,000
Sanitary protection of watershed	50,000
Grand total	$9,307,640

SILVERNAILS RESERVOIR—ESTIMATE OF COST.

Dam.

Earth Excavation—	
Stripping dam base, 7,380 cubic yards, at 25 cents	$1,845
Core wall trench, 3,000 cubic yards, at $1	3,000
Wing walls, waste weir, gatehouse, channels, etc., 167,800 cubic yards, at 35 cents	58,730
Rock Excavation—	
Core wall trench, 510 cubic yards, at $2.50	1,275
Wing walls, waste weir, gatehouse, channels, etc., 138,450 cubic yards, at $1.50	207,675
Embankment, 21,910 cubic yards, at 40 cents	8,764
Soil dressings, 110 cubic yards, at 50 cents	55
Gravel facing, 4,010 cubic yards, at 50 cents	2,005
Paving on slopes, 2,010 cubic yards, at $2.25	4,523
Masonry—	
Concrete, 1,340 cubic yards, at $6.70	8,978
Rubble, 198,840 cubic yards, at $5	994,200
Ashlar, 9,160 cubic yards, at $10	91,600
Dimension stone, 1,935 cubic yards, at $40	77,400
Brick, 700 cubic yards, at $15	10,500
Face work of rubble, 6,600 square yards, at $1.50	9,900
Coping, 122 feet, at $3	366
Iron railing, 1,970 feet, at $1.50	2,955
Gate House—	
Superstructure	15,000
Gates and hoists, six, 3½ by 5 feet, at $1,700	10,200
Stop-plank grooves, 717 feet, at $3.50	2,510

Floor plates, 270 square feet, at $1.35	$364	
Ladders, 717 feet, at $2	1,434	
Stop-planks, 353 feet, at $3	1,059	
Stop-plank lifter,	1,000	
Pipes—		
48-inch B, 195 feet, at $10	1,950	
10-inch gauge, 121 feet, at $1.50	182	
Specials, 6 tons, at $60	360	
Landscape work, including keeper's house, stables, shops, etc	25,000	
	$1,542,830	
10 per cent. for engineering and contingencies	154,283	
		$1,697,113

Cut-off West of Main Dam.

Earth excavation, 24,760 cubic yards, at $1	$24,760	
Rock excavation, 2,130 cubic yards, at $2.50	5,325	
Concrete core wall, 8,000 cubic yards, at $6.70	53,600	
	$83,685	
10 per cent. for engineering and contingencies	8,369	
		92,054

Relocation of Highways.

New Roads—		
1,300 feet, Class B, at $7	$9,100	
36,390 feet, Class D, at $4.50	163,755	
11,125 feet, Class E, at $4	44,512	
13,720 feet, Class F, at $3.50	48,020	
330 feet, embankment type, at $5	1,650	
1,030 feet, embankment type, at $40	41,200	
900 feet, embankment type, at $35	31,500	
1,400 feet, embankment type, at $8	11,200	
1 arch culvert	20,000	
1 arch culvert	30,000	
1 arch culvert	15,000	
1 arch culvert	10,000	
	$425,937	
10 per cent. for engineering and contingencies	42,594	
		468,531

Relocation of Railroads.

C. N. E. R. R.—

New roadbed, track and right of way from Jackson Corners to Pine Plains:

3,200 feet, Class 2, at $9	$28,800	
10,100 feet, Class 3, at $11	111,100	
700 feet, Class 4, at $37	25,900	
5,800 feet, Class 5, at $92	533,600	
2,000 feet sidings, at $3	6,000	
21,800 feet telegraph line, at $1	21,800	
4 highway crossings, at $5,000	20,000	
New station at Mt. Ross	3,000	
New station at Pine Plains	5,000	
	$755,200	
10 per cent. for engineering and contingencies	75,520	
		$830,720

C. N. E. R. R.—

New roadbed, track and right of way from Pine Plains to Ancram:

15,900 feet, Class 1, at $7.50	$119,250	
19,300 feet, Class 2, at $9	173,700	
700 feet, Class 4, at $37	25,900	
800 feet, Class 4½, at $57	45,600	
6,600 feet, Class 5, at $92	607,200	
2,000 feet sidings, at $3	6,000	
43,300 feet telegraph line, at $1	43,300	
8 highway crossings, at $5,000	40,000	
New station at Ancram lead mines	3,000	
New station at Ancram	3,000	
	$1,066,950	
10 per cent. for engineering and contingencies	106,695	
		1,173,645
Interference wit htraffic C. N. E. R. R		50,000

P. and E. R. R.—

Rip-rapping slopes of embankment:

1,700 feet, at $10	$17,000	
10 per cent. for engineering and contingencies	1,700	
		18,700

Removal of Soil.

Excavating 580,000 cubic yards soil, and depositing it in embankments (average haul, 1,600 feet), at 30 cents..........................	$174,000	
Excavating 19,000 cubic yards sand and gravel for beaches, at 30 cents.......................	5,700	
Removal of bodies from three small cemeteries and cost of new cemetery.....................	40,000	
	$219,700	
10 per cent. for engineering and contingencies	21,970	
		$241,670
Sanitary protection of watershed..........................		75,000

Real Estate.

Total area inside taking line, 5,321 acres, at $150 (including all buildings, etc.)...............	$798,150	
Reimbursement of towns of Ancram, Pine Plains and Gallatin for loss of taxable property.....	84,500	
		882,650
Grand total.....................		$5,530,083

CLINTON HOLLOW RESERVOIR—ESTIMATE OF COST.

Dam.

Earth Excavation—	
Stripping dam base, 11,790 cubic yards, at 25 cents	$2,948
Trench for core wall, 9,040 cubic yards, at $1.	9,040
Rock Excavation—	
Core wall trench, 1,850 cubic yards, at $2.50..	4,625
Embankment, 437,940 cubic yards, at 40 cents	175,176
Soil dressing, 8,890 cubic yards, at 50 cents..	4,445
Gravel facing, 23,650 cubic yards, at 50 cents.	11,825
Paving on slope, 5,900 cubic yards, at $2.25..	13,275
Walk, 1,000 feet, at $1....................	1,000
Sodding, 4,060 square yards, at 30 cents.....	1,218
Concrete, 14,460 cubic yards, at $6.70.......	96,882

Gate House—		
Including superstructure and appurtenances...	$45,000	
Waste weir	50,000	
Waste channel, 3,750 feet, at $10...........	37,500	
Landscape work, including keeper's house, stables, shops, etc....................	20,000	
	$472,934	
10 per cent. for engineering and contingencies	47,293	
		$520,227

Relocation of Highways.

New Roads—		
53,000 feet, at $4........................	$212,000	
26,000 feet, at $3.50......................	91,000	
	$303,000	
10 per cent. for engineering and contingencies	30,300	
		333,300

Removal of Soil.

Excavating 620,000 cubic yards of soil, and depositing same in embankments, at 25 cents..	$155,000	
Excavting 20,000 cubic yards of sand and gravel for beaches, at 30 cents....................	6,000	
	$161,000	
10 per cent. for engineering and contingencies	16,100	177,100

Real Estate.

Total area inside the taking line, 3,590 acres, at $150.	538,500	
Reimbursement of towns of Clinton and Milan for loss of taxable property..................	76,000	
		614,500
Sanitary protection of watershed..............		20,000
Grand total		$1,665,127

Estimates of Cost of Aqueduct Work.

UNIT PRICES.

The following standard unit prices have been used in all aqueduct estimates for the principal items, the rates being varied to suit local conditions of each section:

	From	To
Earth excavation	$0.35 per cubic yard	$0.40 per cubic yard.
" borrow	0.25 " " "	0.30 " " "
Rock excavation	1.25 " " "	2.00 " " "
Tunnel " Heading	9.00 " " "	9.40 " " "
" " Bench	3.50 " " "	3.90 " " "
Concrete 1-10	5.90 " " "	8.00 " " "
" 1-7	6.60 " " "	9.00 " " "
" 1-5	7.40 " " "	7.80 " " "
Steel pipe laid	0.05 " pound.	0.05 " pound.
Granolithic	0.75 " sq. yard.	0.75 " sq. yard.
Timbering in tunnels	4.00 " foot.	4.00 " foot.
Dry filling in tunnels (over arches)	1.60 " "	1.60 " "
Shaft excavation	120.00 " "	140.00 " "

HIGH LEVEL AQUEDUCT—ESTIMATE OF COST.

In the following tabulations of cost of aqueduct work are included special structures of every description, such as siphon chambers, gate houses, blow-offs, waste weirs, manholes, culverts, road and railroad crossings, farm crossings, etc.

Division 1.

From Hill View Reservoir to South Side Croton River.

Section.	Station.	Length.	Construction.	Total Cost.	Cost per foot.	Remarks.
2	10+00 to 76+00	6,600	Cut and Cover	$346,480	$52 80	Siphon chambers included.
3	76+00 " 151+50	7,550	Siphon	351,200	46 52	" at Bryn Mawr.
4 & 5	151+50 " 251+00	9,950	Cut and Cover	500,450	50 30	" chambers included.
6	251+00 " 259+50	850	Siphon	36,630	43 10	
7	259+50 " 310+00	5,050	Cut and Cover	248,950	49 30	" " "
8	310+00 " 370+00	6,000	" " "	287,510	47 92	
9	370+00 " 425+00	5,500	" " "	263,670	47 94	
10	425+00 " 475+00	2,600	" " "	146,160	56 21	Tunnel in mica-schist and earth.
		2,400	Tunnel	234,160	97 57	

Section.	Station.	Length.	Construction.	Total Cost.	Cost per foot.	Remarks.
11	475+00 to 521+00	4,600	Cut and Cover...	$243,250	$52 88	Siphon chamber included.
12	521+00 " 533+50	1,250	Siphon........	53,580	42 83	" " "
13	533+50 " 600+00	6,650	Cut and Cover...	331,830	49 90	
14	600+00 " 660+00	6,000	" " " ..	304,000	50 67	
15	660+00 " 710+00	5,000	" " " ..	232,110	46 42	
16	710+00 " 769+50	5,950	" " " ..	293,260	49 29	Siphon chambers included.
17	769+50 " 789+00	1,950	Siphon..........	94,010	48 67	
18	789+00 " 841+00	5,200	Cut and Cover...	261,860	50 36	Siphon chamber included.
19	841+00 " 900+00	5,900	" " " ..	259,340	43 96	
20	900+00 " 953+00	5,300	" " " ..	235,870	44 50	
21	953+00 " 1014+00	4,150	" " " ..	208,900	50 34	
		1,950	Tunnel..........	185,830	95 30	Tunnell in mica-schist and gneiss.
22 & 23	1014+00 " 1148+00	5,350	Cut and Cover...	243,000	45 42	
		8,050	Tunnel	727,220	90 34	Tunnel in mica-schist and earth.
24	1148+00 " 1203+00	5,500	Cut and Cover...	251,310	45 70	
25 & 26	1203+00 " 1292+00	7,050	" " " ..	341,820	48 49	Siphon chamber included.
		1,850	Tunnel..........	163,580	88 42	Tunnel in mica-schist.
	Total..........	128,200	....	$6,846,830	$53 40	

Cut and cover work—Total length, 102,350 feet; average cost per foot, $48.85; total cost...........................	$4,999,770
Tunnel work—Total length, 14,250 feet; average cost per foot, $91.99; total cost..................................	1,310,790
Steel pipe work—Total length, 11,600 feet; average cost per foot, $46.23; total cost..............................	536,270
Total construction.........................	$6,846,830
10 per cent. for engineering and contingencies..........	684,680
	$7,531,510
Right of way from Station 10 to Station 1,292.............	297,540
Total first cost............................	$7,829,050
Subsequent addition of two lines 10-foot pipe at siphons......	1,072,540
10 per cent. of latter for engineering and contingencies..	107,250
Grand total	$9,008,840

HIGH LEVEL AQUEDUCT ESTIMATE OF COST.

Division 2.

From South Side of Croton River to North End of Long Tunnel Near Tompkins' Corners.

Section.	Station.	Length.	Construction.	Total Cost.	Cost per foot.	Remarks.
27	1292+00 to 1313+00	2,100	Siphon	$190,480	$90 70	Steel truss pipe-bridge included.
28	1313+00 " 1382+00	3,150	Cut and Cover...	167,640	53 22	Siphon chamber included.
		3,750	Tunnel	310,300	82 74	Tunnel in granite & gneiss.
29	1382+00 " 1450+00	1,150	Cut and Cover ..	60,690	52 78	
		5,650	Tunnel..........	509,290	90 14	Tunnel in mica-schist and earth.
30	1450+00 " 1500+00	2,350	Cut and Cover ..	119,150	50 70	
		2,650	Tunnel..........	229,180	86 48	Tunnel in mica-schist and diorite.
31	1500+00 " 1561+00	6,100	Cut and Cover ..	304,980	50 00	
32	1561+00 " 1650+00	1,500	" " " ..	95,730	63 82	
		7,400	Tunnel..........	664,220	89 76	Tunnel in granite & gneiss.
33	1650+00 " 1698+00	4,800	"	440,680	93 68	Tunnel in granite, gneiss and earth.
34	1698+00 " 1776+00	1,000	Cut and Cover...	56,990	56 99	
		6,800	Tunnel..........	610,590	89 80	Tunnel in gneiss.
35	1776+00 " 1830+00	5,400	Cut and Cover..	268,370	49 70	
36	1830+00 " 1890+00	6,000	" " " ..	299,440	49 91	
37	1890+00 " 1948+00	5,800	" " " ..	314,880	54 31	
38	1948+00 " 2050+00	350	" " " ..	20,340	58 11	
		9,850	Tunnel..........	840,220	85 30	Tunnel in gneiss
39	2050+00 " 2118+00	6,800	"	646,420	95 06	" " "
40	2118+00 " 2182+00	6,400	"	621,370	97 09	" " "
41	2182+00 " 2246+00	6,400	"	634,440	99 13	" " "
42	2246+00 " 2310+00	6,400	"	626,570	97 90	" " "
43	2310+00 " 2414+00	500	Cut and Cover..	33,880	67 76	
		9,900	Tunnel..........	865,710	87 44	" " "
	Total..........	112,200	....	$8,940,560	$79 68	

Cut and cover work—Total length, 33,300 feet; average cost per foot, $52.01; total cost..........................	$1,742,090
Tunnel work—Total length, 76,800 feet; average cost per foot, $91.25; total cost................................	7,007,990
Steel pipe work—Total length, 2,100 feet; average cost per foot, $90.70; total cost.............................	190,480
	$8,940,560
10 per cent. for engineering and contingencies..........	894,060
	$9,834,620
Right of way from Station 1,292 to Station 2,414..........	110,700
Total first cost...........................	$9,945,320
Subsequent addition of two lines 10-foot pipe at all siphons...	300,000
10 per cent. of latter for engineering and contingencies..	30,000
Grand total	$10,275,320

Division 3.

From North End of Long Tunnel near Tompkins' Corners to East Side of Hudson River. Finally Located Line South of Billings Dam.

Section.	Station.	Length.	Construction.	Total Cost.	Cost per foot.	Remarks.
44	2414+00 to 2464+00	5,000	Cut and Cover...	$239,510	$47 90	
45	2464+00 " 2517+00	5,300	" ...	246,730	46 55	
46	2517+00 " 2557+00	4,000	" ...	183,400	45 85	
47	2557+00 " 2600+00	4,300	" ...	196,460	45 69	
Filters.	2600+00 " 2660+00					
48	2660+00 " 2710+00	5,000	" ...	238,750	47 75	
49	2710+00 " 2730+20	2,020	" ..	102,120	50 56	Crossing Stormville Dam.
50	2730+20 " 2789+00	5,880	" ...	292,750	49 79	
51	2789+00 " 2837+00	4,800	" ...	218,790	45 58	
52	2837+00 " 2933+00	1,100	" ...	70,900	64 45	Tunnel in shale.
		8,500	Tunnel..........	751,770	88 44	
53	2933+00 " 2988+00	5,050	Cut and Cover...	268,360	53 14	" "
		450	Tunnel..........	40,350	89 67	
54	2988+00 " 3045+00	5,700	Cut and Cover...	244,900	42 97	
55	3045+00 " 3078+00	3,300	" ...	171,230	51 90	
	Total....	60,400	....	$3,266,020	$54 07	

Cut and cover work—Total length, 51,450 feet; average cost per foot, $48.08; total cost........................... $2,473,900

Tunnel work—Total length, 8,950 feet; average cost per foot, $88.51; total cost................................ 792,120

$3,266,020

10 per cent. for engineering and contingencies.......... 326,600

Total construction $3,592,620

Right-of-way from Station 2414 to Station 3078............ 83,887

Total of finally located line south of Billings Reservoir $3,676,507

Aqueduct North of Billings Dam.

This aqueduct has been estimated both for a capacity of 300 million gallons per day and 400 million gallons per day.

300 Million Gallon Aqueduct.

Cut and cover aqueduct, 52,200 feet, at $36	$1,879,000
Tunnel, 7,130 feet, at $64	456,320
Steel pipe (one, 7.25 feet diameter), 26,970 feet, at $36	970,920
	$3,306,440
10 per cent. for engineering and contingencies	330,640
Total construction	$3,637,080
Real estate	124,100
Total first cost	$3,761,180
Subsequent addition of one line 7.25-foot pipe	970,920
10 per cent. of latter for engineering and contingencies	97,090
Ultimate total	$4,829,190

400 Million Gallon Aqueduct.

Cut and cover aqueduct, 52,200 feet, at $42	$2,192,400
Tunnel, 7,130 feet, at $71	506,230
Steel pipe (one, 8.2 feet diameter), 26,970 feet, at $39	1,051,830
	$3,750,460
10 per cent. for engineering and contingencies	375,050
Total construction	$4,125,510
Real estate	124,100
Total first cost	$4,249,610
Subsequent addition of one line 8.2-foot pipe	1,051,830
10 per cent. of latter for engineering and contingencies	105,180
Ultimate total	$5,406,620

Summary for Division 3.

(With 300 and 400 million gallon aqueducts north of Billings Dam.)

Total of finally located 500 million gallon aqueduct south of Billings	$3,676,507
First cost of 300 million gallon aqueduct, Billings Reservoir to east side of Hudson River	3,761,180
Total first cost, Division 3	$7,437,687
Subsequent addition of second pipe line	1,068,010
Ultimate cost of Division 3	$8,505,697

Total cost of 500 million gallon aqueduct south of Billings	$3,676,507
First cost of 400 million gallon aqueduct, Billings Reservoir to east side of Hudson River	4,249,610
Total first cost of Division 3	$7,926,117
Subsequent addition of second pipe line	1,157,010
Ultimate cost of Division 3	$9,083,127

Division 3.

With Twin Aqueduct between Stormville Filters and Billings Dam.

	First Cost.	Final Cost.
Single Aqueduct from Station 2414 to Station 2600	$980,610	$980,610
Twin Aqueduct from Station 2660 to Station 3078—		
Cut and cover work..32,850 ft. at $64.40.. $2,115,540		
Tunnel.............. 8,950 " 122.00.. 1,091,900		
$3,207,440		
10% for Eng. and Cont....... 320.740		
$3,528,180		
Real estate.......... 55,990	3,584,170	3,584,170
400,000,000-gallon aqueduct from Station 3266 to Station 4129	4,249,610	5,406,620
Grand Total Division 3	$8,814,390	$9,971,400

Division 3.

Same as Above, but with 300-Million-Gallon Aqueduct North of Billings Reservoir.

	First Cost.	Final Cost.
Station 2414 to Station 2600	$980,610	$980,610
Station 2660 to Station 3078	3,584,170	3,584,170
300-million-gallon aqueduct from Station 3266 to Station 4129	3,761,180	4,829,190
Grand Total Division 3	$8,325,960	$9,393,970

HIGH LEVEL AQUEDUCT—ESTIMATE OF COST.

Division 4.

From East Side of Hudson River to Ashokan Reservoir.

For 300-Million-Gallon Aqueduct.

Tunnel, 17,700 feet, at $64	$1,132,800
Steel pipe (one, 7.25 feet diameter), 49,670 feet, at $36	1,778,120
Cast-iron pipe (two, 5 feet diameter), 9,830 feet, at $100	983,000
Extra cost of grading and special structures between Stations 4400 and 4618, 21,800 feet, at $6	130,800
	$4,034,720
10 per cent. for engineering and contingencies	403,470
	$4,438,190
Real estate	87,780
Total first cost	$4,525,970
Subsequent addition of second 7.25-foot diameter steel pipe, plus 10 per cent	1,966,930
Subsequent addition of third 5-foot cast-iron pipe, plus 10 per cent	540,650
Ultimate total for Division 4	$7,033,550

For 400-Million-Gallon Aqueduct.

Tunnel, 17,700 feet, at $71	$1,256,700
Steel pipe (one, 8.2 feet diameter), 49,670 feet, at $39	1,937,130
Cast-iron pipe (two, 5 feet diameter), 9,830 feet, at $100	983,000
Extra cost of grading and special structures between Station 4400 and Station 4618, 21,800 feet, at $6	130,800
	$4,307,630
10 per cent. for engineering and contingencies	430,760
	$4,738,390
Real estate	87,780
Total first cost	$4,826,170
Subsequent addition of second 8.2-foot diameter steel pipe, plus 10 per cent	2,130,840
Subsequent addition of third and fourth 5-foot cast-iron pipe, plus 10 per cent	1,081,300
Ultimate cost of Division 4	$8,038,310

SUMMARY OF ESTIMATE OF HIGH LEVEL AQUEDUCT (BY DIVISIONS).

	Feet.	First Cost.	Final Cost.
From Hill View Reservoir to Stormville Filters.			
Division 1, Station 10 to Station 1292	128,200	$7,829,050	$9,008,840
" 2, " 1292 " 2414	112,200	9,945,320	10,275,320
" 3, " 2414 " 2600	18,600	980,610	980,610
Total	259,000	$18,754,980	$20,264,770
From Stormville Filters to Billings Reservoir (With Single Conduit).			
Division 3, Station 2660 to Station 3078	41,800	$2,695,897	$2,695,897
(With Twin Aqueduct).			
Division 3, Station 2660 to Station 3078	41,800	3,584,167	3,584,167
From Billings Reservoir to Ashokan Reservoir (300 Million Gallon Aqueduct).			
Division 3, Station 3266 to Station 4129	86,300	$3,761,180	$4,829,190
" 4, " 4129 " 4901	77,200	4,525,970	7,033,550
Total	163,500	$8,287,150	$11,862,740

	Feet.	First Cost.	Final Cost.
(400 *Million Gallon Aqueduct*).			
Division 3, Station 3266 to Station 4129	86,300	$4,249,610	$5,406,620
" 4, " 4129 " 4901	77,200	4,826,170	8,038,310
Total	163,500	$9,075,780	$13,444,930

SUMMARY OF ESTIMATE OF HIGH LEVEL AQUEDUCT (BY CLASSES OF WORK).

	Feet.	First Cost.	Final Cost.
From Hill View Reservoir to Stormville Filters.			
Cut and cover aqueduct	154,250	$8,368,740	$8,368,740
Tunnel	91,050	9,150,670	9,150,670
Steel pipe siphons	13,700	799,430	2,309,220
Real estate	......	436,140	436,140
Total	259,000	$18,754,980	$20,264,770
From Stormville Filters to Billings Reservoir. (*With Single Conduit*).			
Cut and cover aqueduct	32,850	$1,768,580	$1,768,580
Tunnel	8,950	871,330	871,330
Real estate	......	55,987	55,987
Total	41,800	$2,695,897	$2,695,897
(*With Twin Aqueduct*).			
Cut and cover aqueduct	32,850	$2,327,090	$2,327,090
Tunnel	8,950	1,201,090	1,201,090
Real estate	......	55,987	55,987
Total	41,800	$3,584,167	$3,584,167
From Billings Reservoir to Ashokan Reservoir. (300 *Million Gallon Aqueduct*).			
Cut and cover work	52,200	$2,067,120	$2,067,120
Tunnel	24,830	1,748,030	1,748,030
Steel pipe	76,640	3,178,820	6,213,760
Cast-iron pipe	9,830	1,081,300	1,621,950
Real estate	......	211,880	211,880
Total	163,500	$8,287,150	$11,862,740
(400 *Million Gallon Aqueduct*).			
Cut and cover work	52,200	$2,411,640	$2,411,640
Tunnel	24,830	1,939,220	1,939,220
Steel pipe	76,640	3,431,740	6,719,590
Cast-iron pipe	9,830	1,081,300	2,162,600
Real estate	......	211,880	211,880
Total	163,500	$9,075,780	$13,444,930

AQUEDUCT FROM HIBERNIA RESERVOIR TO BILLINGS RESERVOIR—ESTIMATE OF COST.

500-Million-Gallon Aqueduct (Under Project No. 1).

Open Cut—		
Earth excavation, 554,590 cubic yards, at 30 cents	$166,377	
Slope paving, 13,610 cubic yards, at $2	27,220	
Retaining walls at portals	15,000	
	$208,597	
10 per cent. for engineering and contingencies	20,859	
Total for open cut		$229,456
Cost per foot of open cut, $21.64.		
Tunnel—		
Heading excavation, 64,400 cubic yards, at $9	$579,600	
Bench excavation, 160,264 cubic yards, at $3.50	560,924	
Concrete, 1–10, 39,376 cubic yards, at $7	275,632	
Concrete, 1–7, 15,088 cubic yards, at $8	120,704	
Dry filling over arch, 18,400 feet, at $1.62	29,808	
Two gate chambers, at $30,000	60,000	
Supersructure for gate chambers	16,000	
Shafts, 150 feet, at $120	18,000	
	$1,660,668	
10 per cent. for engineering and contingencies	166,067	
Total cost of tunnel		1,826,735
Cost per foot of tunnel, $99.33.		
Right of way, 18,400 feet, at $1		18,400
Grand total		$2,074,591

300-Million-Gallon Aqueduct (Under Project No. 2).

Open Cut—		
This work will be practically the same as for the 500-million-gallon aqueduct........................		$229,456
Tunnel—		
Heading excavation, 64,400 cubic yards, at $9	$579,600	
Bench excavation, 64,400 cubic yards, at $3.50	225,400	
Concrete, 1–10, 29,072 cubic yards, at $7.....	203,504	
Concrete, 1–7, 10,672 cubic yards, at $8......	85,376	
Dry filling over arch, 18,400 feet, at $1.50....	27,600	
Two gate chambers, at $25,000.............	50,000	
Superstructure for gate chambers...........	15,000	
Shafts, 150 feet, at $120..................	18,000	
	$1,204,480	
10 per cent. for engineering and contingencies	120,448	
Total cost of tunnel........................		1,324,928
Cost per foot of tunnel, $72.		
Right of way, 18,400 feet, at $1..........................		18,400
Grand total		$1,572,784

AQUEDUCT FROM SILVERNAILS RESERVOIR TO HIBERNIA RESERVOIR—ESTIMATE OF COST.

Section.	Station.	Classification.	Length.	Cost.	Cost per Foot.	Remarks.
1	13-60	Open canal...	1,650	$101,389	$61 44	Includes gate house.
		Tunnel.......	3,050	159,210	52 20	
2	60-120	Open canal...	6,000	115,485	19 25	Includes road crossing.
3	120-170	Open canal...	5,000	145,447	29 09	
4	170-220	Open canal...	5,000	131,560	26 31	Includes road crossing.
5	220-270	Open canal...	5,000	128,194	25 64	
6	270-320	Open canal...	5,000	118,799	23 76	Includes railroad crossing
7	320-370	Open canal...	5,000	81,103	16 22	Includes railroad crossing. Includes highway crossing. Includes regulating dam. Includes extra channel paving.
8	370-412	Open canal...	4,200	93,696	22 30	Includes three railroad crossings. Includes highway crossing. Includes regulating dam. Includes extra channel paving.
	Totals..................		39,900	$1,074,883	$26 94	Average cost.

Cost of construction	$1,074,883
10 per cent. for engineering and contingencies	107,488
Total	$1,182,371
Right of way	93,400
Grand total	$1,275,771

In this estimate the following average costs have been used for the principal items.

For earth excavation in canal	$0 30	per cubic yard.
For rehandling excavated material	0 25	"
For rock excavation	1 50	"
For paving on slopes	2 00	"
For tunnel excavation	8 00	"
For concrete lining in tunnel, 1–7	8 00	"
For concrete lining in tunnel, 1–10	7 00	"

AQUEDUCT FROM HIBERNIA RESERVOIR TO CLINTON HOLLOW RESERVOIR—ESTIMATE OF COST.

(Considered only under Project No. 1.)

4,000 feet of deep portal cut, at $20 per foot	$80,000
10,600 feet of arch lined tunnel, at $90 per foot	954,000
Gatehouse and appurtenances	75,000
	$1,109,000
10 per cent. for engineering and contingencies	110,900
	$1,219,900
Right of way, 10,000 feet, at 75 cents	7,500
Total	$1,227,400

AQUEDUCT FROM CLINTON HOLLOW RESERVOIR TO ASHOKAN RESERVOIR—ESTIMATE OF COST (UNDER PROJECT NO. 1).

300-Million-Gallon Aqueduct.

Cut and cover aqueduct, 4,200 feet, at $36	$151,200
Tunnel, 26,400 feet, at $64	1,689,600
Steel pipe (one, 7.25-foot diameter pipe), 47,300 feet, at $36	1,702,800
Cast-iron pipe (two, 60-inch diameter pipes), 8,700 feet, at $100	870,000
	$4,413,600
10 per cent. for engineering and contingencies	441,360
	$4,854,960
Real estate	103,800
Total first cost	$4,958,760
Subsequent Additions—	
One 7.25-foot diameter steel pipe line (plus 10 per cent.)	1,873,080
One 60-inch cast-iron pipe line (plus 10 per cent.)	478,500
Ultimate cost	$7,310,340

400-Million-Gallon Aqueduct.

Cut and cover aqueduct, 4,200 feet, at $42	$176,400
Tunnel, 26,400 feet, at $71	1,874,400
Steel pipe (one, 8.2-foot diameter pipe), 47,300 feet, at $39	1,844,700
Cast-iron pipe (two, 60-inch diameter pipes), 8,700 feet, at $100	870,000
	$4,765,500
10 per cent. for engineering and contingencies	476,550
	$5,242,050
Real estate	103,800
Total first cost	$5,345,850
Subsequent Additions—	
One 8.2-foot diameter steel pipe line (plus 10 per cent.)	2,029,170
Two 60-inch diameter cast-iron pipe lines (plus 10 per cent.)	957,000
Ultimate cost	$8,332,020

BRANCH AQUEDUCT TO RONDOUT RESERVOIR.

No definite estimate can now be given of the cost of this aqueduct, no surveys having been made, and unfortunately the geological map being also missing for a part of the route. Enough, however, has been ascertained to establish the fact that at least the greater part of this aqueduct and perhaps the entire aqueduct will be of steel pipe. Acting on this supposition, a line was laid on the geological plan, as far as that plan extends, and the remainder was estimated from the best available data, giving a total length of 20 miles, or 105,600 feet, as the extreme distance between Station 4618, Div. 4, High Level Aqueduct Line, and the proposed reservoir on Rondout Creek.

The elevation of the lowest draft line at the reservoir is about 580; the elevation of the hydraulic gradient at Station 4618, High Level Aqueduct, is about 482; difference in elevation, 98.

With this loss of head and distance, a 9-foot diameter steel pipe will carry 200 million gallons per day.

The estimated cost of such a pipe, of an average thickness of 5/8 inch, laid complete, with all grading, special structures, air-valves, blow-offs, etc., is $50 per foot.

Approximate Cost for 200-Million-Gallon Aqueduct.

105,600 feet of 9-foot steel pipe, laid complete, at $50........	$5,280,000
10 per cent. for engineering and contingencies..........	528,000
	$5,808,000
Right of way, 105,600 feet, at $1.50......................	158,000
Total	$5,966,000

If an aqueduct of 150 million gallons capacity per day be found to be sufficient, the diameter may be reduced to 8 feet and the average thickness to 9/16 inch, at an average cost of $42 per foot for the completed pipe.

With these modifications the cost of the whole line will be as follows:

Approximate Cost of 150-Million-Gallon Aqueduct.

105,600 feet of steel pipe laid complete, at $42..............	$4,435,200
10 per cent. for engineering and contingencies.........	443,500
	$4,878,700
Right of way for 105,600 feet, at $1.50..................	158,000
Total	$5,036,700

There is no doubt that these estimates are safe outside figures, and that surveys of this line will establish the fact that the length of 105,600 feet may be materially shortened.

In the absence of better data, however, it would not be advisable to estimate the cost of the aqueduct in round numbers at less than:

For 150,000,000-gallon aqueduct, about..................	$5,000,000
For 200,000,000-gallon aqueduct, about..................	6,000,000

Time Required to Build Long Tunnels in Putnam and Westchester Counties.

In view of the importance of the time factor in any construction for additional supply, the following estimate is submitted.

It is evident that the time required for the construction of the tunnels north of Tompkins' Corners and south of Shrub Oak is the governing consideration, as all other construction may be easily completed before these tunnels are ready for use.

The length of these tunnels and the depths of shafts are as follows:

Shrub Oak Tunnel.

Station.	Length of Drift.	Depth of Shaft.
1576..............	....	Portal.
1626+10..	5,010 feet.	210 feet.
1676+00....	4,990 "	121 "
1716+20	4,020 "	120 "
1766..............	4,980 "	Portal.
Total	19,000 feet.	......

Tunnel North of Tompkins' Corners.

Station.	Length of Drift.	Depth of Shaft.
1951+50............	....	Portal.
2018+50......	6,700 feet.	190 feet.
2085+90............	6,740 "	409 "
2150+00............	6,410 "	454 "
2214+00............	6,400 "	515 "
2278+00............	6,400 "	483 "
2345+25...........	6,725 "	282 "
2409+00	6,375 "	Portal.
Total	45,750 feet.	......

Central Power Station.

The most economic method of driving these two tunnels will be from one central power station, located either at Mahopac Mines or Mahopac Falls, on a branch line of the Putnam division of the New York Central Railroad.

The requisite power could be carried by wire to the shaft heads and applied to the driving of the compressors or for hoisting, hauling and lighting.

It has been estimated that about 350 h.p. will be required at each shaft for compressor work, and 50 h.p. for other purposes, or a total of 400 h.p. at each shaft for all purposes.

The total power required for all shafts, 4,000 h.p.

A loss of 16 to 20 per cent. of power will probably occur between the boiler and the shafts.

Total power of Central Power Station may be assumed at 5,000 h.p.

Time Required.

The time required for the different portions of work may be approximately assumed as follows:

Plant—The acquisition and setting in place of boilers, engines and electrical equipment, and other plant, from..................	12 to 18	months.
Shafts—500 feet of shafts, at from 15 to 25 feet per week	5 to 8	"
Tunneling—6,400 feet, at from 50 to 70 feet per week..	21 to 30	"
Lining—Extra time after tunneling is completed to finish lining, etc....................	4 to 8	"
Engineering—Preparation of plans and specifications..	3 to 3	"
	45 to 67	months.

Total elapsed time.................3 years 9 months, to 5 years 7 months.

The work may be expedited by the less economical method of commencing construction of the shafts at once without waiting for the installation of the central power plant. By this means, five to eight months may be saved over this estimate, reducing the total elapsed time from start to finish to between three and five years.

In conclusion, it may be stated that, under fortunate circumstances, it is possible, but extremely improbable, that the tunnel may be built in less than four years.

So short a time would call for record progress in all work and an entire absence of accidents, strikes, or any other delays, and it would also entail uneconomical methods of operation.

The most economical methods of construction and a fair allowance of time for misadventures, bad work, etc., which are almost always inevitable, will bring the total up to the more conservative figures of from four years to somewhat more than five years from start to finish.

LOW LEVEL SYSTEM.

Surveys have been made for a low level reservoir and aqueduct system concurrently with those for a high level system. This system was designed to discharge at the surface elevation of the Jerome Park Reservoir.

Aqueduct.

A line of aqueduct was laid out and surveyed, starting from Jerome Park Reservoir and extending to the proposed dam at Rochdale Mills on Wappinger Creek.

The total length of the line between these points is 316,200 feet, or 60 miles, which is classified as follows:

134,800 feet is Cut and Cover work.
178,400 feet is Tunnel.
3,000 feet is Steel pipe siphon.

The surveys for all of this line were made with great care and the entire line was tied in to the United States Coast Survey triangulation points at intervals of every few miles. This work is quite comparable with that performed for the high level line. All of this line has been laid on large roll plans on scale of 200 feet to the inch for cut and cover work, and 400 feet for the long tunnels. The topography has not yet been plotted, as a general rule.

Reservoirs.

The proposed reservoirs on the Fishkill and Wappinger Creeks have been surveyed in a similar manner to the high level reservoirs. The areas of land included within the surveys are as follows:

Wappinger Reservoir	7,040 acres or 11 sq. miles.
Fishkill Reservoir	9,600 acres or 15 sq. miles.

The most favorable locations for dams on these creeks are at Brinckerhoff on the Fishkill and at Rochdale on the Wappinger.

APPENDIX II.

Department of The Catskills.

Appendix II.

Department of the Catskills.

Walter H. Sears, *Department Engineer.*

The territory covered by the investigations of this Department is that included in the watersheds of the Catskill, Schoharie, Esopus and Rondout Creeks at such an elevation as will admit of the supply of water derived therefrom being delivered to the City of New York at an elevation of not less than 295 feet above tide water.

In the briefest possible manner the results of the operations of this Department may be stated as follows, viz.: the territory or drainage area which has been investigated and which may be made tributary to the additional supply is about 770 square miles. The reservoir sites which have been surveyed in this territory have a combined storage capacity of 210,160 million gallons. It may therefore be stated that "The Catskills" can furnish a daily supply to the City of New York of from 600 to 700 million gallons of water daily. The former is a conservative and the latter a not unduly liberal estimate.

General Description of Operations.

The field work in this Department was taken up in the following order:

First—Reconnoissance of possible reservoir sites in the territory under consideration, followed by stadia surveys of such as were believed to be practicable, with plans and estimates of cost. Second—Investigation of sources of sewage pollution with stadia surveys and plans and estimates of cost for disposal of sewage where found to be necessary. Third—Establishment of rain gauge stations and studies of rain fall and run off. Fourth—The drafting department.

The results of the investigations for reservoir sites are as follows in the different watersheds, beginning with the most northerly:

	Drainage Area.	Storage Reservoir Capacity.
Catskill	163 sq. miles.	24,488,000,000 gallons.
Schoharie	228 "	63,585,000,000 "
Esopus	255 "	101,556,000,000 "
Rondout	131 "	20,531,000.000 "
Total	771 sq. miles.	210,160,000,000 gallons.

These results are shown in detail as follows:

CATSKILL CREEK.

The reservoir sites developed on Catskill Creek are as follows:

I.—East Durham Reservoir:
Flow line at elevation of 515 feet above datum.*
Area of water surface, 254 acres.
Estimated capacity .... 2,500,000,000 gallons.

II.—Oak Hill Reservoir:
Elevation of flow line, 700 feet above datum.
Area of water surface, 520 acres.
Capacity .... 6,470,000,000 gallons.

III.—Preston Hollow Reservoir:
Elevation of flow line, 950 feet above datum.
Area of water surface, 520 acres.
Capacity .... 9,366,000,000 gallons.

IV.—Franklinton Reservoir (situated at the northerly limit of the watershed):
Elevation of flow line, 1,200 feet above datum.
Area of water surface, 576 acres.
Capacity .... 6,152,000,000 gallons.

Total in Catskill Valley.......... 24,488,000,000 gallons.

SCHOHARIE CREEK.

The reservoir sites developed on Schoharie Creek are as follows:

I.—Prattsville Reservoir (above the town of Prattsville):
Elevation of flow line, 1,240 feet above datum.
Area of water surface, 700 acres.
Capacity .... 9,398,000,000 gallons.

NOTE.—From the Prattsville Reservoir a tunnel 53,600 feet long connects the Schoharie Valley with the Esopus, the outlet being in the Bushnelville Kill near the town of Shandaken.

* Mean sea level at New York.

II.—Lexington Reservoir (near the town of Lexington):

Elevation of flow line, 1,385 feet above datum.

Area of water surface, 607 acres.

Capacity .... 8,477,000,000 gallons.

III.—Jewett Center Reservoir (near the town of that name):

Elevation of flow line, 1,435 feet above Albany base.

Area of water surface, 433 acres.

Capacity .... 5,578,000,000 gallons.

IV.—West Kill Reservoir (located near the town of West Kill):

Elevation of flow line, 1,485 feet above datum.

Area of water surface, 289 acres.

Capacity .... 3,498,000,000 gallons.

V.—Plaat Clove Reservoir:

Elevation of flow line, 1,930 feet above datum.

Area of water surface, 656 acres.

Capacity .... 5,635,000,000 gallons.

VI.—Ashland Reservoir (near the Village of Ashland):

Elevation of flow line, 1,450 feet above datum. ....

Area of water surface, 421 acres.

Capacity .... 5,372,000,000 gallons.

VII.—Windham Reservoir:

Elevation of flow line, 1,500 feet above datum.

Area of water surface, 923 acres.

Capacity .... 13,025,000,000 gallons.

NOTE.—Ashland and Windham Reservoirs are adjoining. The flow line of Ashland reaches to the foot of Windham dam.

VIII.—Beaches Corner Reservoir:

Elevation of flow line, 1,800 feet above datum.

Area of water surface, 505 acres.

Capacity .... 6,349,000,000 gallons.

IX.—East Jewett Reservoir:

Elevation of flow line, 1,875 feet above datum.

Area of water surface, 488 acres.

Capacity .... 6,253,000,000 gallons.

Total in Schoharie................. 63,585,000,000 gallons.

ESOPUS CREEK.

The reservoir sites developed on Esopus Creek are as follows:

I.—Ashokan Reservoir (with a dam of masonry at Bishops Falls):

Flow line is at elevation 560 feet above datum.

Area of water surface, 5,978 acres.

Capacity .... 66,500,000,000 gallons.

NOTE.—Further statistics relating to the Ashokan Reservoir at elevation of 560 feet above datum are:

Area of water surface, 9.34 square miles.

Additional areas, strip of 1,000 feet wide around margin and islands, amounting to 88.8 acres, 4,710 acres.

Additional areas (as above) 7.36 square miles.

Total area to be acquired, flooded area and marginal area for protection. 16.70 square miles.

Length, 11.5 miles.

Maximum width, 1.7 miles.

Length of shore, islands not included, 38.1 miles.

Maximum depth at dam site, 160 feet.

Length of main dam at Bishops Falls, 1,280 feet.

Length of secondary dam at Brown's station, 1,950 feet.

Length of dikes, 7,725 feet.

Length of spillway, 1,000 feet.

Length of railroad flowed, 11.1 miles.

Length of roads flooded, 37 miles.

Average depth figured as a right prism base equal to the flooded area, 29.3 feet.

Total number of structures, all included	678

Divided as follow:

Dwellings, boarding houses, hotels	343
Barns, outhouses, sheds......	261
Schools	6
Business places, stores, railroad stations	57
Halls, churches, etc...........	11
Total	678

In addition to the Ashokan Reservoir, the following have been surveyed on Esopus Creek:

II.—Wittenburg Reservoir (located on the Little Beaver Kill near Wittenberg or Yankee Town):

Flow line is at elevation 850 feet above datum.

Area of water surface is 878 acres.

Capacity .... 7,456,000,000 gallons.

III.—Lake Hill Reservoir (located on the Big Beaver Kill near Willow):
Flow line is at elevation 1,110 feet above datum.
Area of water surface is 1,067 acres.
Capacity .... 12,493,000,000 gallons.

IV.—Cold Brook Reservoir (located on the main stream of the Esopus near Cold Brook Station):
Flow line is at elevation 720 feet above datum.
Area of water surface is 850 acres.
Capacity .... 9,791,000,000 gallons.

V.—Shandaken Reservoir (located on the main stream of the Esopus not far from the former railroad station of that name):
Flow line is at elevation 1,190 feet above datum.
Area of water surface is 260 acres.
Capacity .... 3,273,000,000 gallons.

VI.—Big Indian Reservoir (located on the main stream of the Esopus just above the town of Big Indian):
Flow line is at elevation 1,310 feet above datum.
Area of water surface is 193 acres.
Capacity .... 2,043,000,000 gallons.

The total storage capacity developed on Esopus Creek is... 101,566,000,000 gallons.

RONDOUT CREEK.

The reservoir sites developed on Rondout Creek are as follows:

I.—Napanoch Reservoir (located north of the Village of Napanoch):
Flow line is at elevation 660 feet above datum.
Area of water surface is 439 acres.
Capacity .... 4,760,000,000 gallons

II.—Lackawack Reservoir (located near the Village of Lackawack, which will be submerged):

Flow line is at elevation 750 feet above datum.

Area of water surface is 1,075 acres.

Capacity .... 13,271,000,000 gallons.

III.—Eureka Reservoir (located near the Village of that name):

Capacity is estimated at............... 5,000,000,000 gallons.

The total storage capacity developed on Rondout Creek is....... 20,531,000,000 gallons.

Ver Nooy Creek, with a watershed of about 21 square miles, adjoining the Rondout to the north and east, is of nearly identical character with that stream as to steep slopes, forest area and lack of population. It may easily be connected with the Rondout outlet, and its watershed is included in the estimate for the latter.

Pl. VII. shows the location of each reservoir in the Esopus Watershed.

The important part played by the Ashokan Reservoir in the development of the Esopus water and its early construction required in the system of additional supply, makes it advisable to give the following detailed approximate estimate of its cost:

APPROXIMATE ESTIMATE OF COST OF ASHOKAN RESERVOIR.

Stripping entire reservoir. 9,600,000 cubic yards, at 30 cents..	$2,880,000
Relocation of roads and reconstruction of old, 26 miles, at $10,000	260,000
Railroad relocation, complete, West Hurley to Boiceville, 13 miles	434,385
Gate house and connections complete at West Hurley and entrance to tunnel................................	250,000
Damages to water power on the Esopus Creek, and other business enterprises...............................	450,000
Cost of land, including a strip 1,000 feet wide around reservoir, and islands and peninsulas included, 7,900 acres, at $20..	158,000

Buildings, dwellings (barns not included), and stores, etc., figured in next item, 343 dwellings, at $2,000		$686,000
Injury to business enterprises, stores, mills, hotels, etc		500,000
Clearing and grubbing wooded land, 1,425 acres, at $50		71,250
Removal of cemeteries and graveyards, 14 large and small, at $5,000		70,000
Protection against turbidity by walls, etc		100,000
Sanitary precautions and sewage disposal		50,000
Masonry Dam, on Esopus Creek, Bishop's Falls—		
Rubble masonry, 154,000 cubic yards, at $4	$616,000	
Facing, 18,000 cubic yards, at $15	270,000	
		886,000

(Second estimate, 172,000 cu. yds. at $6.50, $1,118,000.)

Embankment at dam, excavating the base and replacing	150,000
Wasteway, excavation, wing walls, channel, etc	100,000
Gate house	75,000
Temporary flumes, dam and proposed tunnel during construction	400,000
Power house, in connection with main dam	50.000

(Total, dam and appurtenances, $1,661,000.)

Brown's Station Spillway (Holyoke Station).—

Rubble masonry, 8,000 cubic yards, at $4	32,000
Facing and coping, 5,150 cubic yards, at $15	77,250
Abutments and wing walls, 2,800 cubic yards, at $6.50	18,200
Excavation for Spillway channel	50.000

(Total of Brown's Spillway, $184,450.)

Estimate for all Earth Dikes Except Glenford and West Hurley Dikes.

Earthwork (selected material), 912,375 cubic yards, at 40 cents.	364,950
Core walls, concrete (Portland cement), 134,140 cubic yards, at $6	804,840
Slope paving, first class, 26,050 cubic yards, at $4	104,200
Loose paving, 29,270 cubic yards, at $2	58,540
Broken stone, 5,220 cubic yards, at $1	5,220

(Brown's Station dikes, $1,200,900.)

Glenford Dike and Road Crossing.

Embankment (spoil bank not included), 17,100 cubic yards, at 40 cents	$6,840
Core wall, 4,000 cubic yards, at $6	24,000
Slope paving, all first class, 2,570 cubic yards, at $4	10,200

(Total Glenford Dike, $38,560.)

West Hurley Dike and Cut-off, and Proposed Spillway, Holyoke Section.

Rubble masonry, 1,000 cubic yards, at $4	4,000
Facing masonry, 1,475 cubic yards, at $15	22,125
Embankment, 27,000 cubic yards, at 40 cents	10,800

Wing wall or abutments not included.

(West Hurley dike, $36,925.)

Road Crossing at Brown's Station.

Embankment, 144,900 cubic yards, at 20 cents	28,980
Paving, 19,450 cubic yards, at $2	38,900

Bridge Abutments.

Rubble masonry, 7,230 cubic yards, at $4	28,920
Coping, 21 cubic yards, at $25	525

Steel Work.

150-foot span	5,000

(Road crossing, $102,325.)

Road Crossing at Shokan on Natural Dike.

Embankment, 593,500 cubic yards (taking from stripping), at 20 cents	118,700
Paving, 69,400 cubic yards, at $2	138,800

Bridge Abutments.

Rubble, 20,030 cubic yards, at $4	80,120
Coping, 35 cubic yards, at $25	875

Piers.

Rubble, 4,800 cubic yards, at $4	19,200
Coping, 47 cubic yards, at $25	1,175

Steel Work.

3 spans, at $5,000 each		$15,000
(Road crossings, $373,870.)		
Connecting Channel: Base, 15 feet Wide; at Elevation, 505.		
Total cubic yards of excavation, assuming one-third loose rock, one-third rock and one-third earth.		
Rock	$2.00	
Loose rock	.65	
Earth	.35	
	$3.00	
Average	1.00	
		573,200
Total for construction		$10,203,195
Adding 15 per cent. for engineering and further investigations of details		1,530,479
Making a grand total of		$11,733,674
Hence cost of storage per million gallons		$177

Lengths of structures for elevation of flow line, 560.

Dam at Bishop's Falls, over Esopus Creek	1,280 long.
Spillway at Brown's Station	1,000 "
West Dike	1,750 feet.
Middle Dike	2,350 "
Beaver Kill	1,950 "
East Dike	2,850 "
Glenford	1,050 "
West Hurley	725 "
Total dike	10,675 feet.

The above estimate is approximate only, many items had to be assumed. No borings at dam sites had then been made and the exact location of some of the structures has not been finally determined. Prices used have been carefully considered, but are subject to revision. The cost of water power on the Esopus was estimated on the best data available, and it is believed to be very liberal.

COMPARISON OF STORAGE RESERVOIRS.

Approximate Figures from Best Available Data in Catskill Department, August 8, 1903.

Name of Reservoir.	Area.		Average Depth.	Height of Dam Bed of Stream to Flow Line.	Length of Dam.		Total Capacity.	Daily Supply.	Population Supplied at 100 Gallons per Capita per Day.	Cost.		
	Water Shed.	Full Reservoir.			Masonry.	Embankment. *				Each Million Gallons Stored.	Each Person Supplied.	Total First Cost.
	Sq. Mi.	Sq. Mi.	Ft.	Feet.	Feet.	Feet.	Mil. Gals.	Mil. Gals.	Millions.	Dollars.	Dollars.	Mil. Dols.
Ashokan	255	9.34	29	160	1,280	10,700	66,000	250	2.500	177	4.70	11.731
Croton	360	5.75	27	157	1,270	......	32,000	375	2.750	*200	....	.....
Wachusett	118	6.56	46	129	1,250	13,000	63,000	105	1.030	145	8.70	9.105
Sudbury	22	1.91	19	65	300	1,565	7,400	22	.220	400	13.10	2.922
Hopkinton	6	.29	25	60	30	1,540	1,500	6	.060	565	14.30	.860
Ashland	6	.26	26	49	30	1,857	1,400	6	.060	580	13.10	.787
Wigwam	18	.16	22	70	524	600	750	7½	.075	400	4.00	.300

Ashokan — Figures of cost from preliminary estimate.

Croton and Wachusett statistics mostly from Mass. St. Board of Health Special Report of 1895.

Other data from well authenticated sources.

SEWAGE DISPOSAL.

After a careful examination of the various towns and villages on the different watersheds, a determination was made of those requiring special provision for the safe disposal of the sewage. These were then surveyed by Mr. Nickerson, Assistant Engineer, and plans were drawn and estimates prepared in each case and a report made, giving a description of the methods employed and the results reached. These reports are now filed with other papers and maps of the Commission. In the Catskill and Esopus valleys it was found sufficient to provide special disposal plants for the few centers of population where they were required. In the Schoharie Valley it seemed wise to plan for a trunk sewer from the vicinity of Hunter to a point below Prattsville. This was accordingly done. The greater portion of the dis-

*Freeman Report, page 440 — Probably too low for Cornell Basin and otherwise not comparable as a single reservoir.

tance was actually surveyed and plans and profile drawn. Data for the part of the sewer near Hunter were taken, however, from the plans of the U. S. Geological Survey, but it is believed that sufficient detail was obtained for present purposes. The reports covering all these propositions, in connection with the plans and profiles on which they are based, form a complete system for the safe disposal of all sewage on the various watersheds.

It may be stated in this connection, that the conditions on the Rondout and Ver Nooy Creeks do not at present require any special works for this purpose. The population is sparse and would be rendered still more so, if storage reservoirs should be constructed where required for developing the water supply.

Drafting Department.

Filed among the records of the Commission are 183 plans and profiles relating to the work done in this Department during the season.

Relating to the Ashokan Reservoir	68
Relating to Supplementary Reservoirs	39
Relating to rainfall and run-off	14

Of these

135 are of standard double elephant size,

39 are of letter size,

9 are profiles.

These are all filed in one case, and they have been indexed in the card index.

There are 55 note-books filled with notes.

There are also certain notebooks and plans received from the Department of Water Supply, Gas and Electricity (from Mr. Hill and Mr. Birdsall), relating to previous surveys in this section. These plans were utilized in making estimates for capacity for the East Durham reservoir and wherever they were available.

PHYSICAL CHARACTERISTICS OF THE CATSKILL TERRITORY.

Geologically, the whole territory under consideration seems to belong to the same formation. Quarries of blue stone are found throughout the whole territory from the low lands to the top of the mountains. There is no limestone above Bishop's Falls, and the water is, therefore, soft.

There is also an entire absence of swamps, except at West Hurley and Ashton, in the basin of the proposed Ashokan reservoir, and also except a small area on the Rondout. There are no true swamps on the territory under consideration and therefore there is no color in the streams.

There are a number of small clay beds in various parts of the watershed, and some of the waters, especially of the Esopus and Schoharie, are turbid at times. These small clay deposits can be located and as sources of turbidity they can be eliminated. Sedimentation in the Ashokan Reservoir can also be depended upon to restore the water to its original limpid condition.

A striking feature of the Catskill watershed, aside from its steep slopes and extremes of elevation, is the great extent of forest area. This is particularly true of the Rondout and Esopus watersheds, in which more than ninety per cent. of the territory is covered with forest growth, much of this being forty years old or more. This age is determined by the general denudation of the forest at that time to supply bark for the tanneries then very numerous in all these valleys. The southern slope of the Schoharie is steep and well wooded like the Esopus and the Rondout, but the northern slope is flatter and more cultivated. The Catskill is still better adapted for farming lands and is so utilized, probably not more than twenty-five per cent. of this section being left to forest areas.

A considerable portion of the Slide Mountain district is owned by the State and held as a forest reserve, it being the policy of the Commonwealth to increase these holdings from time to time. The importance of these forest areas in connection with rainfall and run-off is referred to in another part of this report.

The Outflow from the Ashokan Reservoir into the Aqueduct.

It seems desirable, for many reasons, to make the intake to the aqueduct from the Ashokan Reservoir at some point near West Hurley, the opposite end of the reservoir from the point of inflow; that is to say, at a point which will give the water the longest possible period for exposure to the action of sun and wind, so as to secure the highest attainable degree of sterilization.

From this point the conduit should follow a southerly direction to a crossing of the Hudson river near the town of Esopus. This river crossing may be made in a tunnel under the river or in a dredged channel in the bottom of the river, of such size as to carry four 48-inch pipes, so arranged as to be accessible for inspection, repair and renewal in the tunnel plan. Inasmuch as the elevation of the Ashokan water-mass is in excess of that needed for delivering the water at elevation 295 in New York by an aqueduct of with ordinary grade, there remains a considerable head which may be utilized in determining the size of these pipes under the river, and 48 inches is suggested as an economical and advantageous diameter.

From the river a conduit should run by the most feasible and economical route to the Stormville filters, as is shown by the route provisionally adopted on the accompanying plans.

The aqueduct from the Rondout watershed would enter that from the Ashokan at a suitable point westerly of the Hudson river, as also provisionally shown on the accompanying plans.

It would be the purpose of this part of the aqueduct construction to afford an independent aqueduct line for the Esopus and Rondout waters, so as to conduct them to the filters at Stormville without mingling with those from the watersheds on the east side of the Hudson. This separate conveyance of the clear and soft waters from the west side of the Hudson is of the utmost importance in the reduction of the hardness of the waters brought down from the drainage areas east of the Hudson river, as well as for other purposes of control.

Table I.—Appendix II.

Comparison of Storage Reservoirs.

Approximate Figures from Best Available Data in Catskill Department, August 8, 1903.

Name of Reservoir.	Area.		Average Depth	Height of Dam Bed of Stream to Flow Line.	Length of Dam.		Total Capacity, Million Gallons.	Daily Supply. Million Gallons.	Population Supplied at 100 Gals Per Capita Per Diem. Millions	Cost.		Total First Cost. Million Dols.
	Water Shed. Sq. Miles.	Full Reservoir. Sq. Miles.			Masonry.	Embankment.				Each Million Gals. stored — Dols.	Each Person Supplied. — Dols.	
			Feet.	Feet.	Feet.	Feet						
Ashokan.	255	9.34	29	160	1,280	10,700	66,000	250	2.500	177	4.70	11.734
Croton.	360	5.75	27	157	1,270	0	32,000	275	2.750	*200	....	.. ..
Wachusett.	118	6.56	46	129	1,250	13,000	63,000	105	1.050	145	8.70	9.105
Sudbury	22	1.91	19	65	300	1,565	7,400	22	.220	400	13.10	2.922
Hopkinton.	6	.29	25	60	30	1,540	1,500	6	.060	565	14.30	.860
Ashland.	6	.26	26	49	30	1,857	1,400	6	.060	580	13.10	.787
Wigwam	18	.16	22	70	524	600	750	7½	.075	400	4.00	.300

Ashokan—Figures of cost from preliminary estimate.
Croton and Wachusett statistics mostly from Massachusetts State Board of Health Special Report of 1895.
Other data from well authenticated sources.
* Freeman Report, page 440; probably too low for Cornell Basin, and otherwise not comparable as a single reservoir.

Table II.—Appendix II.

Description and Detailed Estimates of Smaller Reservoirs in the Esopus Valley.

Description.	Big Indian.	Shandaken.		Lake Hill.		Wittenberg.	Cold Brook.
Character of dam	Earth.	Masonry and Earth.		Masonry.	Earth.	Earth.	Masonry.
Height of dam, feet	90	120		110	55	75	130
Length of dam, feet	1,520	500	1,135	740	1,800	1,600	2,250
Area of reservoir (acres).	193.3	250.3		1067.5		878.7	853.1
Elevation flow line	1,310	1,190		1,110		850	720
Elevation low-water line	1,245	1,100		1,040		795	655
Capacity in gallons	2,043,000,000	3,273,000,000		12,493,000,000		7,456,000,000	9,791,000,000

Estimates.	Quantities.	Total Cost.	Quantities.	Total Cost.	Quantities.	Total Cost.	Quantities.	Total Cost.	Quantities.	Total Cost.
Land damages	* 570	$36,950	* 830	$59,150	* 2,060	$143,300	* 1,920	$121,400	* 1,910	$190,950
New highways, at $10,000 per mile	3.1	31,000	2.2	22,000	7.7	77,000	4.6	46,000	5	50,000
New railroad	......	......	3	100,000	......	....	......	....	......	......
Clearing and grubbing, at $50 per acre	70	3,500	75	3,750	110	5,500	165	8,250	245	12,250
Stripping, at $0.30 per cubic yard	250,000	75,000	336,000	100,800	1,123,000	336,900	1,382,000	414,600	1,101,000	330,300
Earth excavation, at $0.30 per cubic yard	7,850	2,355	27,520	8,256	23,300	6,990	29,350	8,805	440,000	132,000
Rock excavation, at $1.50 per cubic yard.	18,500	27,750	22,220	33,330	13,600	20,400	27,850	41,775	46,000	69,000
Earth embankment, at $0.50 per cubic yard	495,900	247,950	74,390	37,195	38,200	19,100	193,200	96,600	......	......
Concrete core, at $5 per cubic yard	25,650	128,250	12,080	60,400	9,800	49,000	19,700	98,500	......	......
Concrete coping, at $7 per cubic yard	....	....	1,170	8,190	1,640	11,480	......	....	5,000	35,000

Rubble Masonry, at $5 per cubic yard	1,900	9,500	49,150	245,750	48,970	244,650	......	....	190,200	950,100
Facing for dam, at $12 per cubic yard	1,200	14,400	8,670	104,040	10,010	120,120	230	2,760	22,500	246,000
Slope paving, at $3 per cubic yard	22,160	66,480	8,060	24,180	5,500	16,500	11,700	35,100	3,300	9,900
Seeding slopes, at $0.10 per square yard	26,950	2,695	8,370	837	5,500	550	15,200	1,520	......	......
Gate-house and appurtenances	....	39,110	......	24,360	......	24,110 19,600	......	34,110	......	28,360
Temporary dam and flume	....	12,300	......	4,225	......	1,200	.....	7,600	......	30,000
Total	....	$692,240	......	$836,463	......	$1,036,600	......	$920,020	......	$2,089,860
Engineering and contingencies, 15 per cent	....	104,586	.....	125,469	......	164,490	......	138,003	......	313,479
Grand Total	....	$801,826	......	$961,932	......	$1,261,090	......	$1,058,023	......	$2,403,339
Cost, per million gallons	....	$392	......	$234	......	$101	......	$142	......	$245

* Acres.

CATSKILL DEPARTMENT, September, 1903.

TABLE III.—APPENDIX II.

CITY OF NEW YORK—COMMISSION ON ADDITIONAL WATER SUPPLY.

Description and Detailed Estimates of Proposed Reservoirs in the Rondout Valley.

Name of reservoir	Napanoch.		Lackawack.
Character of dam	Earth.	Masonry.	Masonry.
Height of dam, feet	50	110	115
Length of dam, feet	1,130	970	1,300
Area of reservoir, acres	439		1,075
Elevation, flow line	660		750
Elevation, low water	570		650
Capacity, gallons	4,760,000,000		13,271,000,000

	Quantities.	Total Cost.	Quantities.	Total Cost.
Land damages	1,190	$89,250	2,350	$235,000
New highways, at $10,000 per mile	6.1	61,000	10.6	106,000
Clearing and grubbing, at $70 per acre	60	4,200	110	7,700
Stripping, at $0.30 per cubic yard	702,400	210,720	1,720,000	516,000
Earth excavation, at $0.30 per cubic yard	495,670	148,701	76,420	22,926
Rock excavation, at $1.50 per cubic yard	......	......	500	750
Earth embankment, at $0.50 per cubic yard	625,150	312,575	......	......
Concrete core, at $5 per cubic yard	22,460	112,300	......	......
Rubble spillway, at $10 per cubic yard	4,500	45,000	4,000	40,000
Rubble masonry, at $5 per cubic yard	74,300	371,500	121,190	605,950
Facing for dam, at $12 per cubic yard	14,150	169,800	23,080	276,960
Slope paving, at $3 per cubic yard	23,100	69,300	......	......
Seeding slopes, at $0.10 per square yard	23,100	2,310	......	......
Gate-house and appurtenances	......	22,110	......	25,310
Temporary dam and flume	......	30,000	.....	30,000
Fifteen per cent. for general inaccessibility of location	.....	247,320	......	280,140
Total	......	$1,896,090	......	$2,147,740
Engineering and contingencies, 15 per cent	......	284,410	......	322,160
Grand total	.....	$2,180,500	.....	$2,469,900
Cost per million gallons	......	$458	......	$186

Eureka Reservoir estimated to require an earth dam 80 feet high and 1,200 feet long, giving a capacity of about 5,000,000,000 gallons, at a cost of $275 per million gallons.

CATSKILL DEPARTMENT. October, 1903.

Description and i

Name of reservoir	Prattsville.	Windham.	
Character of dam	Masonry.	Earth.	*kill*
Height of dam, feet	95	100	
Length of dam, feet	1,630	1,700	
Area of reservoir, acres	700	923	
Elevation flow line	1,240	1,500	
Elevation low-water line	1,200	1,405	
Capacity, gallons	9,398,000,000	13,023,000,000	

	Quantities.	Total Cost.	Quantities.	Total Cost.	
Land damages	1,900 acres.	$190,000	1,980 acres.	$347,600	o
New highways, at $10,000 per mile	8.25	82,500	9.1	91,000	
Clearing and grubbing, at $70 per acre	200	14,000	70	4,900	
Stripping, at $0.30 per cubic yard	1,120,000	336,000	1,476,800	443,040	ist.
Earth excavation, at $0.30 per cubic yard	162,580	48,770	1,130,300	339,090	
Rock excavation, at $1.50 per cubic yard	1,300	1,950	....	....	35,250
Earth embankment, at $0.50 per cubic yard	....	....	1,560,580	780,290	23,000
Concrete core, at $5 per cubic yard	....	....	44,000	220,000	7,000
Rubble spillway, at $10 per cubic yard	5,000	50,000	2,500	25,000	76,480
Rubble masonry, at $5 per cubic yard	184,710	923,550	....	....	13,867
Facing for dam, at $12 per cubic yard	35,180	422,160	....	....	......
Slope paving, at $3 per cubic yard	....	....	61,080	183,240	97,900
Seeding slopes, at $0.10 per square yard	....	....	56,480	5,640	13,600
Gate-house and appurtenances	....	23,710	....	42,360	12,500
Temporary dam and flume	....	30,000	....	10,000	......
Fifteen per cent. for general inaccessibility of locations.	....	318,400	....	388,825	......
					9,570
Total	....	$2,441,050	....	$2,980,995	319
Engineering and contingencies, 15 per cent	....	366,160	....	447,150	48,360
					5,000
Grand total	....	$2,807,210	....	$3,428,150	02,930
Cost per million gallons	....	$208	....	$262	55,770

Estimate of Schoharie—Esopus Tunnel: Tunnel, 53,600 feet, at $60=$3,216,000; sha 33,370

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Table V.—Appendix II.

City of New York—Commission on Additional Water Supply.

Description and Detailed Estimates of Proposed Reservoirs in the Catskill Valley.

Name of reservoir	Oak Hill.	Preston Hollow.	Franklinton.
Character of dam	Masonry.	Masonry.	Earth.
Height of dam, feet	130	170	110
Length of dam, feet	2,025	1,750	780
Area of reservoir, acres	520	520	576
Elevation, flow line	700	950	1,200
Elevation, low water line	600	810	1,100
Capacity, gallons	6,470,300,000	9,365,800,000	6,152,000,000

	Quantities	Cost.	Quantities	Cost.	Quantities	Cost.
Land damages acres	1,500	$150,000	1,500	$112,500	1,670	$135,250
New Highways, at $10,000 per mile	7.5	75,000	8	80,000	2.3	23,000
Clearing and grubbing, at $70 per acre	180	12,600	200	14,000	100	7,000
Stripping, at $0.30 per cubic yard	960,000	288,000	950,000	285,000	921,600	276,480
Earth excavation, at $0.30 per cubic yard	225,000	67,500	118,000	35,400	712,890	213,867
Rock excavation, at $1.50 per cubic yard	11,000	16,500	22,000	33,000	......	......
Earth embankment, at $0.50 per cubic yard	......	......	......	......	1,015,800	507,900
Concrete masonry, at $5 per cubic yard	20,000	100,000	......	......	22,720	113,600
Spillway, at $10 per cubic yard	......	......	3,500	35,000	1,250	12,500
Rubble masonry, at $5 per cubic yard	218,000	1,090,000	313,000	1,565,000	......	......
Facing for dam, at $12 per cubic yard	42,000	504,000	62,200	746,400	......	......
Slope paving, at $3 per cubic yard	15,000	45,000	4,000	12,000	3,190	9,570
Seeding slopes, at $0.10 per square yard	10,000	1,000	8,000	800	3,190	319
Gate-house and appurtenances	......	30,000	......	39,500	......	48,360
Temporary dam and flume	......	20,000	......	20,000	......	5,000
15 per cent. for general inaccessibility of location	......	360,000	......	431,800	......	202,930
Total	......	$2,759,600	......	$3,310,400	......	$1,555,770
Engineering and contingencies, 15 per cent.	......	$415,400	......	$497,600	......	$233,370
Grand Total	......	$3,175,000	......	$3,808,000	......	$1,799,140
Cost per million gallons	......	$490	......	$407	......	$292

A reservoir at East Durham was estimated in 1901 to require a 65-foot dam; flow line, 515; area, 254 acres; capacity, 2,500,000,000 gallons.

Catskill Department. October 31, 1903.

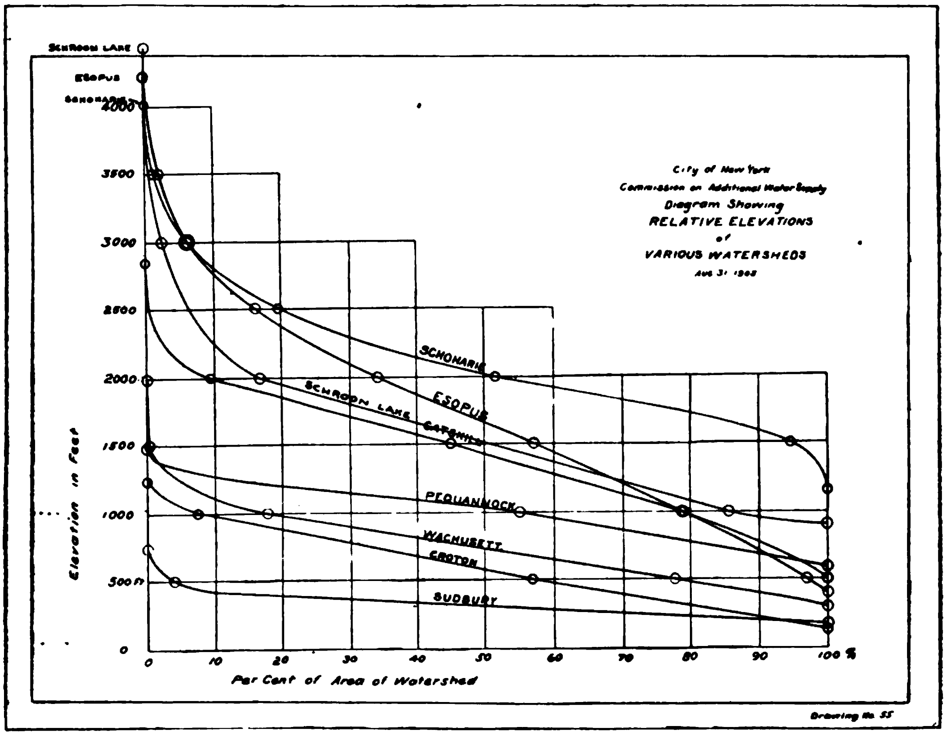


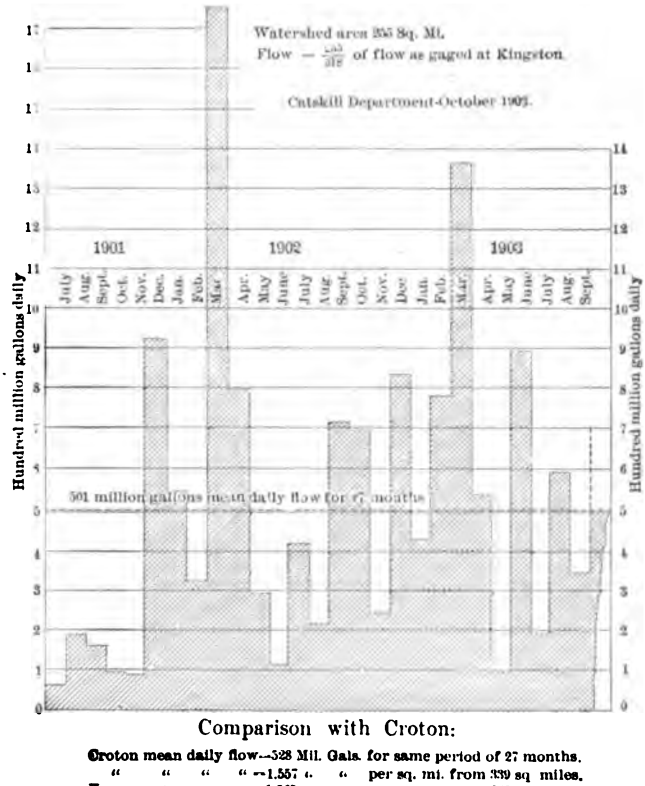
PLATE I. APP. II.

PLATE II. APP. II.

ESOPUS WATERSHED

MONTHLY DISTRIBUTION OF YIELD

27 months ending Sept. 30, 1903



Comparison with Croton:

Croton mean daily flow—528 Mil. Gals. for same period of 27 months.
" " " " —1.557 " " per sq. mi. from 339 sq miles.
Esopus " " " —1.965 " " " " " " 255 " "

If ultimate safe yield from furture Croton area of 360 Sq miles is 275 M. G. daily — .764 M. G. daily per square mile.
then: 1.557 : 761 . : 1.965 : x — .964 Mil. Gal. daily per Sq. Mile
Hence: .951 x 255 — 216 Mil. Gal. daily safe yield of Esopus.

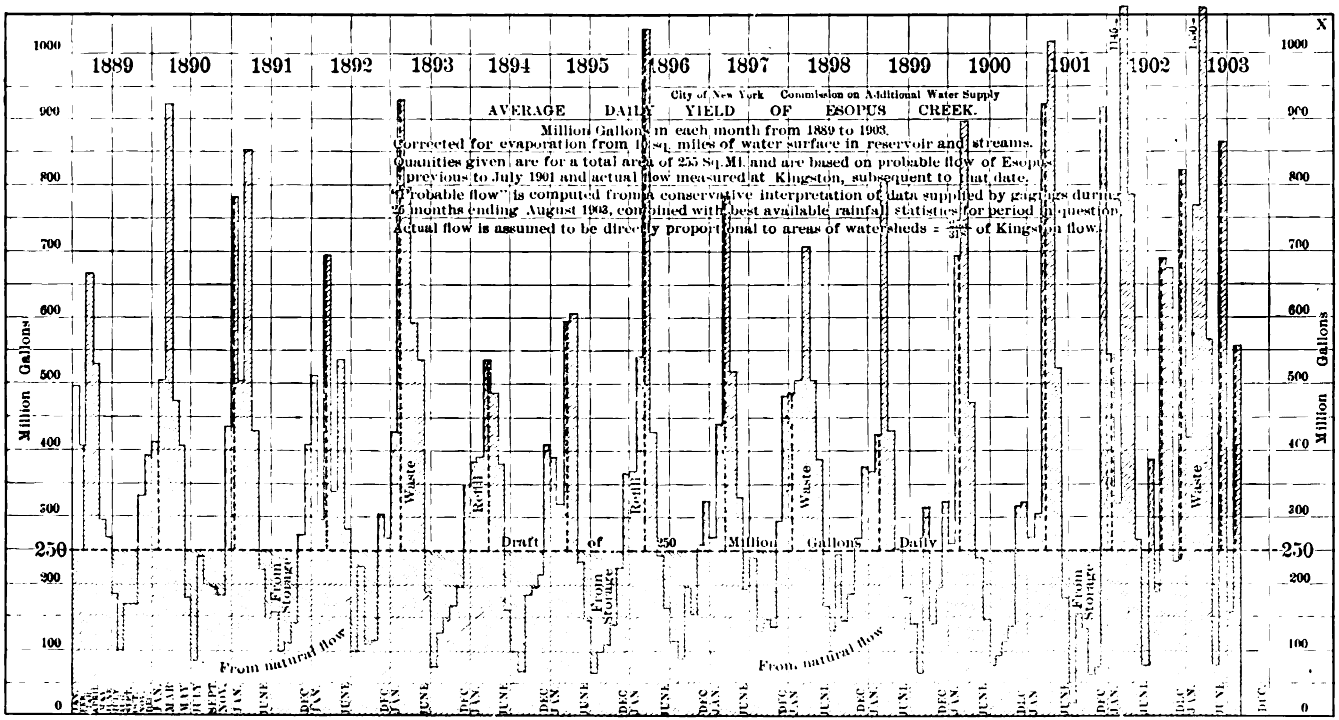


PLATE III. APP. II.

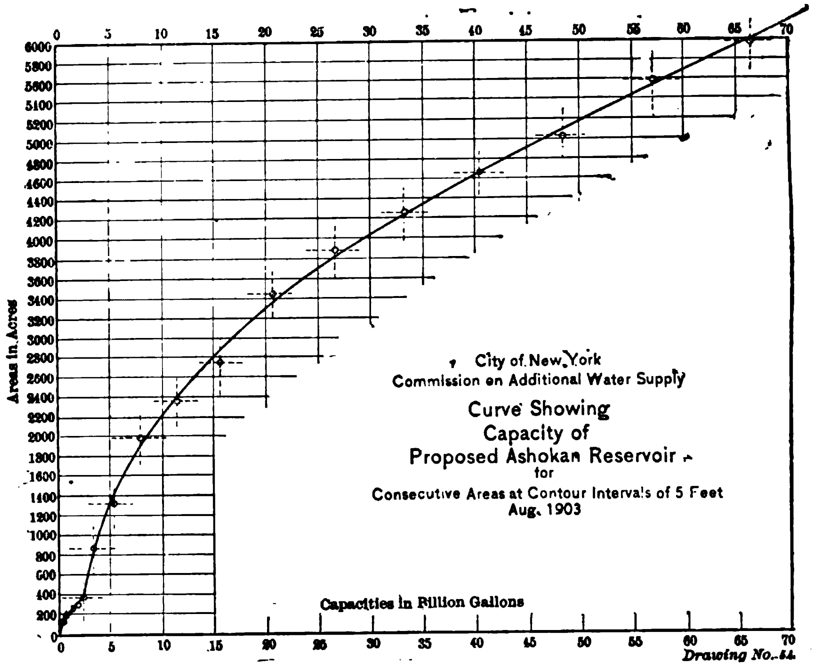


PLATE IV. APP. II.

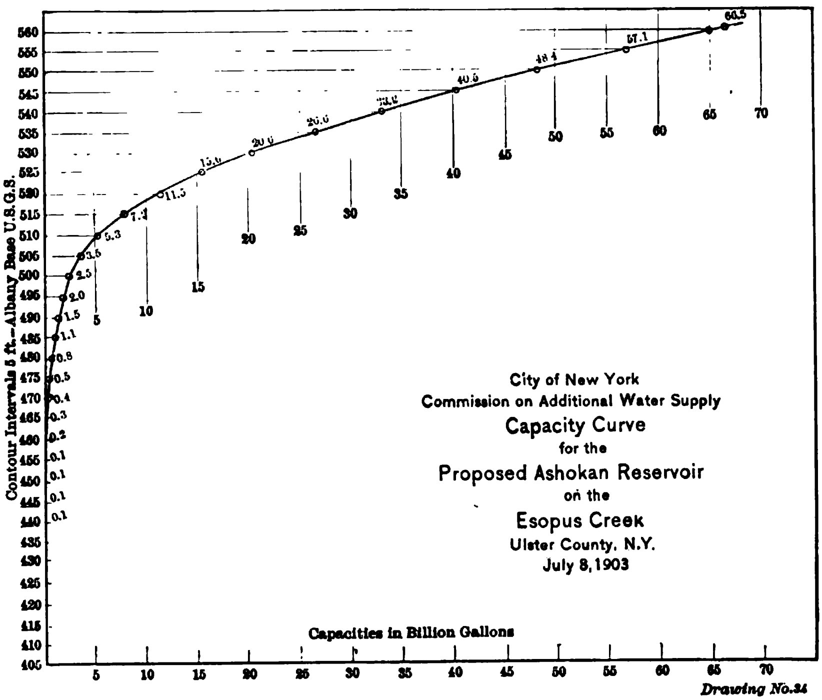


PLATE V. APP. II.

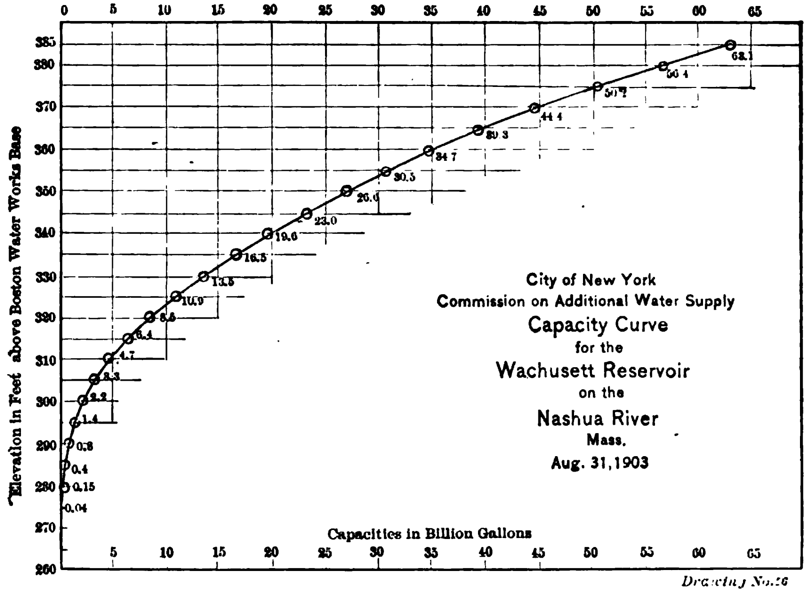


PLATE VI. APP. II.

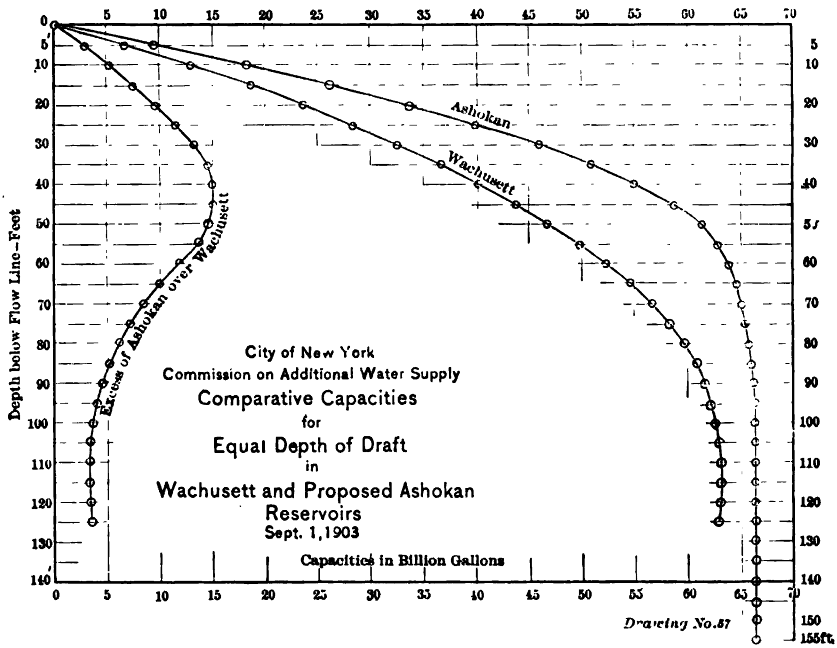


PLATE VII. APP. II.

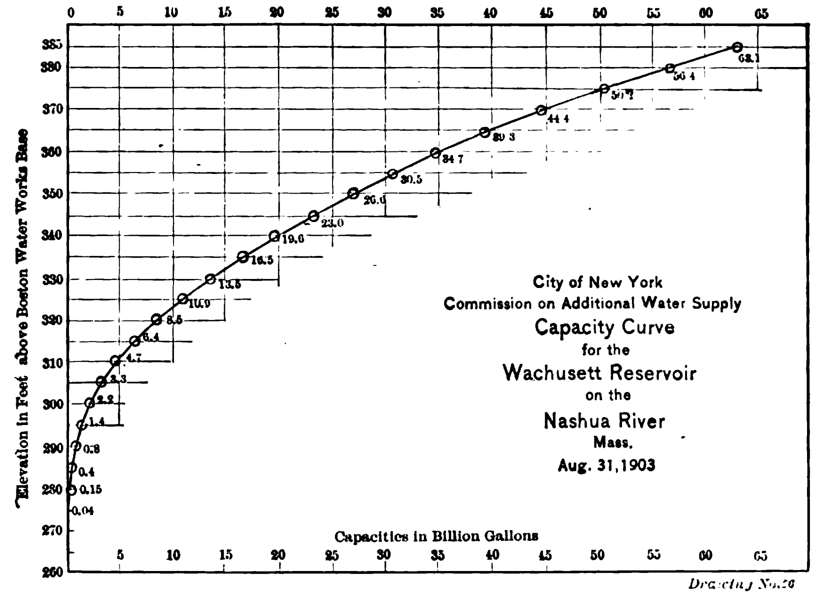


PLATE VI. APP. II.

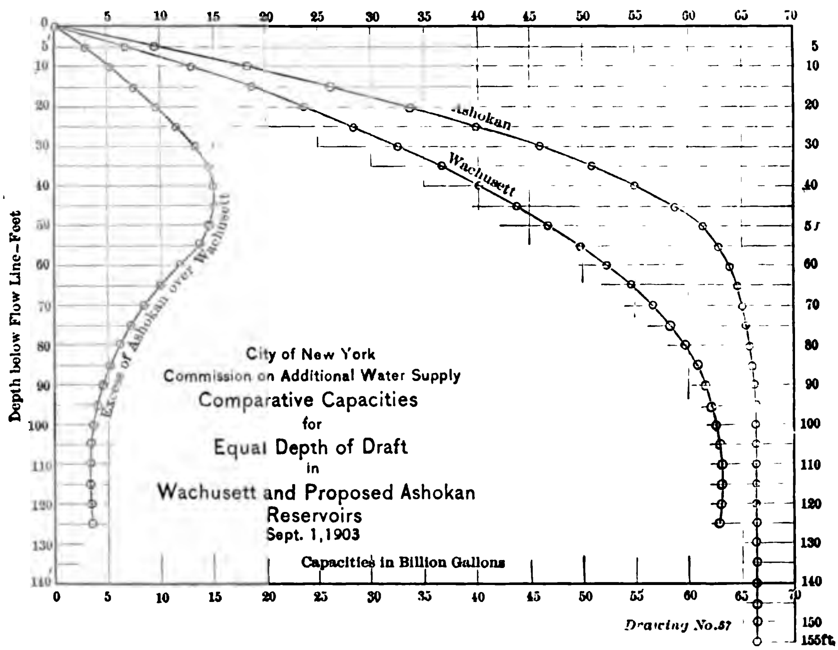
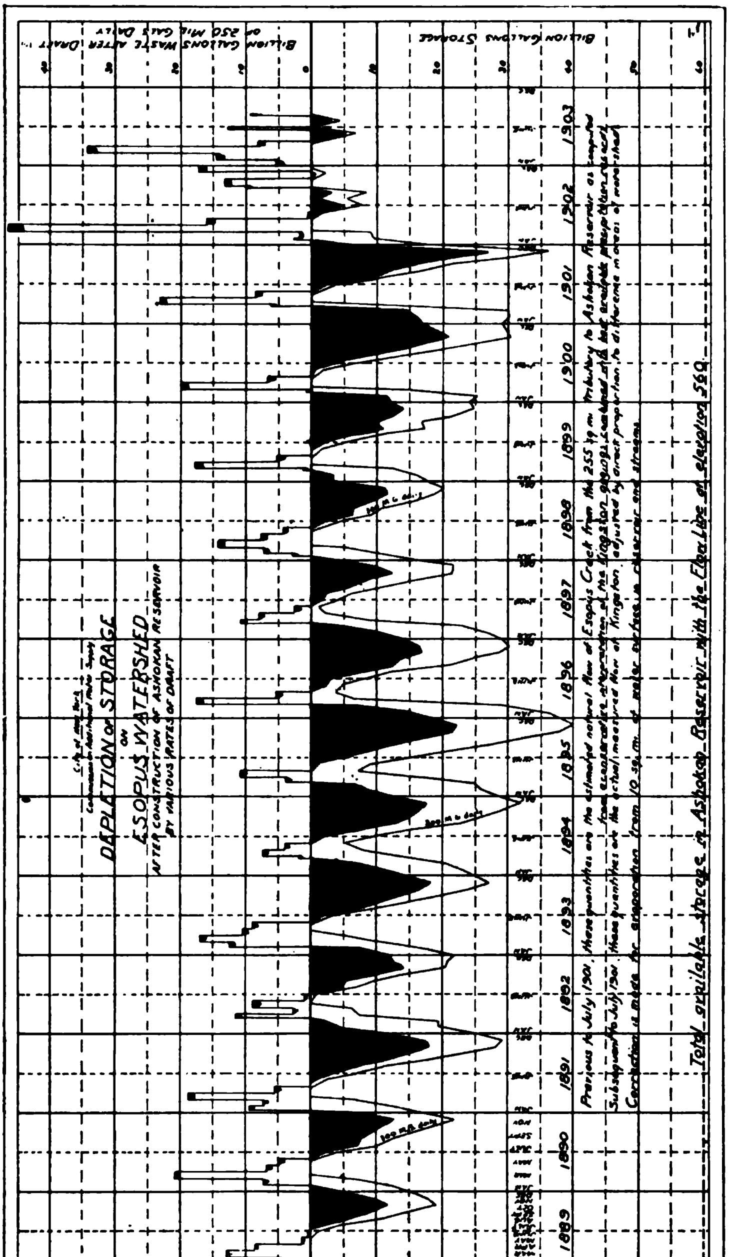


PLATE VII. APP. II.



PL. VIII. APP. II.

APPENDIX III.

Proposed Aqueduct Sections.

Appendix III.

PROPOSED AQUEDUCT SECTIONS.

E. G. HOPSON, *Department Engineer.*

These designs involve some novel features, based partly on previous works and partly on present studies. The proposed changes from existing types are, however, not extreme, and consist of certain modifications by which economy may be effected without any sacrifice of necessary strength or stability. This is especially the case with the design of the tunnel section.

The waterworks tunnels thus far built have generally been costly, as a rule averaging double or more than double the cost of an equal length of cut and cover work. The chief reason for this has been the costly nature of the material used for lining and the disadvantageous arrangements that have been adopted for excavation, whereby unnecessary and useless work was performed at a high cost. In the Wachusett Aqueduct, a considerable length of tunnel through firm rock was left unlined, and in consequence, built at a low cost. Circumstances are such that this method cannot be often adopted, for reasons hereafter mentioned. A decided step toward greater economy in tunnel work was adopted in the Weston Aqueduct by the use of Portland cement concrete as a tunnel lining. This material, so much cheaper than brick, has proved a conspicuous success for this purpose, and it has been largely used during the past few years for railroad and other work. The shape of tunnel used in the Weston Aqueduct does not, however, admit of all the economy that may properly be brought into a design for this aqueduct, as it necessitates a costly arch for the entire length.

In the proposed high level aqueduct, the great length of tunnel work will bring this matter of economical tunnel design into prominence and warrant an extended study of the question.

By the proposed design, the cost of tunnel work is expected to average not more than about 1 2-3 times the cost of cut and cover work, if built on the proposed gradients.

Carrying Capacity of Masonry Aqueducts and Tunnels.

The aqueducts have been designed to carry 500 million gallons daily when flowing at a depth of eight-tenths of the inside vertical diameter. The coefficients of flow used in the design are shown on sheet dated May 27, 1903, and entitled:

Curves of Coefficient " C " in formula, $V=C\sqrt{R S}$.

The data on which chief reliance has been placed are those obtained from the careful gaugings of the Wachusett Aqueduct, giving values of " C " corresponding to hydraulic mean radii of 3 and under. This curve of coefficients has been extended for higher values of " R " by paralleling the curve plotted from the original gaugings of the New Croton Aqueduct, and has been adopted for clean aqueducts. The highest value of " C " from this curve is 146.5, which is considerably lower than that given by Kutter's formula for values of " N " corresponding to a roughness equal to that of the Wachusett Aqueduct. As a matter of fact, it is evident that results obtained from Kutter's formula in computing flows in aqueducts of the size under consideration only approximate the true conditions, as will be seen by comparing the curve from Kutter's formula with the curve of actual coefficients obtained. This is no more than might be expected with any formula derived from experiment on a small scale.

A comparison of the curves of coefficients of the Croton, Sudbury and Wachusett Aqueducts and the Stony Brook Conduit, shows the unmistakable tendency of these curves to flatten out for the higher values of "R," and also the danger of estimating with higher coefficients than those shown by the curve adopted.

The Wachusett Aqueduct is brick lined to a depth of about 5 feet and arched with concrete. The bricks are laid with great nicety, and a true and smooth surface has been obtained; the concrete arch has been skim coated with cement, and finished with a cement wash applied with a brush, each stroke of the brush being lengthwise of the conduit. It is anticipated that the proposed aqueduct will have hydraulic properties at least equal to those of the Wachusett, and perhaps superior.

The capacity of the Sudbury Aqueduct has been diminished at times 13½ per cent. through the growth of slime on the inside surface, the Cochituate Aqueduct as much as 11¾ per cent. and the Wachusett from 10 to 11 per cent. It has been considered advisable to allow for a diminution of 12½ per cent. in the carrying capacity of the open trench portion of the proposed aqueduct, as a safe margin on this account.

The lining of tunnels has been proved to be clearly of inferior hydraulic qualities to those of the cut and cover work. The New Croton Aqueduct, practically an all tunnel aqueduct, shows materially lower coefficients than the Sudbury or Wachusett, although lined with the same material. The brick lined portion of the Wachusett Aqueduct tunnel has been found to approximate closely the Croton Aqueduct in this respect. On this account it has been considered advisable to use the coefficients of the Croton for the proposed tunnels when clean.

The concrete lining for the new tunnels will, at least, be as smooth as the rough brickwork of the Croton and Wachusett tunnels, although not so smooth as the concrete surface in the cut and cover sections.

In making an allowance for growth of slime in the tunnels, it has been considered that the carrying capacity of a tunnel which, when new, is much rougher than an open trench aqueduct, will not deteriorate so much as the latter. It is believed that the growth of slime inside an aqueduct retards the flow by an action differing essentially from that of a roughly constructed interior surface. The fine hair like filaments of the organisms forming the slime adhere or cohere to the layers of the water in contact with them, and by an action akin to that of eel grass on a larger scale, act as a brake on the velocity of the whole prism of water without necessarily causing eddies or swirls in the current. On the other hand, roughly constructed lining, or on a larger scale a rough rock surface will retard flow by causing eddies and swirls that deflect the current from a direct line of flow, and thereby cause obstruction and loss of head.

It is probable that the formation of slime on the sides of a rough unlined tunnel would not sensibly affect its carrying capacity, already extremely low; and by analogy, it seems fair to infer that with a lined tunnel of considerably rougher surface than a cut and cover aqueduct, the proportionate loss will be much less in the former than in the latter.

Mr. Freeman found that in the Croton Aqueduct, between Goulds Swamp Siphon and Ardsley, the original capacity had apparently not been diminished more than 4 per cent. after many years' constant use, although in the upper portions of the same aqueduct, the capacity had lessened much more. The loss of head in the upper portions of the Croton Aqueduct may have been largely due to growth of spongilla, or deposits of sediment or rubbish.

It has been considered sufficient to allow a reduction of 5 per cent. in the capacity of tunnels consequent upon the growth of slime. This will reduce the coefficients of both cut and cover aqueduct and lined tunnel to about the same amount when foul, and, taking everything into consideration, this appears to be based on fairly sound reasoning.

Using these coefficients, the section of cut and cover work has been designed to carry 500 million gallons, flowing at eight-tenths of its full depth, which will give a flow of 528 million gallons when flowing full and 549 million gallons when at its maximum capacity (about 92 per cent. of its full depth).

The coefficients used are those for foul aqueduct, that is to say, for an aqueduct coated with slime, but no allowance has been made for obstruction that may be caused by deposits of leaves, or rubbish, or the growth of spongilla. It has been considered that the aqueduct would be periodically cleaned and inspected, and any trouble from the latter causes would be removed at these times. The formation of slime in unfiltered surface water takes place with great rapidity, and cannot be prevented or held much in check by yearly cleanings. The reduction of flows in the Sudbury, Wachusett and Cochituate Aqueducts takes place very largely in the first few weeks after cleaning, and reaches a maximum after about four or five months' use; after that time apparently no appreciable increase takes place. As it is not practicable to clean and inspect an aqueduct oftener than at intervals of from six to twelve months, it is evident that the fouling due to slime formation will exist most of the time during operation to a greater or less extent. The larger and more serious obstruction will, however be removed or prevented from forming at each annual or semi-annual cleaning.

Cut and Cover Aqueduct.

The Weston Aqueduct, in Massachusetts, belongs, without doubt, to the most economical type of all masonry aqueducts of its size now existing. It is almost identical in general design with the Wachusett Aqueduct, built in the same State a few years before, both being part of the new Metropolitan supply, the only points of difference between the two aqueducts being of a minor character.

Prior to the construction of the Wachusett Aqueduct, the Sudbury probably represented the best type of cut and cover aqueduct construction in this country. The Old Croton Aqueduct and the Cochituate Aqueduct were the pioneers of this class of work in this vicinity, but both of them have developed serious structural defects. By comparing the various sections of aqueducts built at different periods, the approach to the horseshoe type of section is noted, which has, in a sense, become practically standard. The gradual introduction of concrete in the designs is also a matter of significance.

Brick is being displaced in the new designs, and rubble masonry has almost entirely disappeared. In the Wachusett Aqueduct brick was used for invert and side wall lining in the cut and cover sections, and for all tunnel lining. Brick was only used for invert and side wall lining in cut and cover sections of the Weston Aqueduct, but concrete was used for tunnel lining.

The chief reasons for the retention of brick lining are:

First—That it furnishes a hard, smooth inside surface of good hydraulic properties.

Second—That it is necessary to supplement the natural cement concrete or rubble backing with carefully laid brickwork to obtain good watertight work.

Third—The force of habit, or perhaps it would be fairer to say, the knowledge gained by experience that brick makes a very satisfactory lining.

All brick-work is expensive, especially when occurring in a four-inch lining where each brick has to be carefully lined up with great nicety and bedded with extreme care. First-class bricklayers and scrupulously careful inspection are required. Hence the total cost of the small amount of brick-work laid is out of all proportion to its actual value in the design. The use of the brick, moreover, necessitates the retention of the horseshoe shaped aqueduct, as it is practically essential to build the side walls at such an inclination as will prevent the brick lining from tending to separate from the concrete backing. In the proposed section the brick is entirely omitted, different classes of Portland cement concrete being used wholly. It is expected that some economy will result from the entire elimination of the brick from the section, and an especial advantage will be obtained by substituting work performed by common labor for that performed by skilled labor controlled by labor unions of uncertain temper.

A serious objection heretofore to the use of large monolithic masses of non-reinforced concrete masonry has been the tendency to crack through elongation or contraction due to temperature changes. With an aqueduct of large diameter these cracks are liable to cause serious leakage and even become a source of danger. Some cracks in the concrete arch of an aqueduct recently built, due to this reason, were observed to have a width of about 3/8 of an inch.

In the Wachusett Aqueduct it was found that in general transverse cracks occurred in the arch at places where a day's work had terminated during construction. This would naturally be expected as being the weakest point.

In the Weston Aqueduct lead water stops were inserted at intervals corresponding with a day's work in laying concrete, with a view to prevent any leakage at these points. It was noticed, however, that when an interval between these water stops was longer than about 50 or 60 feet, cracks had often developed between the water stops. In short, the conclusion formed after studying these aqueducts is that a complete vertical transverse joint may judiciously be inserted at intervals of about 50 to 70 feet in any concrete aqueduct of large size. In forming these joints, paper or soft soap or some other suitable material may be used to prevent any adhesion of the newly laid concrete to that of the section already built. Thus the aqueduct will consist of a series of short separate lengths, each of which will be practically independent. Leakage at the several joints can be easily prevented by inserting lead water stops built into the masonry, and by this means it will be reasonable to expect that trouble from transverse cracks will be obviated. Other effective measures may also be employed to overcome these difficulties.

This method of construction will also be of great advantage in cases where an aqueduct is built on embankment and settlements are likely to occur, as a considerable deflection from the true gradient through settlement of embankment may take place without rupturing the masonry or injuring the water stops.

It is proposed to shape the arch and side walls to a curve approximating a parabola, this shape more nearly coinciding with that of the true line of resistance of the arch under working conditions. The bottom inside corners are rounded off in order to distribute the thrust of the side walls over a larger area, and also for hydraulic considerations. The inside shape thus more nearly approaches a triangular than a horseshoe shape.

Portland cement concrete is recommended for the entire construction. The proportions of the concrete mixture should be determined by careful study of the sand, gravel and broken stone available for the work. A suitable balance of fine and coarse materials should be attained so as to secure both an impervious concrete and the strongest possible mixture with a given amount of cement. Special care should be taken to form all joints with strong and watertight bonds.

The bulk of the side walls and the invert may be of less rich concrete than the arch.

In the construction of a concrete aqueduct it is imperative to take such measures as will insure the interior surface being both durable and smooth. This will depend chiefly upon the kind of centers used and the character of the surfacing after their removal wherever that treatment may be necessary. It is the judgment of this Commission that in the construction of the aqueduct considered for the additional supply, means for accomplishing these ends should be the subject of further thorough and careful investigation, so as to give the highest possible hydraulic qualities to the completed channel.

Concrete Steel Aqueducts.

During the limited time available for the work of the Commission it has not been possible to complete extended studies for the details of concrete steel aqueducts, but they have been given full consideration and general designs have been made. The combination of steel rods and concrete required for this type of construction has already been the subject of much study and experimental investigation by engineers. There are a number of effective forms of steel rod sections available for this purpose, and experience with works already completed show that aqueducts of the highest excellence can be made of reinforced concrete. Wherever the steel reinforcement is used, the liability of the concrete to crack is greatly reduced, if not eliminated. The high degree of tensile resistance possessed by the concrete-steel material makes it specially valuable for the construction of the usual closed aqueduct section.

The general observations made in the preceding section regarding the best proportions for concrete holds with equal force for the reinforced material. The number, size and distribution of the steel rods required will depend upon the size of the aqueduct and the local conditions under which it is constructed, and these conditions have been recognized in the sections designed by the Commission. Before the construction of the aqueducts for the additional supply, all conditions affecting their strength and hydraulic qualities should be considered with scrupulous care, so as to attain the best results with the greatest possible economy.

Tunnels.

The horseshoe type of tunnel has been used in the New Croton Aqueduct, the Weston and Wachusett Aqueducts.

In the Weston Aqueduct concrete is now being used for a lining, but in the other two aqueducts, brick backed with rubble was the standard material for this purpose. The Wachusett Aqueduct was for a large portion of its length unlined except for paving on the invert.

The hydraulic qualities of the unlined tunnel were found to be so poor that it is necessary to run the aqueduct under a head in order to obtain its full capacity of flow.

To obtain the same flow through two tunnels of the same slope, the one unlined and the other lined, it has been found to be necessary to use a waterway for the former approximately double the sectional area of the latter, with tunnels of the size under consideration. To make an unlined tunnel of the required sectional area and depth, the width would have to be disproportionately great; so much so that it would be a matter of much difficulty subsequently to build side walls and arch, should such a step become necessary.

By smoothing up the rough surface of the rock excavation with concrete, the total cost of the tunnel will be as economical as if the lining were entirely omitted, and the general results will be much more satisfactory for obvious reasons. This fact was thoroughy explained by Mr. J. R. Freeman, in his report on "The New York Water Supply" of 1900. This side lining may be finished to serve as an abutment for an arch wherever it may be necessary.

APPENDIX IV.

Rainfall and Yield or Run-off of the Available Watersheds.

Appendix IV.

RAINFALL AND YIELD OR RUN-OFF OF THE AVAILABLE WATERSHEDS.

E. G. HOPSON and WALTER H. SEARS, *Department Engineers.*

The elevations, slopes, surfaces and rainfall of the watersheds are so different on the two sides of the Hudson River that it will be necessary to give separate consideration to those on each side. The watersheds of the Fishkill and Wappinger Creeks and of the Jansen Kill have comparatively small elevation and gentle slopes and are extensively cultivated. The rainfall is not much different in amount or in rate of precipitation from that of the Croton basin. The watersheds in the Catskill Mountain region, on the contrary, are characterized by many steep, wooded and rocky slopes, high elevations and are little cultivated. The rainfall is much greater in some portions than in others and as a whole is sensibly greater in amount than in the watersheds on the easterly side of the Hudson River. The rainfall and yield of the latter will be considered first.

Watersheds East of the Hudson River.

The climatic conditions prevailing over the Fishkill, Wappinger and Roeliff Jansen Kill drainage areas are similar to those of the Croton Watershed which the Fishkill adjoins and are not much dissimilar from the Sudbury and Nashua Watersheds of the Metropolitan Water Supply for the City of Boston.

The data regarding the rainfall and yield of the first three areas named above are meagre and extend only over limited periods of time. The examination and comparison of all existing evidence shows, however, that in consequence of the general similarity of conditions, reasonable conclusions regarding rainfall and yield of the three areas under construction may safely be drawn by the aid of the imperfect known data when compared with the more complete data of the Croton, the Sudbury and Nashua areas.

The only permanent rain gauges established either on or adjacent to these three watersheds are at Wappinger Falls and Red Hook on the Wappinger and Saw Kill Watersheds and at Canaan Four Corners and Old Chatham, both of the latter points being located a few miles north of the Roeliff Jansen Kill Watershed. Fortunately, the permanent records of the Croton basin have been taken closely adjacent to that of Fishkill Creek.

During a few months of the current year (1903) this Commission established rain gauge stations at Brinckerhoff and Matteawan, on Fishkill Creek, and at Rhinecliff and Saugerties, on the Hudson River. The records from these stations were made with care and furnish a comparison of value with other permanent records in this general vicinity, particularly those of the Croton Watershed, which have been maintained through a long series of years.

The records at Wappinger Falls, Red Hook, Canaan Four Corners and Old Chatham have been kept by voluntary observers for the Department of Agriculture and some of them are known not to be reliable. Mr. Robert G. Alle, Section Director of the Weather Bureau, states that the Wappinger Falls records are good and that those of Canaan Four Corners are fairly so, but that those at Red Hook and Old Chatham are less valuable. It appears from such examinations as have been made that the unreliable records fall short of the actual results in most cases. These records, however, are presented for what they may be worth. The following tabulation exhibits the results of the observations of this Commission for five months of 1903 and those for the same months from the Croton records and the voluntary observations of the Department of Agriculture:

Monthly Rainfall Records in Inches.

Months.	Com'n on Add'l Supply Observations.			Croton Records.	United States Voluntary Observations.			
	Brinckerhoff.	Rhinecliff.	Saugerties.		Wappinger Falls.	Red Hook.	C. F. C.	Old Chatham.
April	1.15	....	2.14	2.97	3.19	2.63	2.05	....
May	2.11	0.89	0.61	0.93	5.92	0.69	1.25	0.15
June	12.20	9.28	7.12	11.29	20.63	9.95	10.86	7.09
July	3.06	....	4.35	2.90	6.25	4.08	8.15	2.67
August	11.43	7.53	....	7.74	11.87	8.51	7.30	7.82

The next tabular statement is of distinctly greater value, as it extends through series of years ranging from two to thirteen. It exhibits annual rainfall records for these different stations, those belonging to Wappinger

Falls and the Croton area being directly applicable to the new available watersheds:

Annual Rainfall Records in Inches.

Year.	Nashua.	Sudbury.	Croton.	Wappinger Falls.	Red Hook.	C. F. C.	Old Chatham.
1890	....	53.00	54.05	....	....	....	....
1891	....	49.52	47.20	42.11	....	...	....
1892	....	41.83	44.28	46.68	...	....	....
1893	....	48.23	54.87	51.35	....	....	....
1894	....	39.74	47.33	38.12	....	....	....
1895	..	50.62	40.58	34.05	....	....	....
1896	....	43.70	45.85	46.98	....	....	....
1897	51.84	46.19	53.12	53.75	....	....	....
1898	57.92	55.88	57.40	54.10	....	....	....
1899	41.40	37.21	44.67	47.64	....	....	..
1900	52.46	50 65	48.11	43.48	30.51*	....	34.74
1901	55.70	56.11	64.23	59.80	38.38*	45.79	39.94
1902	48.58	46.07	53.28	55.36	52.40	46.78	....
Average	51.32	47 59	50.38	47.79	...	.. .	....

The comparison to be made by the aid of the results contained in this table is of marked value and it shows a strong similarity in the general features of the rainfall on the Croton, Wappinger, Nashua and Sudbury Watersheds. The records taken at Red Hook, Old Chatham and Canaan Four Corners are so meagre than they have little value in this comparison.

The next tabulation exhibits the monthly run-off or yield per square mile for the Fishkill and Wappinger Creeks for the entire time during which gaugings have been taken on those streams. The corresponding yields of the Croton River, the Sudbury River and Nashua River are given for the same period, so that direct comparison may be made between them. This table, if extended throughout a long series of years, would be of the greatest value in determining with accuracy the yields of Fishkill and Wappinger Creeks, but the observations of even a brief period are significant in demonstrating the relative yields of those two creeks as compared with other neighboring or similar streams for which records of run-off have accrued during a long series of years.

*11 months only.

Yield in Gallons Per Day Per Square Mile of Watershed.

Date.	Fishkill Creek (Watershed 186 Square Miles, 0.6% Water Surface.)	Wappinger Creek (Watershed 198 Square Miles Water Surface.)	Croton River (Watershed 338.8 Square Miles, 3.6% Water Surface.)	Sudbury River (Watershed 175.2 Square Miles, 6.5% Water Surface.)	Nashua River (Watershed 119 Square Miles, 2.2% Water Surface.)
1901.					
July	307,000	....	749,000	306,000	477,000
August	1,314,000	....	2,131,000	424,000	512,000
September	628,000	....	1,232,000	305,000	320,000
October	600,000	....	1,432,000	412,000	647,000
November	473,000	....	685,000	474,000	517,000
December	2,211,000	....	2,491,000	2,659,000	3,234,000
1902.					
January	2,135,000	....	2,223,000	1,763,000	1,676 000
February	2,107,000	....	1,529,000	1,674,000	1,401 000
March	4,746,000	....	5,638 000	4,199,000	3,992,000
April	1,590,000	....	1,759,000	1,885,000	2,159,000
May	976,000	....	982,000	743,000	1,031,000
June	466,000	....	458,000	303,000	410.000
July	562,000	....	422,000	66,000	292,000
August	304,000	....	352,000	135,000	297,000
September	310,000	....	322,000	178,000	241,000
October	1,031,000	....	1,246,000	506,000	950,000
November	673,000	......	860,000	444,000	635,000
December	2,625,000	....	2,827,000	1,779,000	1,848,000
1903.					
January	1,778,000	....	1,998,000	1,736,000	1,265,000
February	2,173,000	....	2,202,000	2,279,000	2,133,000
March	3,491,000	....	3,380,000	3,454,000	3,123,000
April	1,793,000	....	1,957,000	2,261,000	2,238,000
May	490,000	....	399,000	351,000	569,000
June	2,142,000	2,106,000	1,818,000	1,987,000	2,131,000
July	1,318,000	880,000	867,000	445,000	624,000
August	1,676,000	1,218,000	863,000	307,000	474,000
September	1,391,000	857,000	1,051,000	130,000	3,705,000
Totals	39,310,000	....	41,873,000	31,241,000	33,571,000

Records extending over a long series of years for such well known streams as the Croton, Sudbury and Nashua Rivers, furnish accurate bases for the determination of reservoir storage and depletion, not only in their own watersheds, but in others either adjacent or similar to them. The draft on reservoirs of a public water supply system is practically constant, but the waters are received into them with great irregularity. It is necessary, therefore, to establish certain general relations between the draft and the reservoir storage and depletion in order that the supply may be maintained at a desired rate. Tables bearing upon the storage of reservoirs subject to constant drafts during a period of unusual drought in the Sudbury Watershed, prepared by

Desmond Fitzgerald* have been much used by engineers designing storage reservoirs in the Eastern States, and the Commission has availed itself of this source of information.

The records for the Croton Watershed have been shown in the report on the water supply of New York City by Mr. John R. Freeman, March, 1900, to be similar to those for the Sudbury Watershed, and his studies of this question have also been made use of by this Commission.

The preceding tables and the comprehensive study of all the available data show that the rainfall and run-off of Fishkill Creek drainage area approximate very closely the corresponding features of the Croton Watershed; in deed, the Fishkill and Croton results approximate each other more closely than do either of those results with the Sudbury and Nashua Rivers. It appears from all the data available that the rainfall and run-off during the same periods, in the preceding tables, were materially higher for both Fishkill Creek and the Croton River than for the Sudbury and Nashua Rivers. As Wappinger Creek and the Jansen Kill are in the same vicinity with the Fishkill and Croton Watersheds, and as the meagre rainfall records show no great difference as far as they afford any comparison, it is probably safe to use the same general rainfall and run-off data for them as for the Croton River. At any rate, that is the best procedure that now can be followed, and there is reason to believe that judicious inferences drawn from experience in the Croton Watershed may safely be used for the three drainage areas lying north of it and east of the Hudson, especially as the general elevation above sea level, slopes and other physical features of these areas do not vary greatly.

In considering the available run-off from any drainage area, it is necessary to have clearly in view the minimum for a long series of years as the water value of a drainage area during dry years is obviously only the annual run-off of those years. It is also to be borne in mind that the percentage of rainfall available as run-off or yield decreases materially with the decrease in rainfall. Approximately speaking, that portion of the total rainfall running off as yield in the water courses of a given drainage area in the vicinity of New York and New England may average 45 to 50 per cent. Observations in the Croton Watershed extending over a period of thirty-four years, beginning in 1868, show that the average run-off is about 48 per cent. of the rainfall, but the lowest rainfall years may show a run-off as low as about 31 per cent. The dry condition of the ground during such years enables the soil to hold back in its interstices a considerably higher percentage of the rainfall on it than in years of greater precipitation.

* Published in the transactions of the American Society of Civil Engineers, 1892.

During the thirty-four-year period of 1868 to 1902 the four years of least rainfall in the Croton basin were 1872, 1876, 1880 and 1895, the least of the four (1880) being a total of 36.92 inches, which gives an average yield of only 603,000 gallons per square mile per day for that year. The next lowest rainfall year (1895) gave a total run-off of 15.95 inches, or an average daily amount throughout the year of 760,000 gallons per square mile per day. Again the average run-off per year for the entire thirty-four years was 22.93 inches, giving a rate of 1,094,400 gallons per square mile per day.

In view of the preceding data taken from the Croton Watershed it would clearly be unsafe to assume an average run-off as high as 1 million gallons per square mile per day from the three drainage areas on the easterly side of the Hudson. On the other hand it would be unnecessary and unjustifiable to assume a minimum as low as 603,000 gallons per square mile per day, which is the lowest year of the thirty-four. Three of the four years of minimum rainfall, to which allusion has been made, show very clearly the same total rainfall, and the run-off in none of the three years falls below 760,000 gallons per square mile per day. For these reasons, and after a comprehensive consideration of all the results of this investigation, it has been considered safe to take an average yield of 750,000 gallons per square mile per day for the purpose of estimating the value of the additional supply from the three drainage areas east of the Hudson River.

Furthermore, general experience with such watersheds as those of the Croton and Sudbury Rivers has shown that it is not practicable to make constant drafts of more than 750,000 to 825,000 gallons per day per square mile without keeping the storage reservoirs below high water level for periods longer than two years. The same experience has shown that it is not judicious to expose the margin of storage reservoirs below the high water level longer than a period of two years as a maximum in consequence of the objectionable growth of vegetation if the period of exposure is longer. In the designs and estimates relating to the storage and depletion of reservoirs in the districts of the proposed additional supply, this period of two years' exposure of the margins of depleted reservoirs has been taken as the maximum limit. In order to secure safely this limit the maximum average daily draft of 750,000 gallons per square mile of watershed has been taken as a basis on which to calculate all reservoir development in the Fishkill, Wappinger and Roeliff Jansen Kill Watersheds, proper allowance being made for the proportion of water surface to land surface in each of the areas.

Before closing this portion of its work, the Commission desires to record its most earnest expression of need for immediately establishing permanent rainfall and stream flow gauges on each of these drainage areas, so that accurate data may be available for use in the final designs of any of the proposed works.

Catskill Mountain Watersheds.

The establishment of rain gauges at various points in this territory was completed at the dates and points indicated in the following table. These instruments were standard 8-inch Friez gauges, except one 12-inch automatic tipping bucket gauge, installed on the roof of the hotel in West Shokan. All the 8-inch gauges are supported by wrought-iron frames on light platforms resting on the ground, with lip of gauge about three feet above surface of ground. The placing of each gauge was carefully considered and chosen with a view of giving a fair exposure. Efforts were also made to secure careful and intelligent local observers.

Table of Rain Gauges.

Date of Installation.	Location of Gauge and P. O. Address of Observer.	Elevation.	Name of Observer.
1903.			
April 7 ..	West Shokan, No. 1	530	S. K. Clapp.
April 21 .	West Shokan, *No. 2	575	S. K. Clapp.
April 10 .	Lake Hill	1,130	A. W. Cooper.
April 19 .	Prattsville	1,150	J. H. Brennan.
			A. A. Disbrow.
April 24 .	Highmount	1,890	E. T. Gale.
May 23..	Slide Mountain, No. 1	1,900	John Atkins.
May 23..	Shandaken	1,070	J. S. Whitney.
April 17 .	Preston Hollow	900	Geo. S. White.
April 17 .	East Durham	550	Frank Owen.
August 21	Slide Mountain, No. 2	3,000	John Atkins.
August 25	Plateau Mountain§	2,900	A. J. Connelly.
1900.			
April 1...	Kingston Reservoir°	340	E. H. Carroll.

These gauges were installed with a view to beginning permanent records in this territory where none have heretofore been kept and also for purposes of comparison with outside records for the current year.

Application was made early in the season to the Chief of the United States Weather Bureau for statistics of precipitation. Recent reports on canal surveys and other public documents were consulted and although many elaborate compilations of figures showing rainfall in New York were found presented in these reports it was soon revealed that there was a great dearth of reliable data for this immediate vicinity. With a view to making the most of the few available records and for the purpose of scrutinizing the original sources of information, as far as possible, a number of days were spent in Albany by Mr. D. W. Cole, Assistant Engineer, examining the various data

* 12-inch automatic electric registering.
§ P. O. at Edgewood, A. J. Connelly, Postmaster.
° Kingston Waterworks record, P. O. at Kingston.

on file in the offices of the United States Weather Bureau, the State Engineer and Surveyor and in the State Library. As a result of these researches it appears that all available data on this subject have their primary sources in the following group of statistics:

(*a*) "New York State Meteorology."
(*b*) "New York State Weather Bureau Reports."
(*c*) New York State Climate and Crop Service.
(*d*) United States Weather Bureau Reports.
(*e*) Certain special reports containing rainfall data, such as Croton records and various other waterworks records outside the State.

(*a*) The New York State Meteorology is composed of two quarto volumes of weather statistics which were collected and compiled by the Regents of the New York State Academy system, beginning 1826 and ending 1863. The late Prof. Guyot appears to have been actively interested in the methods of collecting these statistics and this is assuring as to their general reliability, although some of the individual records show abnormal features like that for Hudson, where the average rainfall is given as three times the minimum, an extreme variation not observed elsewhere in this region. The Kingston record shows values so different from late figures that it is thought best to disregard the older records. A study of the tables presented also reveals clerical errors and other discrepancies.

Several different types of rain gauges have been used at different periods. One of these gauges was wide open at the top with no guard against evaporation; another with cone shaped cover projecting above the lip of the gauge was ill adapted for collection of rainfall during wind storms.

The single record of this old series which seems applicable to the work of this Commission is that of Liberty, Sullivan County, which tallies very well with the modern Weather Bureau records. It has been used by several authorities with expressed confidence and is therefore given equal weight with the later figures.

(*b*) The New York State Weather Bureau Records are next in order of time and probably first in order of importance for this work. This Bureau was established by the statute of 1889 and the following distinguished officers were immediately appointed:

President and Superintendent of Instruction, Andrew S. Draper.

Director, E. A. Fuertes, Professor of Civil Engineering, Cornell University.

Consulting Meteorologist, E. T. Turner, C. E.

Their reports began with the annual summary for 1889 and ended with 1899, when the Bureau was merged in the United States Weather Bureau. They were published in monthly bulletins of pamphlet form, with annual summaries in book form. They contain daily, monthly and annual figures from a few stations applicable to the Commission's work for brief periods only, ranging from a few months to several years. These "Stations" are described, exposure of gauge and name of observer stated and a fair idea given of the relative accuracy of results. It seems probable that these records of the State Bureau are of special value, having been made under the supervision of able and experienced men. It appears that during this campaign of meteorological education, beginning with 1889, all existing records of the weather were brought to the attention of the active searchers of the Bureau and put into shape for permanent history. From an examination of these records, together with the descriptive text accompanying the reports, and, also from a study of the water supply features of recent Reports on the Barge Canal and of the Commission on Deep Waterways, in both of which precipitation figures were of great importance, it appears certain that all reliable records of railfall in this section of the State have been secured and published in one or another of the forms reviewed here.

(c) The Climate and Crop Service bulletins give monthly details which are afterwards condensed in the annual reports. They have been found useful in giving fragmentary records for a few months at a time, which do not always appear in the annual form, and for the records of the current year.

(d) The United States Weather Bureau reports give a continuation of the records begun by the State Bureau, with the occasional gain or loss of a Station here and there.

(e) The special records from fifty miles or more distant from the watersheds under consideration, are principally valuable in connection with the study of the yield of their respective streams, and as preciptation records solely they are not of great importance to the work of this Commission.

The best collections of statistics found have been derived wholly from these five primary sources, and are contained in the two Canal Reports previously mentioned. In addition to these, the full and elaborate tables in the calculation books of Mr. Kuichling on file in the State Engineer's office have been examined and used.

Access has also been had to a set of rainfall tables published by the Geological Survey of New Jersey.

Miscellaneous matter of interest has also been found in the United States Weather Bureau office and in the Astor Library of New York City. The United States Weather Bureau offices at Washington, D. C., and Ithaca, N. Y., have also furnished copies of certain records.

Appendix IV.

RAINFALL AND YIELD OR RUN-OFF OF THE AVAILABLE WATERSHEDS.

E. G. HOPSON and WALTER H. SEARS, *Department Engineers.*

The elevations, slopes, surfaces and rainfall of the watersheds are so different on the two sides of the Hudson River that it will be necessary to give separate consideration to those on each side. The watersheds of the Fishkill and Wappinger Creeks and of the Jansen Kill have comparatively small elevation and gentle slopes and are extensively cultivated. The rainfall is not much different in amount or in rate of precipitation from that of the Croton basin. The watersheds in the Catskill Mountain region, on the contrary, are characterized by many steep, wooded and rocky slopes, high elevations and are little cultivated. The rainfall is much greater in some portions than in others and as a whole is sensibly greater in amount than in the watersheds on the easterly side of the Hudson River. The rainfall and yield of the latter will be considered first.

Watersheds East of the Hudson River.

The climatic conditions prevailing over the Fishkill, Wappinger and Roeliff Jansen Kill drainage areas are similar to those of the Croton Watershed which the Fishkill adjoins and are not much dissimilar from the Sudbury and Nashua Watersheds of the Metropolitan Water Supply for the City of Boston.

The data regarding the rainfall and yield of the first three areas named above are meagre and extend only over limited periods of time. The examination and comparison of all existing evidence shows, however, that in consequence of the general similarity of conditions, reasonable conclusions regarding rainfall and yield of the three areas under construction may safely be drawn by the aid of the imperfect known data when compared with the more complete data of the Croton, the Sudbury and Nashua areas.

The only permanent rain gauges established either on or adjacent to these three watersheds are at Wappinger Falls and Red Hook on the Wapnormal, there can be written as an approximate value of mean annual rainfall at the given station 42.3 inches x 100:90 = 47 inches.

By extension of the formula a fair estimate can be made of the rainfall in each missing year of the series, and the mean of these weighted annuals is believed to be much nearer the true mean annual rainfall than that derived by merely averaging the annual values of ten years or less. This proposition is sustained by trial in the case of stations with full records.

Precipitation on Esopus Watershed.

In the absence of any records of even one complete year, within this territory, the assumption is made that the rainfall is approximately the mean of four stations situated a short distance outside of and in various directions from its limits.

For the purpose of compiling a record giving monthly values of precipitation on Esopus Valley for 15 years, beginning 1889, the records of the following four stations have been adopted as the most promising basis of computation.

(*a*) Kingston record of 3 to 10 miles east is made up of the Weather Bureau, Kingston-Rondout record, elevation of 200, years 1889-1893; the Kingston Water Works record at reservoir No. 1, elevation of 340, years 1900-1903, and the weighted values for intervening years as derived by methods outlined above.

(*b*) Mohonk record, 12 miles southeast is founded on Weather Bureau records for Minnewaska, elevation of 1890, and Mohonk, elevation of 1,245, for years 1891-1903.

(*c*) Liberty, 20 miles southeast, elevation of 1,500-1,800, Regents record for years 1850 to 1863 and incomplete Weather Bureau records for 1890-1903.

(*d*) S. Kortright, 15 miles northeast, modified by fragmentary records from Delhi, Bloomville, Oneonta, Griffins Corner, Windham, Tannersville, Elka Park and Lake Hill, all on the northwest side, at elevation of 1,500 to 2,000, for years 1889-1903.

These four records are assembled and combined on pages 38 to 40 of " S. & T., loose leaf " letter size calculation book " A " of the Commission's file, and much confidence is felt that the result represents closely the mean annual rainfall on Esopus Valley during the 14 years considered.

As to the relation between the mean of these 14 years and the true normal precipitation, it may be pointed out that for the same years Sudbury on the east showed 1 inch above its normal. Croton, southeast, showed 3 inches above normal; Albany, northeast, 3 inches below normal, while S. Kortright on northwest and Liberty on southwest quarters, the only two good, near records, showed exactly their normal precipitation. From this it is judged that the annual precipitation on this territory during the 14 years ending with 1902, was very nearly what long term records could prove to be the true normal, and this test is believed to be more conclusive than the present application of the frequently quoted Birnie formula for deriving the long term mean from averages of shorter terms of years by percentage corrections. Hence, it is estimated, that the mean annual precipitation on the Esopus portion of this territory is represented by the mean of these 14 years, viz.: 46½ inches. A further examination of "Precipitation Sheet No. 1," in connection with the map, will show that the area of greatest annual precipitation lies along the southern edge of this territory and from this zone of the maximum the records show a gradual decrease northward. Following out this general principle, there may be estimated from records shown:

Mean Annual Precipitation.

Rondout Valley	49 inches.
Esopus Valley	46½ "
Schoharie Valley	42 "
Catskill Valley	39½ "

As an independent check on these amounts, reference is made to Plate XXVII of Report on Barge Canal, 1901, upon which are shown isohyetal lines or contours of equal rainfall at intervals of 5 inches of depth.

The later records and the more specific application made in these computations tend to restrict the zone of 45-inch rainfall to a smaller portion of the Catskill area, but the general correctness of the chart is sustained by these estimates.

II.

YIELD OF STREAMS.

The principal basis for estimating the flow of the Catskill streams is the series of gaugings which have been carried on since July, 1901, by the United States Geological Survey, with the co-operation of the State and City of New York.

A detailed description of location, methods and results of these measurements to the end of 1902 is found in United States Geological Survey Water Supply Paper No. 76, by H. A. Pressey, and in Supplement to State Engineer's Report for 1902. A review of all the data for Esopus, Schoharie and Catskill Creeks and extension of them to July 1, 1903, is found in R. E. Horton's report of July 17, to Commission on Additional Water Supply.

A condensation, extension and analysis of the data from all these sources and from the local hydrographer at Kingston, Mr. Tillinghast, to October, 1903, has been made and used in making the estimates for this part of the work of the Commission.

Comparison of Yield.

The diagram herewith published as Pl. I. shows a comparison of yield of these four watersheds with that of the Croton, Sudbury and Wachusett for the same period. Referring to this diagram, it is observed that the yield of the four mountain streams is materially greater than that of the other three streams during the flood seasons of the year, and it averages greater for the series of 25 months. The rate of precipitation was substantially equal in amount above the normal for each locality, except in case of the Croton, which, notwithstanding its extremely high rainfall, gave much less discharge per unit of area of watershed than the Catskill streams. This unusually high proportion of rainfall delivered into the latter streams appears to require an explanation.

In the case of the Esopus, the figures given are those of the deduced record, as already described.

The Rondout rainfall is the mean of records at Mohunk and Liberty, on opposite sides of the valley and that for Schoharie and Catskill Creeks is based mainly on the single record at Windham in Schoharie Valley.

While it is believed that the deduced Esopus record is as good an estimate as can be derived from the data extending over the 15 years for which it is compiled, there seems to be no escape from the conclusion that the figures are somewhat too low for the two years' period covered by the stream gaugings.

Either the precipitation on the high mountain areas above all rain gauges must have been very much in excess of that shown by available records, or else it happened that within these two years there occurred (most probably during winter months) certain heavy local storms which did not appear at the widely separated rainfall stations.

During the summer spent in surveys in these mountains, there has been afforded opportunity for observing the local weather conditions in addition to the information given by the rain gauges.

It has frequently been noticed that during comparatively fair weather in the valleys the mountain tops have been enveloped in clouds, and local showers have been observed on the high slopes and in the " hollows " when no rain fell on the lower levels. At times there are days together when the mountains are folded in clouds and mists while fair weather prevails in the valleys. These conditions exist both in summer and winter, and it is probable that they sensibly affect the run-off of the streams.

The effect of these causes must be materially enhanced by the physical condition of at least a large portion of the high mountain areas in these watersheds. Actual observations show that the shallow substrata of much of these high areas are composed of fragments of broken rock, ranging from small size to great masses, on which mosses and scant vegetation, as well as trees, find opportunity for growth until they are destroyed by forest fires, denuding and laying bare the rock talus to which reference has just been made. Rainfall upon such a mountain slope quickly finds its way into the interior cavities, where it is completely protected from evaporation. In the winter large quantities of this entrained water freeze and remain there until gradually thawed by the warm weather of the spring and early summer. It is certain that masses of ice sometimes remain in these interior cavities as late as July. During the spring rains this mass of interior or stored ice acts not only in making the mountainsides impervious to the falling rain, but adds substantially by its thawing to the flow or yield at that time. In other words, the spring run-off is composed not only of an unduly large proportion of the rainfall in that season, but also of considerable portions of the late autumn and winter rain or snowfalls. While there is obviously serious lack of data regarding these winter storage effects, they are undoubtedly real, and account in a large measure, if not entirely, for the apparently abnormal spring yields of some of these mountain streams.

These conditions complicate the relation existing between rainfall and run-off. A great deal of study has been devoted to the formulation of data for determining the amount of stream-flow which may be expected from a given rainfall on a watershed of known characteristics, but, owing to the small number of streams for which adequate statistics have been collected, no general reliable statement can be made. The most enlightening recent consideration of the subject, as applied to this vicinity, is that of Mr. Kuichling, detailed in " Report on Barge Canal," page 795 *et sequitur*, and especial attention is called to the "Method of computing run-off," on page 800. The data so comprehensively marshaled for that purpose and finally reduced to the form of diagrams shown on Plate XXIX, can be made to serve as a basis for this local study. Accepting these diagrams as showing the *average* relation between the amounts of rainfall and run-off in each month of the year for the watersheds in this neighborhood, they have been replotted and are herewith published. For the purpose of adapting them to the Catskill territory, particularly the Esopus area, there have been plotted in addition all the data derived from the two years of gauging of the Catskill streams, using the rainfall values previously determined; the Croton data for the same period, and a number of years' data for the moderately high Tohickon and Pequannock Watersheds. These show that Esopus points are in most cases far above the original curves of averages and usually above the Croton points for the same period, while in the main the hilly Tohickon and Pequannock confirm the position of the Esopus points. In the month of March for both years, the Esopus curve is far above the average curve and all others, and it appears reasonable to draw the new curves much higher than is shown, but to keep well within justifiable limits the very conservative straight line is drawn. For the other months also moderate positions are taken for the straight lines or broken lines which are thought to represent probable results for the peculiarly prolific Esopus. As evidence of this moderation, it may be noted that the average monthly rainfall applied to the diagram would give 92 per cent. of yield for six winter months and 62 per cent. annually; whereas, the average of our two years of gauging shows an actual yield of 133 per cent. for the six winter months and 80 per cent. annually, with estimated rainfall of 15 per cent. to 20 per cent. above the normal. If 92 per cent. collected in the six wet months and 62 per cent. annually seem too high for average values, comparison is offered in the following:

Table of per cent. of Rainfall Yielded.

Name of Stream.	No. of Years, Record.	Per Cent. 6 Wet Months.	Of Yield Annual.	Authorities.
Esopus	..	92	62	Mean value from diagram.
Esopus	2	133	80	U. S. Geolog. Survey.
West Canada	2	150	68	U. S. Geolog. Survey.
East Canada	2	153	72	U. S. Geolog. Survey.
Schroon River	4	107	61	G. W. Rafter.
Schoharie	2	98	56	U. S. Geolog. Survey.
Upper Mohawk	2	124	60	U. S. Geolog. Survey.
Upper Hudson	12	91	57	U. S, Geolog. Survey.
Tohickon	14	90	57	Philadelphia Water Board.

Besides the high percentages of yield indicated above, there are many well authenticated reports of still higher values for streams of the British Islands and continent of Europe (see "Report on Barge Canal," pages 834-836); and in view of the scant information as to the run-off of these domestic mountain streams, it would be reasonable to expect that when fully gaged they will show results comparable with some of the precipitous European streams in zones of equal rainfall with our own.

The evidences of an exceptionally large yield for Esopus Creek may briefly be stated:

(*a*) Probabilities based on topography and climate, such as comparatively high elevation and steep slopes; the very large proportion of wooded area, about 80 per cent.; the combination of porous top crust of loose rock and forest floor with nearly impervious bed rock at shallow depth and the considerable area of gravel valleys, the absence of swamps and evaporating areas, the large precipitation and low mean temperature resulting in heavy rains in summer and cold storage of precipitation in winter.

(*b*) Common Report:

The Esopus is notorious as a stream of floods, and though it has been called a "flashy" stream, it is also known to maintain a comparatively good dry-weather flow, the grist mill at Bishop's Falls on the Esopus being the mill of last resort when all other neighboring mills have shut down for want of water.

(*c*) High Water Marks:

From Slide Mountain at its source to Saugerties at its mouth, the Esopus has scored high up on the slopes of the valley, and driftwood is found massed in caves or tangled in trees at elevations which are astonishing. In a recent flood, velocities of 20 feet per second and upward were observed at midstream on ordinary slopes of the river. And all its tributary streams have likewise scribed their own high records on the face of the landscape.

(*d*) By Actual Measurements:

There appears to be no ground for questioning the substantial accuracy of the gaugings of Esopus Creek as carried out after the well devised methods of the U. S. Geological Survey, and accepting these, it is conclusively shown that the yield of this stream is phenominally high. Results are exhibited by various tables and diagrams hereto appended. A matter of much interest is the monthly distribution and two-year total of Esopus yield, shown on Diagram IV. for period ending June 30, 1903. The comparison of run-off of Esopus Creek and Croton River, shown in Table III., is also significant.

Among the interesting features of this comparison, attention is called to the figures showing the rainfall and run-off during and after the great drought of May, 1903, the dryest May in the State of New York since the establishment of the U. S. Weather Bureau. Average conditions had prevailed early in the spring, then came the drought of fifty days, followed by floods of rain in June. On both watersheds the rainfall was measured by observers employed by New York City, the gauges of the Commission being well distributed for showing accurate results in Esopus Valley. Figures for Croton flow are also official, while Esopus flow is computed from Kingston gauging data after complete development of the curve of discharge and with every indication of correctness.

The table shows that the Esopus yielded from the floods after the great drought a proportion of the rainfall just twice as great as that of Croton.

Esopus Daily Yield, Storage and Depletion.

The key to the promise of large run-off from the Esopus area lies in the high summer rainfall, frequently concentrated in heavy storms, which afford great opportunities for the replenishment of reservoirs, and in the cold storage of winter precipitation which ensures large and sustained spring floods.

As a test of the capacity of Ashokan Reservoir with available storage of sixty billion gallons to sustain given rates of draft, computation has been made in calculation book "A," pages 41-46, for a period of fifteen years. In order to make this more readily intelligible, the results have been plotted on a diagram after the form employed in the "Freeman Report," and adopted by the Department of Water Supply for exhibiting similar data for Croton River. The computations are based on the compiled precipitation for the fifteen-year period already described, excepting, however, that the rainfall beginning with May, 1903, is the actual precipitation on Esopus Watershed as reliably measured, and the run-off beginning with July, 1901, is the actual flow of the river as derived from the gaugings at Kingston.

From the study of both diagrams it will be appreciated that the yield previous to 1901 is estimated with very large allowance for the possibility that the flow of the last two years has been unprecedented during the period considered, although there is little or no reason to believe in such a possibility. Or in case it is the rainfall that has been underestimated for the last two years, then the same allowance applies as a liberal factor of safety in using the diagrams as measures of the discharge which has taken place in the past and may confidently be expected in the future.

These diagrams include the dry years of 1894-'95-'96 and 1900-'01 (the latter period being locally known as an exceptional "dry spell"), and they afford strong support to the claim that Esopus Creek, from the total area of 255 square miles tributary to Ashokan Reservoir and with the 60,000 million gallons available storage in that basin, will safely sustain a uniform daily draft of 250 million gallons.

RONDOUT CREEK.

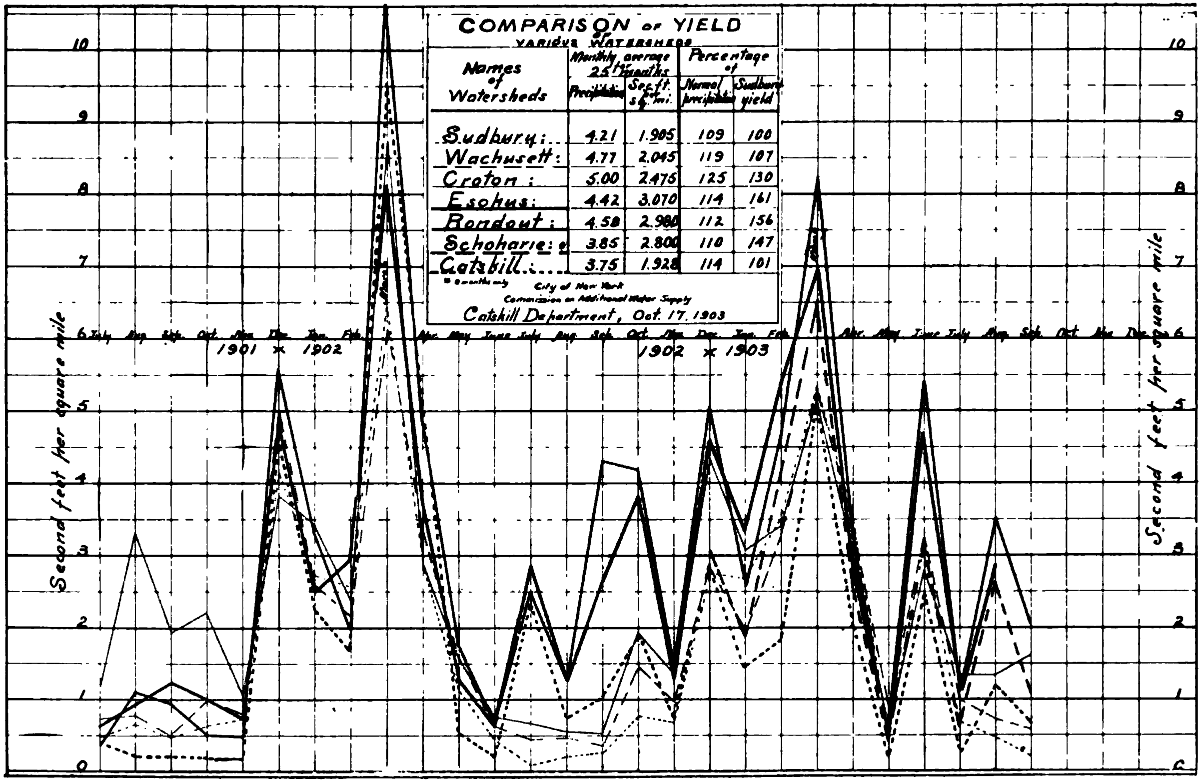
The valley of the Rondout lies in the zone of maximum rainfall and the gathering ground on the rocky and wooded slopes of the highest mountains is ideal. The quantity of water yielded per unit of area is second only to that of the Esopus, and the quality is equally excellent. By reference to the diagram of Comparison of Yield, it will be seen that the curve of discharge for Rondout Creek is parallel with and only a little below the Esopus curve. The portion of the watershed which it is proposed to develop is spread out like a fan on the rocky and wooded mountain slopes, and it is believed that this portion will give even a larger percentage of yield than is indicated by measurements plotted on the diagram which apply to the total drainage of the creek above the Rosendale gauging station. There is every indication that this upper Rondout country is a most promising field for development to the limit of its capacity.

SCHOHARIE CREEK.

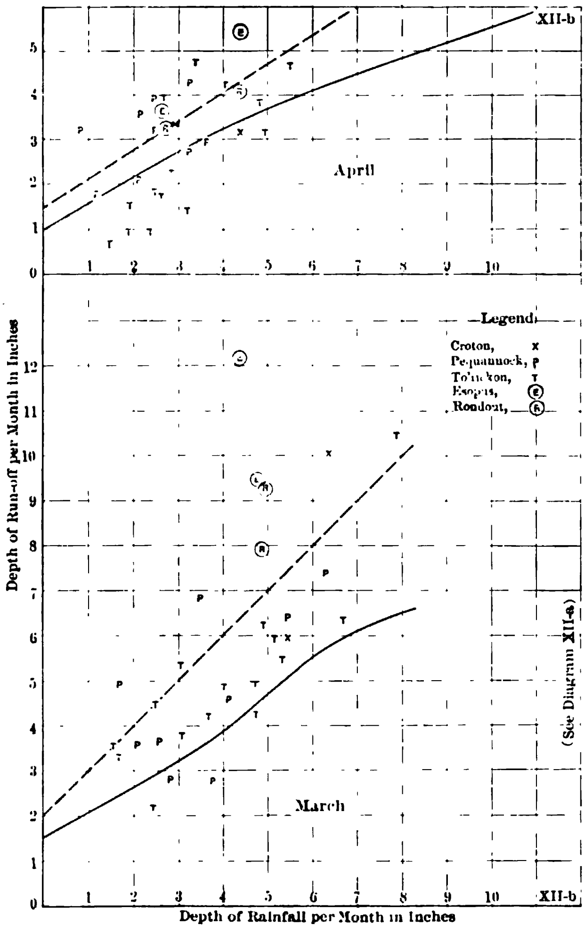
Schoharie Valley is in the zone of lower rainfall, but also in the heart of the mountain country which gives the highest proportion and best quality of yield. Unfortunately, there are gaugings for only a few months on this stream, and comparison with other streams is, therefore, limited to this short period. The diagram shows that with about the same percentage above normal precipitation the proportion of run-off is greater than that of Croton and other well-known streams, and exceeded only by Esopus and Rondout.

CATSKILL CREEK.

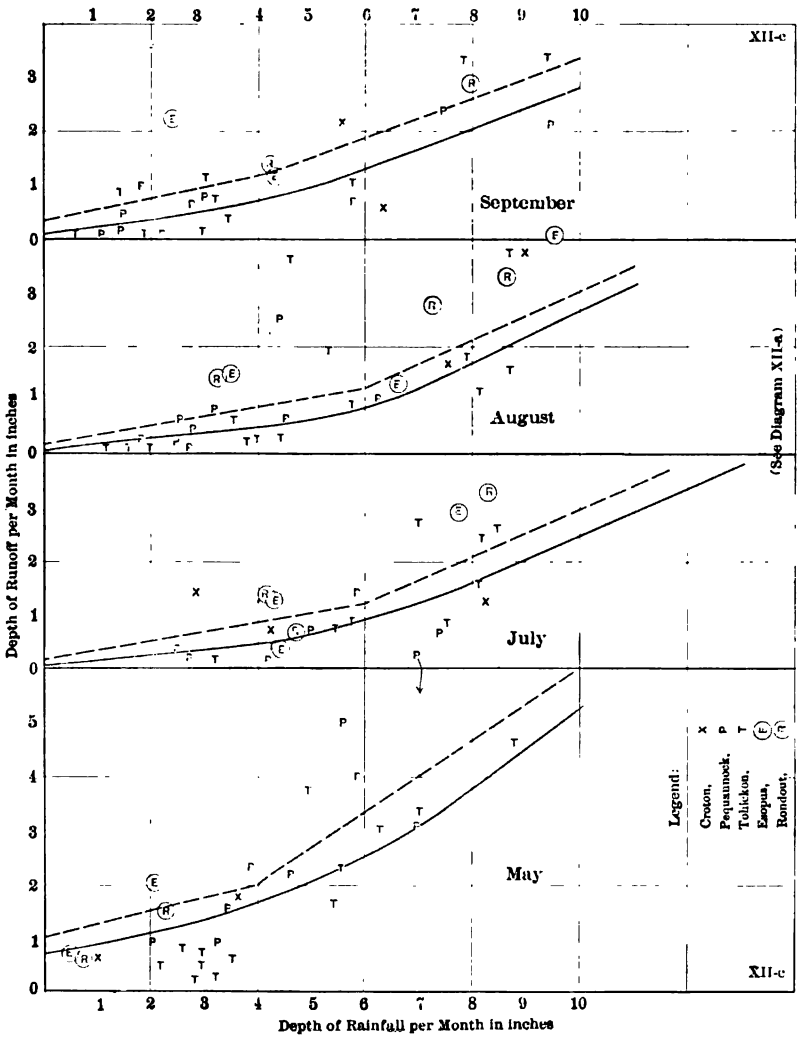
The Catskill Valley is mostly cleared agricultural land on the flatter slopes of the northern limits of the mountains. The precipitation is the least which appears on any of this territory, and the yield, especially for long periods in summer, is lower than that of the other streams. The quality of the water also is less satisfactory.


COMPARISON OF YIELD
VARIOUS WATERSHEDS
Names of Watersheds
Monthly average 25 months
Precipitation
Sec. ft. per sq. mi.
Percentage of
Normal precipitation
Sudbury yield
Sudbury: 4.21 1.905 109 100
Wachusett: 4.77 2.045 119 107
Croton: 5.00 2.475 125 130
Esopus: 4.42 3.070 114 161
Rondout: 4.58 2.980 112 156
Schoharie: 3.85 2.800 110 147
Catskill: 3.75 1.928 114 101
City of New York
Catskill Department, Oct. 17. 1903
1901 × 1902
1902 × 1903
Second feet per square mile
Second feet per square mile

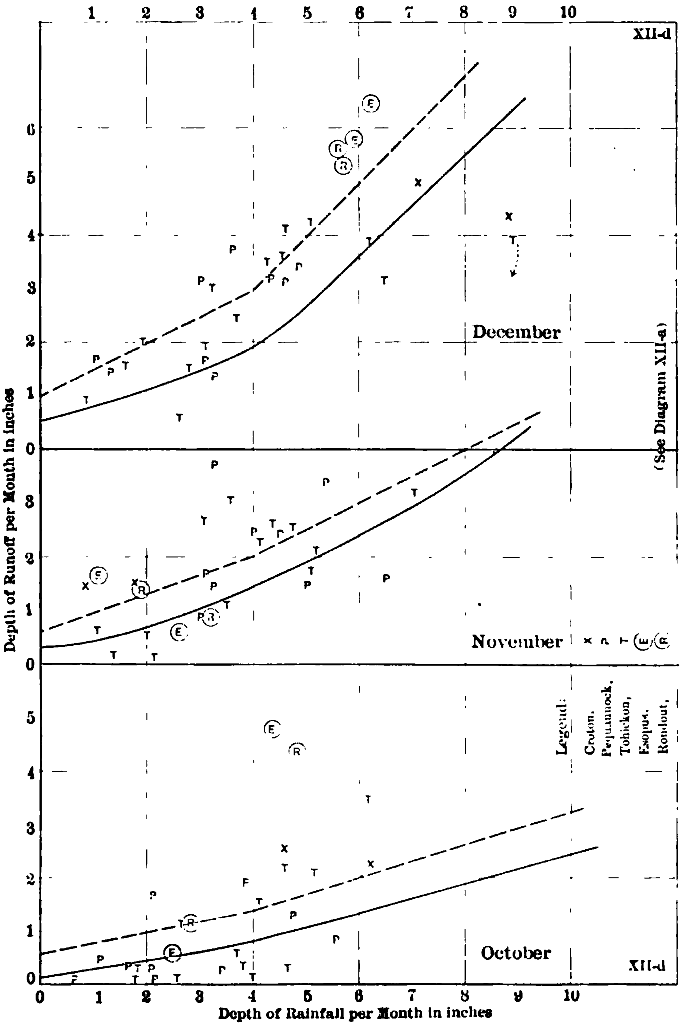
PL. I. APP. IV.


XII-b
April
March
Legend
Croton, x
Pequannock, P
Tohickon, T
Esopus, Ⓔ
Rondout, Ⓡ
(See Diagram XII-a)
Depth of Run-off per Month in Inches
Depth of Rainfall per Month in Inches

PL. II. APP. IV.


XII-c
September
August
July
May
(See Diagram XII-a.)
Legend:
Croton, X
Pequannock, P
Tohickon, T
Esopus, (E)
Rondout, (R)
XII-c
Depth of Runoff per Month in Inches
Depth of Rainfall per Month in Inches

PL. III. APP. IV.


XII-d
December
November
October
(See Diagram XII-a)
Legend: Croton, × Pequannock, P Tohickon, T Esopus, (E) Rondout, (R)
Depth of Runoff per Month in inches
Depth of Rainfall per Month in inches
XII-d

PL. IV. APP. IV.

APPENDIX V.

FILTRATION.

Appendix V.

FILTRATION.

WM. B. FULLER, *Department Engineer.*

INTRODUCTION.

In order to obtain a clear understanding of the recommendations of this Commission regarding the filtration of the future water supply of The City of New York, it is well to preface them with a general statement, showing what filtration practically means as applied to municipal water supplies, and particularly under the conditions presented by this City.

Spring water is the production of Nature's process of filtration, and gives the well known clear, colorless and pure water, free from tastes and odors. This process, in a general way, has long been understood, and for centuries various efforts cn a small scale have been made to imitate it by filtration in artificial ways.

Object to Be Attained by Filtration.

It is desirable first to inquire what work a filter has to do, and this is best shown by comparing the character of spring water with that of surface waters. As the population increases in the vicinity of large cities, it becomes more and more difficult to obtain from natural sources and with absolute safety, large volumes of water which can be used for domestic purposes in its natural condition. This difficulty results from the population resident on the watersheds, because there is no source of pollution so serious as that coming from the waste products of human life and activity. As is well known, there are many diseases, particularly such as typhoid fever and diarrhoeal diseases which can be transmitted by water, even when the water comes from areas comparatively sparsely populated and which, under ordinary conditions, may be considered a good safe water supply. There have been too many experiences like those at Plymouth, Pa., Providence, R. I., New Haven, Conn., and Ithaca, N. Y., where hundreds of people have contracted typhoid fever from drinking a water supply which was polluted by very few persons, in some cases not more than one, for such lessons to go unheeded.

Surface water supplies, therefore, in order to be made thoroughly safe, should be either filtered in a manner to remove disease germs, which they may carry from time to time, or else treated by some process producing the same or similar results.

Storage reservoirs are helpful to this end when they are large enough to prevent water passing through them until it has been stored for a period corresponding to the longevity of practically all disease germs in the water. In such storage reservoirs much assistance, of course, is derived from sedimentation, but this has its natural limitations, owing to the stirring up of sediment by changing velocities of flow, by the action of winds and by vertical circulation of the waters in deep reservoirs during spring and autumn months, due to temperature changes. Speaking generally, it may be said that sedimentation in reservoirs alone is a less efficient means for eliminating unsanitary products in water than filtration when conducted according to improved modern methods.

Nearly all surface waters as they flow off after heavy rains, are more or less muddy, due to the surface washings which they contain. Many waters also are unsightly in appearance, due to the deep vegetable stain which they possess; others contain vegetable growths such as are associated with objectionable tastes and odors. While mud, vegetable stain and those properties which produce tastes and odors are presumably incapable of producing disease, they certainly detract much from the palatableness of the water. At the outset of these investigations, it was the conviction of the Commission that the future water supply of New York should be free, not only from pollution, but also from odor, turbidity and noticeable coloring matter.

Early Filtration Works.

Filtration was first adopted in connection with municipal water supplies in the year 1829 at London, England. In its earlier years its sole function seems to have been the removal of visible suspended matters and the consequent improvement in the appearance of the water. Thus in the case of the turbid water of the Thames, the filters made it a bright clear water, or what is sometimes called a clean water. In the large centres of population in Europe this process gradually was adopted, its application being most rapid shortly after the middle of the last century, when it was learned in many instances that filtration improved the sanitary quality of the water, although it was not then known just how this was brought about.

The germ theory of disease, which established the relationship between the production of disease and infection by waters containing bacteria which had come from dejecta of patients sick of typhoid and other water-borne diseases, stamped a new phase upon the question of filtration, and beginning some twenty years ago the new science of bacteriology gradually led to the formulation of tenable views regarding the manner in which filters accomplish their work.

Filtration is now known to be able not only to remove silt, clay and other surface washings, as well as a considerable amount of vegetable stain, algae and the tastes and odors associated with them, but it is also capable of removing disease-producing germs. For our practical information as to the ways and means by which filtration is accomplished in a sanitary sense, we are indebted to many carefully conducted investigations, part of which were made in Europe, but the most notable of which was the series conducted by the Massachusetts State Board of Health.

Investigations of the Massachusetts State Board of Health.

In 1887 the Massachusetts State Board of Health established the Lawrence Experiment Station, where a remarkable series of carefully conducted experiments were made for the purpose of investigating various features of the filtration of liquid sewage and water through sand. These investigations were made from the general standpoint of engineering, chemistry and biology. Various test filters were constructed of a wide range of materials found throughout the State, suitable for purposes of filtration, including all grades between fine sand and coarse gravel. These experiments also included determinations of the effect upon the efficiency of filters of various depths of material and various velocities of flow. A great mass of valuable results have been recorded in much detail in the annual publication of the Board and its various reports have been regarded throughout the civilized world as contributions of great value to the science of filtration of both potable water and sewage.

Description of Filtration Works.

Filtration as practiced for the past seventy-five years in Europe and at a number of places in America, consists essentially in passing water downward through beds of sand of medium-sized grains, the sand layers being contained in water-tight basins and supported on graded layers of gravel. Ordinarily, the sand layer is three to four feet thick and the gravel about one foot. The raw water is pumped or flows to the filter basin and enters it above the sand layer, where it stands usually to a depth of three to five feet; thence it passes by gravity through the sand and enters the gravel, which is arranged in graded layers as stated, so that the sand is prevented from leaving the basin; thence it flows to the collecting pipes or conduits on the floor of the basin that connect with the main outlet pipes, which conduct the filtered water to storage reservoirs or to the pipes leading to the consumers. The individual filter beds or units range in size in different plants from about one-half to two acres, the smaller size being the more common. The structures are of masonry, and other than the sand layer itself their life is, therefore, long. In the climate of New York it is desirable to cover the filters so as to protect them from freezing weather.

In earlier years it was not understood how sand layers were able to remove bacteria, the size of which is not more, perhaps, than the one ten-thousandth part of an inch, which is only a small fraction of the size of the opening or pores of a sand layer. This was first explained in general terms by the investigations made at Berlin, where it was pointed out that there was formed at the surface of the sand layer a deposit of "bacteria jelly," so-called, or "dirt cover," which, being gelatinous in its nature, retained bacteria until they were either removed or died there. While it is now known that clay, suspended organic matter, and other materials in water, are capable of forming films upon the sand grains and allowing bacteria to adhere to the surface, this adhesion hardly justifies the importance attached in earlier years to the so-called bacterial jelly. But the fact remains that with practically every water encountered in this section of the country, the sand layer soon became coated with films capable of reducing the numbers of bacteria, as the water leaves the sand layers, to about 1 per cent. or two per cent. of those present in the water before filtration. The majority of the bacteria in the unfiltered water are retained at or near the surface of the sand layer, by the gelatinous films covering the sand grains to a depth of a foot or so below the surface.

As the suspended matters accumulate at and near the surface of the bed, the upper half inch or so requires to be removed from time to time, generally once in about four weeks, but varying from two to eight weeks. The clogged material is scraped off by laborers with shovels, who enter the filter beds after the water has been drawn off. The dirty sand is washed and replaced upon the sand bed. The loss of head, or the pressure required to overcome the friction which the water meets in passing through the filter, is generally allowed to reach three or four feet before a filter is scraped.

The speed or rate of flow of water continuously percolating through a sand layer, is usually about four to five inches vertical velocity per hour, equal to a yield per square foot of about three gallons per hour, or in the neighborhood of three million gallons per acre per day. In most cases this rate is regulated by changing a valve (operated automatically or by hand) on the outlet pipe, but as it is important to guard against serious fluctuation in the rate of filtration, the flow of water, through the filter, is best controlled automatically.

Sanitary Results Achieved by Filtration.

In Europe there are now more than twenty-five millions of people who are supplied with filtered water, which with few exceptions has been filtered under conditions, both as to construction and operation, which are approved by local or state sanitary authorities, or both. Largely as a result of the use of filtered water, the deaths from water-borne diseases in the large towns and cities of Central and Western Europe have become reduced almost to a minimum. In fact, typhoid fever death-rates in European cities, generally speaking, are only a small fraction of those found in American cities. From Table 4, Appendix VI., containing the annual typhoid fever death-rates in American cities, it is seen that the rates are found frequently within the limits of 50 to 100 per 100,000 population per annum, but that the average is about 35. It is significant to compare with these rates those of European cities supplied with filtered water, and where the rates range from 5 to 15 per 100,000, as shown by the following average rates for typical cities for the years 1890-'95.

European cities using filtered water:

	Average Annual Typhoid Fever Death Rate per 100,000.
Berlin	8
Breslau	10
The Hague	6
London.	15
Rotterdam	5
Zurich.	8

Perhaps the most striking illustration of the benefit of filtration was afforded by the well-known experience of the cities of Hamburg and Altona, during the cholera epidemic of 1892. These cities are situated side by side on the right bank of the Elbe, and both take their water supplies from that stream, the Altona intake being placed but a few miles below the point where the sewers of Hamburg discharge into the Elbe, the sewage of nearly 800,000 people. The two cities are practically one, being built up thoroughly to the dividing line on each side. In the winter of 1892-93 when the cholera visited the valley of the Elbe, Hamburg, which used the unfiltered Elbe water, suffered severely, as is well known, from that disease, while Altona, which used the same water, after it had been further polluted by the cholera polluted sewage at Hamburg, but filtered it, had only a relatively few scattering cases, which were generally traceable to the use of Hamburg water by transient visitors to the adjoining city.

Filtration of Surface Waters Practically Compulsory in Germany.

As a result of wide experiences, including that with the cholera at Hamburg and Altona in 1892, the Imperial Board of Health of Germany has issued an edict making it practically compulsory for all German cities to adopt filtration works for water supplies drawn from surface sources. Not only is there an edict as to the adoption of filtration works, but (for the better protection of the health of water consumers) there is a series of rules and regulations which are faithfully lived up to both regarding the essential features of construction and of operations of the filters. These relate to the kind and to the rate of filtration, loss of head and other technical details, all of which are kept under control by daily observations and analyses.

Comparison of the Sanitary Character of Filtered Surface Water and that of Ground Water.

Illustrative of the sanitary quality of surface water taken as a source of supply by leading German cities and filtered as compared with that of ground water supplied to corresponding cities in the same country, the following comparative table of typhoid fever mortality, taken from an exhibit offered at the Paris Exposition (1900) by the Imperial Board of Health of Germany, is presented:

AVERAGE TYPHOID FEVER DEATH RATE IN GERMAN CITIES OF OVER 1,000,000 POPULATION, FOR THE YEARS 1896, 1897 AND 1898.

Filtered Surface Water.		*Ground Water.*	
Stuttgard	4	Munich	3.6
Chemnitz	4	Dresden	4
Berlin	4.6	Charlottenburg	4.3
Altona	6	Nuremburg	4.6
Magdeburg	6	Hanover	5.3
Hamburg	6		
Bremen	6	Crefeld	6.3
		Elberfeld	6.3
Brunswick	8.3		
Breslau	8.6	Aix-la-Chappelle	7.3
		Barmen	8
Koenigsburg	17.6	Leipzig	8.3
Stettin	20.6		
		Cologne	9
		Manheim	9.3
		Cassel	1.3
		Flensburg	11.3
		Strasburg	12
		Dantzig	12.3
		Halle	13
		Essen	13.6

Statistics corresponding to the above are also available for the smaller German cities, so that it may be fairly said as a general conclusion that, with other sanitary conditions the same, it is possible by means of filtration so to purify surface waters that they may be substantially equal in purity to ground water of the best quality.

General Adoption of Filtration Works in Europe as a Precautionary Measure.

In the densely-populated sections of Europe the larger cities which derive their supply from surface sources are following the general lines which have perhaps been crystallized more sharply in Germany than elsewhere. This applies not only to those municipal water supplies which have their source in streams that are quite polluted, but also to those supplies drawn from comparatively distant sources where the opportunities for pollution are accidental and infrequent.

Perhaps the most striking illustration of this is afforded by the recently constructed extension to the water works for the supply of the city of Liverpool, England. The water is taken from a comparatively uninhabited region in the Welsh Mountains and impounded there in large reservoirs. Before this water reaches the consumers, however, it is carefully filtered, largely as a precautionary measure.

Early Filters in America.

In America various devices and contrivances in earlier years were adopted in different parts of the country in imitation of filtration as carried on in Europe. Most of them could be better classed as strainers rather than filters, and it was not until 1870 that this subject was moderately well understood by our own water works engineers. This information was first made available largely through the admirable report made by the late Mr. James P. Kirkwood, of Brooklyn, on "The Filtration of River Waters," resulting from several trips of inspection to Europe at the instance of the Water Commissioners of St. Louis, Mo., to which Board he was at that time chief engineer. It is of interest to point out that several features later adopted in filtration works abroad resulted from suggestions made by Mr. Kirkwood, as his report, which was translated into German, remained for an entire generation the leading work upon this line of water works engineering.

While the filters recommended by Mr. Kirkwood for the treatment of the muddy Mississippi River water at St. Louis were never built, there were several plants which were constructed in accordance with his designs, notably those at Poughkeepsie and Hudson, N. Y., which are still in service in preparing the Hudson River water for the use of consumers in their respective cities. These plants, now some 30 years old, have been examined by this Commission, which has also had access to frequent analyses and detailed observations made regarding their efficiency as regularly operated. While these filter plants have not the modern improvements which would facilitate their operation, nor are they provided with covers to protect them from the formation of ice to a disturbing degree in winter weather, they are nevertheless producing a water which, due to its filtration, is far superior to that of the raw Hudson River water.

For twenty years following the construction of the filters at the cities noted on the Hudson River, practically no progress in the application of filtration works to American water supplies was made, due largely to the various doubts then existing as to the sanitary benefit of filtration in the absence of the definite establishment of the germ theory of disease, and partly to the uncertainty as to the cost and efficiency of operation under the widely varying conditions in the character of rivers as found in America, particularly in the southern and western sections.

The Filter at Lawrence, Mass.

An important epoch in the development of water filtration in this country was marked by the construction of the filters built for the purification of the city water supply of Lawrence, Mass., and completed in 1893. This city is situated on the Merrimack River, about eight miles below the city of Lowell, the sewers of which discharge directly into the river. Severe typhoid fever epidemics occurred in the Merrimack Valley, especially at Lawrence, for several years prior to the construction of the filters. The appearance of cholera on a vessel in New York Harbor in the autumn of 1892 was instrumental in leading the city government of Lowell to place at the disposal of the Water Board such sums of money as were available from their limited funds for the construction of filtration works. Construction was carried on under the guidance of Mr. Hiram F. Mills, engineer member of the State Board of Health, and was based, in a large measure, upon the results of carefully conducted investigations made by the Massachusetts State Board of Health under his direction into the fundamental principles controlling the purification of water and sewage at the Lawrence Experiment Station.

Effect of Lawrence Filter upon the Prevalence of Typhoid Fever in that City.

As to the efficiency of the Lawrence city filter, which is 2½ acres in area, uncovered, and has a normal capacity of 5,000,000 gallons daily, it may be said that the filter has succeeded in reducing the typhoid fever death-rate in that city, while still using the highly polluted Merrimack River water as a source of supply, down to as low limits as generally found in the case of those American cities supplied with pure ground water. This is shown by the following table of typhoid fever statistics of the city of Lawrence for five years before and five years after the introduction of filtered water. The latter rates are as low as those now obtained in the neighboring city of Lowell, which formerly was supplied with raw Merrimack River water, but which in 1897 changed to a ground water supply from unpolluted sources.

Annual Typhoid Fever Death Rates per 100,000 Population in Lawrence, Mass., for Five Years Before and Five Years After the Adoption of Filters.

	Year.	Typhoid Rate.
5th year before filtration	1889	127
4th year before filtration	1890	134
3d year before filtration	1891	119
2d year before filtration	1892	105
1st year before filtration	1893	80
1st year after filtration	1894	47
2d year after filtration	1895	31
3d year after filtration	1896	19
4th year after filtration	1897	16
5th year after filtration	1898	14

Prior to the construction of the Lawrence filter, in 1893, the aggregate area of all filters in this country did not exceed one and one-half acres, having a rated capacity of about 3,500,000 gallons daily. Since that time progress in the field of water purification in America has been rapid and substantial.

Filter at Albany, N. Y., and Results Accomplished by it.

The next important filtration plant of this type following the Lawrence filter was that constructed in Albany, N. Y., for the purification of the polluted Hudson River water at this point, and which has been in serviec since September, 1899. These works were constructed on somewhat more modern lines, and with more liberal allowances as to available funds than at Lawrence. Hence they represent a composite effect combining to a large degree the salient features both of the Lawrence investigations and of the more recent experiences in water filtration as practiced in Europe. In brief, it may be said that this plant consists first of a settling basin holding about twenty-four hours' supply, and of eight covered filters, each having an area of seven-tenths of an acre. The sand layer is four feet thick, supported by about twelve inches of graded gravel. The structures are built of concrete, with brick linings to the filter walls. The covers are built as groined arches. This filter is operated on the continuous, not the intermittent, plan. The efficiency of this filter, which has been, up to this time, well operated, is shown in the following table of annual typhoid fever death rates.

Annual Typhoid Fever Death Rates per 100,000 Population in Albany, N. Y., Before and After the Adoption of Filters.

	Year.	Typhoid Rate.
5th year before filtration	1895	165
4th year before filtration	1896	99
3d year before filtration	1897	86
2d year before filtration	1898	94
1st year before filtration	1899	87
1st year after filtration	1900	51
2d year after filtration	1901	24
3d year after filtration	1902	28

In examining this table it is, of course, to be borne in mind that the city of Albany is supplied in part with unfiltered water from small gravity streams, and that this explains the turbid appearance from time to time of part of the supply as delivered to Albany consumers.

Efficiency of Slow or Sand Filters in Removing Mud and Vegetable Stain.

This type of filter, which is sometimes called the slow filter or sand filter, and sometimes referred to as the English filter, is generally considered to be the most applicable for the purification of waters which are not highly turbid or highly discolored by vegetable stain. In the treatment of the muddy waters of the South and West it has its limitations, as it has been found that it is hardly feasible satisfactorily to treat water by this type of filter which has a turbidity for many days in succession in excess of 75 parts per million, silica standard.

This does not mean, however, that its field of usefulness is as limited as might seem off-hand, as it is perfectly feasible in many cases to reduce either the vegetable stain or the turbidity prior to its delivery to the filters, by means of preliminary treatment such as that afforded by certain types of preliminary filters, and by sedimentation basins either with or without the aid of coagulation produced by various chemicals.

Of the various waters under consideration by this Commission, that of the Hudson River during freshet periods has the highest degree of turbidity, which would make it necessary or desirable to give it some preliminary treatment in order to prepare it properly for filtration. It is possible that at rare intervals the effluent of the sand filters treating the Hudson River water in the vicinity of Poughkeepsie might be distinctly cloudy, but it is not believed that these periods would be of sufficient frequency or duration to effect seriously the sanitary character of the water. A thoroughly satisfactory effluent could be regularly obtained on all occasions from the Hudson River by the slow sand filter, were a small amount of coagulant, such as sulphate of alumina, added to the water prior to its entrance into settling basins at times of great turbidity; or other means without the use of alum are also available.

With these works properly built and properly operated, there is no longer any room for doubt as to their efficiency, notwithstanding the frequent references made to the prevalence of typhoid fever in some places, alleged, by opponents, to be due to using filtered water. In some instances these criticisms may have been just, but they are readily explained either by features of improper construction or of improper operation, both of which conditions, as has been well learned by several generations of experience in Europe, are absolutely inadmissible in view of the health of water consumers.

Rapid or Mechanical Filter as Used in America.

There is another type of filter which has become widely used in the last few years in this country. It consists of sand layers arranged in small units, generally less than 1,000 square feet each, through which water is passed at very rapid rates, perhaps 40 times as fast as through the slow or sand filters. This makes a rate of filtration equal to about two gallons per square foot per minute, corresponding to a vertical velocity of about 16 feet per hour, or about 125 million gallons per acre daily.

This type of filter depends for its efficiency almost entirely upon the gelatinous material obtained from the decomposition of a small quantity of sulphate of alumina or iron or similar substance (about 1 grain per gallon). The resulting product of aluminum hydrate (or iron hydrate) forms the necessary gelatinous films around the sand grains so as to permit the bacteria to be retained there, to be removed later by a cleaning process. The latter consists in allowing filtered water to pass upward through the sand layer at a sufficiently high velocity to float the sand grains of the entire layer and to remove the greater portion of the suspended matter attached by stirring of the sand, either by means of compressed air under a low pressure or by revolving rakes.

This style of filter had its origin in the industrial works of America, where it was used for clarifying waters for mill purposes. When first introduced for the purification of municipal water supplies, some twenty years ago, it was a very crude affair, arranged as a series of tubs, and engineers and sanitarians were sceptical as to its hygienic merits. They were also disposed to be somewhat prejudiced against the use of a coagulant, notwithstanding the fact that this process is many centuries old, and has been used for many generations in this country in clarifying muddy river waters in the South and West. So long as no undecomposed sulphate of alumina enters the filtered water, it may now be confidently stated that there is no evidence whatever to show that this treatment is in any way injurious to those who drink water purified by it.

This type of filter is variously spoken of as the rapid or mechanical or American type of filter, and its scientific merits have been carefully worked out in series of investigations made during the past ten years, at Providence, Louisville, Pittsburg, Cincinnati, Washington, New Orleans and Harrisburg.

There are nearly 200 small filter plants of this type now in service in this country, most of which are employed for the clarification of muddy waters in the South and West. The plants are operated essentially to clarify the water during the freshet periods, rather than to produce a high sanitary grade of water at all times. Consequently, the effect of these filters upon the death rate from typhoid fever among the people using water so filtered, has not, generally speaking, been entirely satisfactory, although there are some exceptions to this general statement, as the instances of York, Pa., and Lorain, O. Notwithstanding this evidence, which is precisely similar to that obtained with sand filters in their early days, it may be definitely stated that filters built in accordance with the knowledge now available concerning this method, will, if well operated, produce satisfactory results.

Plants of this type, as built a few years ago, bear but little resemblance to the works of recent design, either as to efficiency, durability or conveniences of careful and systematic operation. Filtration works completed by the East Jersey Water Company, in 1902, at Little Falls, N. J., for the treatment of the water taken from the Passaic River and supplied to Paterson, Passaic and neighboring smaller cities, are perhaps the best example of modern works of this type representing the scientific development of this method of filtration.

While this type of filters is generally more applicable to the treatment of muddy waters, and waters deeply stained with vegetable matter, its field of usefulness also extends to nearly all types of waters for some particular cases where land is expensive or limited in available area, on account of the much smaller amount of land required as compared with the other type of filtration works.

Storage of Filtered Water in Reservoir.

After a water supply is filtered, it is best to store the pure water in covered reservoirs and not expose it to the atmosphere. Bright, colorless filtered water when exposed in open reservoirs will generally develop green vegetable (algae) growths more quickly than in the case of the water in its raw condition; while covered filtered water reservoirs are not always essential, they are always to be preferred, and should be provided where practicable.

SUMMARY OF WORK OF THE DEPARTMENT.

The following pages contain a brief description of the manner in which the detailed work of this Department was carried on, including an outline of the various projects considered, a description of the filter site and the filter plant recommended for adoption, together with estimates of its cost, both of construction and of operation, as well as specifications for the manner of constructing the filters shown on the plans which accompany and form a part of this report.

Work of Field Force.

The efforts of the field force have been applied to the discovery, surveying and mapping of all areas suitable for filter sites, the locations and elevations of which were such as to accord with any of the projects of water supply extension which have been considered. In addition to the survey of filter sites, a part of a reservoir site for impounding the water of Wappinger Creek was surveyed in the vicinity of Pleasant Valley, also a site for a "wash water reservoir" south of Stormville, and also a part of a site for a covered reservoir at Hill View.

The basis of all this work has been the published maps of the U. S. Geological Survey, without the assistance of which such an investigation would have taken a much longer time. As portions of the Geological work, however, were done a number of years ago, by less accurate and complete methods than those now in use, and as the contour interval of the Government maps (20 feet) was too large, even if accurate, to show the ground adequately, it was found necessary to make independent surveys of all plots that gave promise of being useful.

First of all, a careful reconnoissance was made of all the available country which the Government survey maps indicated as in any degree suitable for filter sites. This work consisted for the most part in driving over all the roads and walking over the intervening territory not readily observed from the highway; taking notes of the general topographical and geological features bearing on the problem, and from these observations determining the sites which it would be desirable to examine closer by instrument survey.

As a next step, lines of levels had to be run to determine the elevation of certain points above the sea level. Here, again, the U. S. Government results were invaluable, as the elevation of many points along the Hudson River had been very accurately determined by the Government engineers. Starting at one of the Government points at Fishkill Landing, levels were run through Hopewell and Stormville and from Hopewell north through Freedom Plains to Pleasant Valley, and thence to another Government point at Poughkeepsie—about thirty-five miles in all. This line of levels furnished the basis of elevation for the surveys in Duchess County. Another line of levels was run from a Government point in Tarrytown through Elmsford to White Plains, southerly and back again—fourteen miles in all—to use as a basis of elevations for surveys in that vicinity. Further levels in that vicinity were supplied by the Aqueduct Department.

Based on the above levels, stadia surveys have been made of areas at Brinckerhoff, Fishkill, Stormville, Freedom Plains, La Grangeville and Pleasant Valley, in Duchess County, and at Hill View, Elmsford, Scarsdale and Greenville, in Westchester County. This work has involved the surveying of 41 square miles of territory, the running of 290 miles of traverse lines and the taking of about 40,000 independent observations of elevation and distance. The surveys were made entirely by the stadia method, no tape or wye-level being used in connection with them. A sufficient number of points on the ground were taken to admit of the interpolation of 5-foot contours with fair accuracy.

The detached position of the plots surveyed made it desirable to ascertain their locations with reference to each other and to the country in general. The most desirable way was decided to be the absolute location on the earth's surface furnished by latitude and longitude, on account of the additional advantage of enabling the detached plots to be placed in their correct position on the Geological Survey maps, which are also based on latitude and longitude. As a basis for these latitude and longitude measurements, recourse was had again to the U. S. Government and from them, through the Aqueduct Department, the geodetic properties of many triangulation points were obtained. Great difficulty was experienced in finding the Government points, due to cultivation of the ground and lack of adequate ties and monuments; but several points were finally located and necessary triangulation work begun to tie each plot surveyed to these known points. The work was hindered for several weeks by haze and forest fires, but finally the latitudes and longitudes of several new triangulation stations were determined.

Maps were made of all territory surveyed, these maps being in general on mounted drawing paper on a scale of 200 feet to an inch, and, as determined from the triangulation, parallels of latitude one-half minute apart and meridians one minute apart were placed on the maps. Tracings of these maps were made, each embracing an area of one-half minute of latitude by one minute of longitude (in this latitude, about 3,036 feet by 4,560 feet=318 acres). This work has required the making of 115 tracings.

After the location of the filter site was definitely determined, 370 acres of land covering this site were cross-sectioned, so as to admit of the interpolation of one foot contours with fair accuracy.

Work of Office Force.

The office force was first employed in estimating from locations taken from the Government maps the probable cost of various projects suggested for obtaining a desirable supply of water.

After a careful preliminary study, it appeared that these projects would divide into three general classes, each class having certain distinct advantages which would probably have to be weighed in part on grounds other than cost. These general projects are as follows:

First—The establishing of a large pumping station at some point on the Hudson River above the least trace of salt water, the pumping of the water to high-level filters and the delivering of filtered water at Hill View, at the northern limit of the city, at an elevation of about 295.

Second—The establishing of a pumping station on the Hudson River, as above, the pumping of water to low level filters and the delivering of filtered water at the height of Jerome Park Reservoir.

Third—The obtaining of sufficient water tributary by gravity to filters and the delivery of filtered water to either of the elevations above mentioned.

Variations and combinations of these three general projects made an interesting study to determine the direction the surveys should take in the time available.

Outline of Projects Considered.

1st. Pumping 500 million gallons daily from a station at Greer Point, on the Hudson River, to filters at Freedom Plains, and delivering by aqueduct to Hill View.

2d. Pumping 500 million gallons daily from a station at Greer Point, on the Hudson River, to filters at Clove, and delivering by aqueduct to Jerome Park.

3d. Pumping 500 million gallons daily from a station at Greer Point, on the Hudson River, to filters at Green Fly, and then repumping to a high level aqueduct, delivering by aqueduct to Hill View.

4th. Pumping 500 million gallons daily from Fishkill Creek at Brinckerhoff, when it can be obtained, but supplementing this by a 500 million-gallon-daily station at the Hudson River, at Greer Point, to supply any deficiency of the Fishkill; filters at Stormville, delivering by aqueduct to Hill View.

5th. Building a reservoir at Brinckerhoff, on Fishkill Creek, to give a steady supply of 125 million gallons daily, and pumping this 125 million gallons daily to filters at Stormville, supplementing this by 375 million gallons daily from the Hudson River, at Greer Point; delivering by aqueduct to Hill View.

6th. Building a reservoir at Stormville and another at Brinckerhoff, on the Fishkill Creek, to give a steady supply of 40 million gallons daily from Stormville and 85 million gallons daily from Brinckerhoff; supplementing this by 375 million gallons daily from the Hudson River, at Greer Point; filters at Stormville, delivering by aqueduct to Hill View.

7th. Developing the watershed of Fishkill Creek up to a total average of 147 million gallons daily by an inlet at Stormville and reservoirs giving a steady supply at Brinckerhoff and Billings; taking by gravity 19 million gallons daily from Billings, everything coming up to 200 million gallons daily from Stormville and pumping the balance from Brinckerhoff Reservoir. Supplementing this by a maximum of 375 million gallons daily from the Hudson River at Greer Point. Filters at Stormville, delivering by aqueduct to Hill View.

8th. Developing the watershed of Fishkill Creek up to a total average of 148 million gallons daily, by an inlet at Stormville and reservoir giving a steady draft at Brinckerhoff; taking everything up to 200 million gallons daily from Stormville, and pumping the balance from Brinckerhoff Reservoir. Supplementing this by a maximum of 375 million gallons daily from the Hudson River at Greer Point. Filters at Stormville, delivering by aqueduct to Hill View.

9th. Developing Fishkill Creek watershed by an inlet at Stormville and reservoir giving a steady draft at Brinckerhoff, up to a total average of 148 million gallons daily, taking everything up to 200 million gallons daily by gravity from the Stormville inlet, and pumping the balance from the Brinckerhoff Reservoir. Developing Wappinger Creek watershed by reservoirs, giving a steady draft at Rochdale, Clinton Hollow, Washington Hollow and Hibernia, up to a total average of 142 million gallons daily by pumping from the Rochdale Reservoir. Supplementing this by a maximum of 225 million gallons daily from the Hudson River at Greer Point. Filters at Stormville, delivering by aqueduct to Hill View.

10th. Same as No. 9, with the exception of having one large reservoir at Rochdale instead of small reservoirs at Clinton Hollow, Washington Hollow and Hibernia.

11th. Building a reservoir at Brinckeroff on Fishkill Creek and one at Rochdale on Wappinger Creek. Delivering this water by gravity to filters at Clove. The reservoir at Brinckerhoff to develop 125 million gallons steady draft. The reservoir at Wappinger to be small, but flood flows to be taken into aqueduct up to 375 million gallons daily. Supplementing this by a maximum of 375 million gallons daily from the Hudson River at Greer Point, delivering by aqueduct to Jerome Park Reservoir.

12th. Building a reservoir at Brinckerhoff on Fishkill Creek and delivering this water by gravity to filters at Clove. The reservoir at Brinckerhoff to be developed up to a total average of 149 million gallons daily, and the reservoir at Rochdale to be developed up to a total average of 113 million gallons daily, by utilizing flood flows in each reservoir up to 250 million gallons daily. Supplementing this by a maximum of 262 million gallons daily from Hudson River at Greer Point; delivering by aqueduct to Jerome Park Reservoir.

13th. The same as No. 12, but with filters at Elmsford, near Tarrytown, instead of at Clove.

14th. Building a reservoir at Brinckerhoff on Fishkill Creek, developing 125 million gallons daily, flowing by gravity to filters at Green Fly. Supplementing this by a maximum of 375 million gallons daily from Hudson River at Greer Point. Repumping to a high level aqueduct and delivering at Hill View.

15th. Building a smaller reservoir than in No. 14 at Brinckerhoff, and taking the flood flows up to a maximum of 500 million gallons daily by gravity to filters at Green Fly. Supplementing this by pumping up to a maximum of 500 million gallons daily from Hudson River at Greer Point. Repumping to a high level aqueduct and delivering at Hill View.

16th. Same as No. 15, but with a still smaller reservoir at Brinckerhoff.

17th. Same as No. 14, but with a cheaper reservoir at Brinckerhoff, developed from later studies.

18th. Same as No. 15, but with a still smaller reservoir at Brinckerhoff.

19th. Same as No. 15, but with only an inlet at Brinckerhoff.

20th. Building a reservoir at Brinckerhoff on Fishkill Creek and at Rochdale on Wappinger Creek, developing the Brinckerhoff Reservoir to 125 million gallons daily, but drawing on flood flows up to 250 million gallons daily; developing the Rochdale Reservoir to 113 million gallons daily by drawing on flood flows up to 250 million gallons daily, this water flowing by gravity to filters at Green Fly. Supplementing this up to a maximum of 262 million gallons daily from the Hudson River at Greer Point. Repumping to a high level aqueduct and delivering at Hill View.

21st. 125 to 148 million gallons daily obtained from Fishkill Creek, 40 million gallons daily from Stormville and the balance pumped from Brinckerhoff. 120 million gallons daily obtained from Wappinger Creek by four reservoirs, Clinton Hollow, Washington Hollow, Hibernia and Rochdale, by establishing one pumping station for the first three reservoirs and one for Rochdale. 102 million gallons daily obtained from Roeliff Jansen Kill by reservoir at Silvernails. Filters at Stormville and delivery at Hill View.

22d. Chain of lakes at Silvernails, Clinton Hollow, Hibernia and Billings developing 255 million gallons daily steady draft, also reservoir at Stormville developing 37 million gallons daily. Filters at Stormville, delivering by aqueduct to Hill View.

During these studies numerous diagrams and tables were prepared serving for quickly estimating various costs and giving a general idea of the direction to look for further economies.

These studies were first completed; the office force was then continuously employed in making detail designs and estimates for a reservoir at Hill View and for slow sand filters at Stormville, to have an ultimate capacity of 500 million gallons daily, the first installation to consist of filters having a capacity of 50 million gallons daily.

Decision as to Site for Filters.

The work of the field force indicated the existence of reasonably economical filter sites in connection with each of the schemes of water supply studied by the office force. The difference in cost of grading the different sites was not large enough to be a controlling factor in the choice of any of the projects of water supply suggested, therefore, the location of the filter site became dependent on the general project of water supply, and the decision to build a reservoir at Stormville logically compelled a filter site somewhere along the aqueduct line between the Stormville Reservoir and the Hill View Reservoir.

The sites that fulfilled these conditions were three in number, namely, at Stormville, at Scarsdale and at Greenville. The last mentioned site was rocky and uneven and scant in area, and involved expensive siphons in the connecting aqueducts, and hence was not comparable with the other two. The Scarsdale site was more favorable from a topographical point of view, but was on expensive land and involved expensive siphons. The Stormville site, while varying so much in level that it would not at first be thought of as a desirable location for filters, is favorably located with respect to the aqueduct in a section where land is cheap and where stone for construction purposes can be easily obtained and it has abundant area for further extension on a large scale. It was therefore deemed more suitable for the purpose.

Description of Stormville Filter Site.

The site chosen for filters and appurtenances in the vicinity of Stormville lies directly south of the Stormville Depot, and is about 1½ miles long and ¾ of a mile wide, covering an area of about 780 acres. It is rolling territory consisting of hills and marshes; the maximum difference of elevation being about 80 feet.

The excavation, so far as it has been examined, appears to be a gravelly material overlying dolomite ledges, and when the covering over the ledges is deep, as it appears to be in many places, the material can be easily handled by steam shovels. While there are numerous swamps in this location, a detailed examination of them has revealed that the swampy material extends only a few feet in depth, the underlying material being an excellent clay. In excavating some of the hills rock will be encountered, but as this rock is dolomite it is not difficult of removal and as it is a good rock for concrete construction, its presence on the site is an advantage rather than a detriment.

General Features of the Filter Design.

The general relation of the proposed filter plant to the surrounding country and the general plan of the plant are shown on Pls. I. and II.

Raw water will be received at the upper end of the plant in two conduits, each carrying about 250 million gallons daily. At this end there will be a switch gate-house which will allow the flow of the water to continue along in the same conduit, to be concentrated from both conduits into either, to change so that water from each conduit will flow in the other, or to discharge from either or both conduits into a compensating basin. Passing this switch gate-house, the twin conduits will skirt the west side of the compensating basin to its lower end, where there will be a compensating gate-house which will allow surplus flows in either conduit to pass into the compensating basin and back again if the flow in the conduits becomes less than normal.

Provision will also be made at this point for taking water from the compensating basin into either conduit or both conduits when it is desired to maintain a flow through the basin. Passing through this compensating gate-house, the twin conduits will continue to the regulating gate-house at the filter plant. At this regulating gate-house, provisions are made for dividing the raw water into three streams, one passing to the east side of the plant, one to the west side and a third down the centre. At the regulating gate-house, the gates will be so manipulated as to maintain a practically constant raw water level over the entire filter plant.

The compensating basin will have an area of 62 acres, and it is designed so that its water surface may fluctuate 6 feet in depth.

The filters will be covered filters constructed entirely of concrete, with groined arch concrete roofs, covered with soil. The general layout of the plant shown in the plans, includes sufficient filter area to allow of filtering 500 million gallons daily at the rate of 3 million gallons daily per acre of sand surface, with 11 per cent. reserve, under ordinary conditions, for cleaning and storing sand. This rate is the general, accepted standard for filters of this type to-day. It has been recognized, however, that the water received from a few or all sources may be capable of being filtered at a higher rate, in which case the plant would cover less area. Provision is therefore made in the size of all conduits for the first installation for filtering water at the rate of 6 million gallons daily per acre of sand surface, with a plant having one-half the area; the plant being so arranged in units that a decision on this matter is not necessary until after a part of the plant is in running condition and actual trials have been made to determine the most desirable rates for the particular waters filtered. The filter plant will be divided into units, each consisting of 20 filters; each filter having a net area of 0.93 acre. There are no open sand courts, but instead each unit has a long covered pipe gallery connecting with the filters, which are ranged along the gallery on either side. In this gallery will be located all pipes for operating the filters, and the apparatus for transporting and washing the sand. No sand will be stored, it being washed and placed immediately in one filter in the unit which will be held in reserve until entirely refilled. An operating station will be provided at the centre of each unit from which all the operations of each filter in the unit will be controlled. After being filtered, the water is discharged into two main filtered water conduits, which connect at the by-pass gate-house at the lower end of the plant, and from them into the aqueduct leading to New York. To this gate-house will be extended the central raw water supply conduit, providing the only by-pass between the raw water supply and filtered water conduits. This by-pass, which will be for use only in emergencies, will be properly safeguarded so that the filtered water cannot be contaminated by leakage into it of raw water.

Details of Filter Plant.

A more detailed description of the leading features of the filter plant is as follows:

Raw Water Supply Conduits—Two conduits extend from the switch gate-house to the regulating gate-house, skirting the west edge of the compensating basin, a total distance of about 3,360 feet. These conduits will be constructed as twin conduits, each of an approximate horseshoe shape, about 12 feet 6 inches in diameter. They will be laid on a grade of 1 in 5,000, and will be constructed of concrete with re-enforcing steel in the side walls.

Gate-Houses—In design, the gate-houses will be simple, special attention being paid to keeping the loss of head through the houses at a minimum, and to reducing the number of chambers to the lowest limit for satisfactory operation. Openings that are used frequently will be closed by sluice gates, operated by hydraulic or electrical power—those used infrequently will be closed by stop planks. The substructures of all gate-houses will be of mass concrete, the floors being of concrete re-enforced with steel. The superstructures will be of brick, with granite trimmings and of attractive design.

Compensating Basin—The object of the compensating basin is to facilitate the holding of the raw water at a practically constant level on the filters. In the ordinary operation of the filter plant, owing to filters going out of service and other filters being placed in service, the rate of application of the raw water is necessarily somewhat fluctuating. The aqueducts delivering water to the filters receive it at the upper end, a long distance from the filter plant, and accordingly the flow at the lower end cannot be changed except after the lapse of considerable time. The filters, on the other hand, must be operated without any thought as to the amount of water flowing in the aqueducts, and it thus seems advisable to construct a basin which will act as a balance between the amount of water coming in the aqueduct and the amount of water used by the filters, water flowing to or from the aqueduct and the compensating basin according to the demands of the filters. A plan of the basin is shown on Pls. I. and II. Its area is 62 acres, and its capacity between the elevations 240 and 246—which represents the amount of fluctuation it can take care of—is 116 million gallons; its total capacity to elevation

246 is 420 million gallons. The size of the basin was determined by the configuration of the ground, it being thought advisable to utilize all of the low ground between the filters and the railroad for this purpose, as in this case the north end of the basin would be formed by the aqueduct and the railroad banks which would be necessary in any case, and the total cost of construction would be small.

It is proposed to regrade the natural surface of the ground within the basin limits between elevations 230 and 251, and below elevation 230 to strip the surface, the slopes between elevations 230 and 247 being paved with field stone, laid on a slope of 1 on 5. A blow-off will be provided at the north end of this basin and an overflow having a capacity of 500 million gallons daily will be provided on the west side.

Filters—The filters will be constructed of concrete of dimensions and details as shown on Pls. III. and IV., with pier-groinoid floors, piers, side walls and groined arch roof. The main collectors will be of concrete laid monolithic with the floor. The lateral collectors will be of vitrified pipe, laid as shown on Pl. III. The gravel layer will consist of 4 layers of graded sizes, the total thickness being 16 inches.

The sand in the filters of each unit will be placed in varying thickness; the minimum thickness being 20 inches and the maximum thickness being 3 feet 8 inches. This is done so that the filters, when first started, will go out of commission in proper order and the process of refilling a filter with the washed sand from the other filters can be begun as soon as the unit is put in operation.

The sand used will be a silica sand, having an effective size of from 0.28 to 0.35 millimeter and a uniformity coefficient not greater than 2.5. It will probably be necessary to bring this sand from a distance, transporting it to the filter site by rail.

The water level can be maintained at 6 feet above the maximum elevation of the sand layer or at a less height, as may seem to be desirable in the operation of the filters.

Ventilators will be provided at every other bay in the filters, as shown on Pls. III. and IV. They will be provided with movable covers, to be opened and closed when desired; the hinges being on the north so that the cover may be opened to an angle of 45 degrees to let in the sun light.

Rain which falls on the roof of the filters will be taken down each pier through an opening, discharging at the level of the maximum sand layer. Each filter will be provided with an inlet for raw water from the raw water conduit, an outlet for raw water to the raw water drain, an outlet for the waste water from the sand receiver to the wash water drain, an outlet from the main collector to the effluent conduit and to the effluent drain and inlet and outlet from the main collector to the refill pipes. Entrance from each filter will be from the pipe gallery through a sluice gate, placed with its bottom at the same elevation as the maximum sand level. When the filter is in operation, this sluice gate will be closed; when the filter is to be scraped the water will be run off from above the sand and the sluice gate opened, allowing entrance direct from the pipe gallery to a filter.

Pipe Gallery—The pipe gallery extends the entire length of each unit: Entrance to this gallery is from the operating station, and the filters open out from it on each side as shown on Pls. VI. and VII. The roof is a concrete arch of 29 feet span, continuous with the roofs of the filters and covered with earth in the same manner.

The gallery contains all the pipes, valves and meters for the operation of the filters; all such apparatus being easily accessible for inspection and repairs. A concrete platform situated above the pipes, and on a level with the entrance to the filters, is available for the passage of men and materials throughout the whole length of the gallery and into each filter.

The "booster" stations and all pipes for the transportation and washing of sand are also installed in this gallery, as well as all the pipes, wires, etc.; for the operation of the valves of each filter from the operating station and for the lighting of the filters.

The gallery and all filters not in commission will be ventilated by the plenum process, the fans being located in the basement of the operating station.

Raw Water Supply System—Beginning at the regulating gate-house, three concrete conduits of rectangular cross-section carry the raw water to the filters. Two of these conduits extend along the outside of the filter plant and the third, which may be used also as a by-pass, down the centre of the plant as shown on Pls. III., IV., V., VI., VII. and IX. From these conduits, lateral conduits of ¼-inch riveted steel plate, surrounded by concrete, are laid in each pipe gallery, and from these lateral conduits cast-iron pipe connections are made to the inlet chamber of each filter. It is not intended to place any regulating valves at any points in these conduits, the raw water being maintained at a practically constant level by an attendant at the regulating gate-house.

Filtered Water System—The main collectors under each filter will be of concrete as shown on Pl. IV. These collectors will be connected by cast-iron pipes and the proper valves, to three different conduits, the effluent, the effluent drain, and the refill pipes; between these conduits and the main collector there will be a Venturi meter, by which the rate and amount of flow of all water from the main collector of each filter is measured and controlled.

The effluent is situated in the pipe gallery and is a 48-inch riveted steel pipe, ¼ of an inch thick, laid in concrete. This effluent discharges into a rectangular concrete filtered-water conduit, as shown on Pls. V., VI., VII., VIII. and IX., there being two provided for, situated respectively in the east and west courts. These two filtered-water conduits come together and connect with the aqueduct to New York at the lower end of the plant in the by-pass gate-house.

Effluent Drain System—Cast-iron pipe will be provided in the pipe gallery to take the effluent from the filters when it is necessary to draw the water below the sand level for scraping the filters, or when for any cause it is found desirable to exclude from the filtered water the effluent from a filter, as may be the case during ripening. Each lateral effluent drain will discharge into one of two main 48-inch concrete drains situated respectively in the east and west courts. These drains have an outlet at the south end of the plant for wasting the water and at the north end will be connected with the pumping station. Under normal working conditions, the water in these drains will be pumped to a reservoir. It is intended to use this water for washing and transporting sand and for operating the hydraulic valves. Should there be a deficit in the amount of water furnished while drawing the filters below the sand level, it is intended to pass the first part of the run from newly cleaned filters into this drain until the necessary amount is obtained. If it becomes desirable to run more water into this drain than will be required, as for the purpose of continuing the period of ripening, this surplus water can be allowed to run to waste or it can be pumped by a special set of pumps, back into the raw water conduit; this lift being only about 15 feet, the additional expense would be small.

Refill Pipe—The refill pipe is located in the gallery and consists of a 20-inch cast-iron pipe connected with the main collector of each filter. When it becomes desirable to refill any filter from below, the valves are opened so as to run the water from a newly started filter into the refill pipe and thence to the filter to be refilled.

Raw Water Drain System—At times when the raw water is very turbid and filters are going out of commission after short runs, it is desirable to draw off the water quickly from the top of the sand; the raw water drain provides a means of accomplishing this. It consists of a cast-iron pipe laid in the pipe gallery and connected with each filter through the raw water inlet chamber. This drain, after passing through the pipe gallery, discharges into one of two concrete conduits, as shown on Pl. V.; these conduits discharging into a ditch at the south end of the plant. For the first installation, this raw water will be thrown away, but as the plant nears completion and the capacity of the raw water supply is reached, this water can be pumped back to the raw water conduit by establishing at the lower end of the conduit a few centrifugal pumps run by electricity. The lift will only be about 15 feet, so that the cost of pumping will be very small.

Pressure System—A 36-inch cast-iron pipe extends from the pumping station through the east and west courts to the wash water reservoir: 12 and 14-inch branches are taken off from this main through each pipe gallery and from each pipe gallery main to three 4-inch lines in each filter. The pipes supply the water for washing and transporting sand and for operating the hydraulic valves.

Wash Water Reservoir—Details of the location of the wash water reservoir, in which the water used in washing the filter sand will be stored, are shown on Pls. I. and XI. It will be situated to the southeast of the plant on a side hill with its high water level at elevation 655. It will be an open reservoir with earth embankments and division wall made tight with concrete and puddle. Its capacity will be 10 million gallons.

Wash Water Drain System—In each pipe gallery there will be provided a line of cast-iron pipe, connected to the wash water inlet chamber of each filter, and to catch basins near each booster to remove water that has been used for washing and transporting sand. This pipe will discharge into one of two concrete conduits, situated respectively in the east and west courts, both of which discharge at the south end of the plant at about elevation 324. In the first installation, it is proposed to let this water, together with the wasted water, and the wasted effluent drain water spread out on the swamps to the south and east of the plant, but ultimately it will be necessary to build an open canal to the Fishkill Creek, as shown on Pl. I.

Overflows—No overflows will be provided in the filters, the regulation of the level of the raw water being governed entirely from the regulating gate-house.

Operating Station—An operating station, situated at the intersection of the pipe gallery and the east and west courts, as shown on Pl. II., will be provided in each unit. This station will contain a large office from which all of the valves in the unit will be operated by hydraulic or electrical devices, the movement of the valves being clearly indicated on dials. The indicating apparatus from each Venturi meter will also show in this office, so that one man will be able to control the working of all of the 20 filters in the unit. It is believed that this will secure entire uniformity in working conditions. In addition, this house will contain two large mine ventilating fans which will deliver large volumes of air into the adjacent pipe galleries.

When any filter in the unit is opened for cleaning, this air will pass through the open filter removing the dampness. It is believed that this forced ventilation of the pipe galleries and filters will be of great benefit to the workmen and will allow of much more efficient work. Above the office there will be dressing-rooms for the use of the workmen employed about the plant outside of working hours. The station will also contain a large toolroom and necessary lavoratory conveniences, so that practically all of the operations of the unit will centre at this house, the men being able to pass to any filter through the pipe gallery without being exposed to, or delayed by, the elements.

Pumping and Electric Lighting Station—A station will be located at the north end of the plant which will contain pumps for the supplying of the necessary water at 100 pounds pressure for washing and transporting sand; also additional pumps, if necessary, for the pumping of the effluent drain water into the raw water conduit; also an electric equipment for the general lighting of the plant and for the lighting and ventilating of the filters during cleaning; also a steam heating plant for the heating of the operating stations, pipe galleries, and laboratory. A siding 3,000 feet long from the main track of the New York, New Haven and Hartford Railroad will terminate in a coal pocket, providing three months' storage of coal, and from this coal pocket coal will be delivered by gravity to the boilers in the pumping station.

Transportation and Washing of Sand—The method to be used for transporting and washing of the sand is shown on Pl. X. Permanent cast-iron pipes will be placed in each filter to which portable sand ejectors can be attached, thus delivering sand to "booster-stations" situated in the pipe gallery. Through these stations the sand will be discharged into sand receiving tanks in the filter which is being refilled. The sand will be taken from the bottom of this tank and wheeled to its proper location in the filters, the dirty water running off from the top of the inlet to the wash water drain through temporary pipes. By this method of handling sand, no courts for the storage of sand are needed, their place being taken by one of the filters which will be held out of commission until it is entirely refilled, at which time another filter will take its place. All of the sand transporting pipes will be of cast-iron, with the exception of the connections to the ejectors and "boosters" and for switching from one line to another, which will be of bent wrought-iron pipe, or rubber hose. The water for the sand washing and transporting will be obtained from the wash water reservoir, and will be used at about one hundred pounds pressure per square inch.

Laboratory and Superintendent's Office—There will be a large chemical and bacteriological laboratory and Superintendent's office situated on the bluff to the north of the filter plant, as shown on Pl. II. The laboratory will be of brick and stone, and will be fitted up with the most approved appliances for bacteriological and chemical analysis. The building will be lighted by electricity and heated with steam brought from the pumping station.

Superintendent's House—There will be a brick house erected near the bacteriological laboratory as a residence for the Superintendent in charge of the entire plant.

Stables and Store Sheds—There will be a brick stable and store shed in the rear of the pumping station.

Roads—The location of the plant necessitates the discontinuing of a number of country roads, and the construction of 3.4 miles of new road to take their place and to allow communication between different parts of the plant. All new roads will be of macadam, built in accordance with the standard practice of the State.

Estimated Cost of Stormville Filters.

There will be twenty filters built in the first installation, sufficient to serve for the filtering of 50 million gallons of water at the rate of 3 million gallons per acre of net sand surface per day, and in connection with these filters there will also be built in the first installation the twin conduits supplying the raw water, all the gate-houses, the pumping station and the bacteriological laboratory, all the conduits located in the east court as planned for the completed plant and also the central raw water and by-pass conduit. The cost of this first installation is estimated at $3,581,457, as shown in detail in Table No. 1. The first installation will be completed in 1905, and thereafter it will be necessary to build a few filters each year until 1924, when the entire plant will have been constructed. The cost of this deferred construction will be $14,646,116, as shown also in detail in Table No. 1—making a total cost of $18,227,573, which can be met by a bond issue of $14,620,000 in 1905. It is estimated that the operating expenses will not exceed $882,800 in 1905, and $1,293,500 in 1924. These expenses include interest, sinking fund, taxes and repairs.

Hill View Reservoir.

This reservoir will occupy the entire top of the hill situated just north of the City line, between the town of Mount Vernon and the City of Yonkers.

It will be a covered reservoir, as shown on Pls. XII. and XIII., 35 feet deep, having a water surface of 162 acres and a total capacity of 2,030 million gallons. The reservoir will be constructed entirely of concrete and covered with two feet of earth, and the entire excavation will be used in making an embankment and boulevard drive around the outside of the reservoir limits. It is designed to build only Basin No. 1, of a capacity of 600 million gallons at first, leaving the other basins to be constructed in the future.

The aqueduct will pass through the reservoir, discharging into the reservoir at Inlet Gate-houses Nos. 1 and 2. In the centre of the reservoir will be built a large ornamental terminal gate-house, from which distribution pipes will lead to all parts of the City, and in which the water may be by-passed around the reservoir.

Owing to the limited time available, sufficient examination could not be given to the character of the excavation at this place, and the plans and estimates are in consequence somewhat tentative and subject to correction after the information from a detailed set of test pits is available.

Estimated Cost of Hill View Reservoir.

The first cost of construction of Basin No. 1 is estimated at $9,058,860, and the cost of completing the other three basins at $13,168,530, the total cost being $22,227,390, which will require a bond issue in 1905 of $18,983,780, as shown in detail in Table No. 2.

Filtering Water from the Croton Watershed.

In the course of an investigation for filter sites for a low level supply—that is, for delivering water at the height of Jerome Park Reservoir—examinations were made in detail of all available sites for sand filter plants below the present Croton shed, and it was found that there were only two sites available; these sites are situated respectively at Gould's Meadows, about two miles southeast of Tarrytown, and at Elmsford, about three miles southeast from Tarrytown.

By raising the hydraulic grade line of the New Croton Aqueduct from the Croton Reservoir to this point, thereby running the aqueduct under a 20-foot head, it will be possible to utilize Gould's Meadows as a site for a filter plant of a capacity of 250 million gallons per day, on a basis of a rate of filtration of 3 million gallons per day per acre of sand surface. The water would pass through the filters by gravity, and would then return into the lower portion of the aqueduct. By this proposition, the lower 20 feet of the storage of the New Croton Reservoir could not be utilized without pumping; this, however, would still give a gravity yield of 242 million gallons per day in an extreme dry year, and it would be only a small matter to install temporary pumps to obtain the balance if required.

The cost of installing a 250 million gallon plant at Gould's Meadows would be about $8,500,000, and the total cost of operation, including interest, sinking fund and extraordinary repairs and depreciation, would not exceed $766,000 per year.

The Elmsford site is similarly situated to that of Gould's Meadows. The water would have to be backed up in the present New Croton Aqueduct about 40 feet in order to flow by gravity to filters on this site and would then return to the aqueduct below the filters. It would also be necessary at this site to turn the Sawmill River from its present course into a tunnel discharging into the Hudson River near Tarrytown.

At the Elmsford site a plant having a capacity of 500 million gallons per day on a basis of 3 million gallons per acre per day can be installed.

To build a plant of 500 million gallons daily capacity would cost about $15,000,000, and the operating expenses, including interest, sinking fund, and extraordinary repairs and depreciation would be about $1,500,000 per year.

TABLE No. 1.

Detailed Estimate of Approximate Cost of High Level Filter Plant, Stormville, N. Y.

RECAPITULATION.

First installation 50 million gallons daily in 1905	$3,581,457
Deferred installation for complete plant of 500 million gallons daily in 1924	14,646,116
Total cost	$18,227,573

Operating Expenses.

	In 1905.	In 1924.
Interest on entire cost of structures and land, $14,620,000, at 3 per cent	$438,600	$438,600
Sinking fund to pay off cost in 40 years, $14,620,000, at 1.326 per cent	193.900	193,900
Taxes and special assessments, $14,620,000, at 0.4 per cent	58,500	58,500
Extraordinary repairs and depreciation, $14,620,000, at 1 per cent	146,200	146,200
Maintenance, operation, labor and supplies, at $2.50 per million gallons filtered; 50 million gallons daily in 1905; 500 million gallons daily in 1924	45,600	456,300
Total	$882,800	$1,293,500

TABLE NO. 1—(*Continued*).

DETAILED ESTIMATE OF APPROXIMATE COST OF HIGH LEVEL FILTER PLANT, STORMVILLE, N. Y.

Items.	Unit.	Price.	First Installation 50 Million Gallons Daily in 1905.		Deferred Installation 450 Million Gallons Daily, 1905–1924.	
			Quantity.	Amount.	Quantity.	Amount.
Land	Acres	$150 00	950	$142,500	....	....
Excavation	Cubic yards	75	718,000	538,500	2,732,000	$2,049,000
Sodding	Square yards	20	34,960	6,992	84,310	16,862
Seeding	Acres	35 00	50	1,750	220	7,700
Broken stone	Cubic yards	1 50	5,200	7,800	....	....
Slope paving	Square yards	2 50	6,200	15,500	....	....
Riprap	Cubic yards	1 50	....	....	21,860	32,790
Paving	Square yards	2 00	....	....	7,320	14,640
Puddle	Cubic yards	2 25	4,540	10,215	2,480	5,580
Gravel in walks	"	1 50	1,000	1,500	....	....
Macadam roads	Miles	10,000 00	1.8	18,000	1.6	16,000
Railroad siding and structures		... ...	....	20,000	....	....
Concrete in floors and walls, filters and pipe galleries	Cubic yards	6 50	40,250	261,625	353,980	2,300,870
Concrete in floors and walls, raw water supply conduit	"	6 50	10,710	69,615	14,730	95,745
Concrete in piers and vaulting of filters and pipe galleries	"	8 00	24,980	199,840	228,360	1,826,880
Concrete in roof of raw water supply conduit	"	8 00	5,030	40,240	10,180	81,440
Concrete in other structures	"	6 50	14,390	93,535	3,920	25,480
Reinforcing steel in concrete	Tons	100 00	330	33,000	940	94,000
Drains for vaulting	No.	50	3,000	1,500	27,000	13,500
Fasteners in vaulting	"	20	7,200	1,440	64,800	12,960
Covers for ventilator shafts	"	10 00	1,440	14,400	12,960	129,600
Twin conduits, 12 ft. 6 in. x 12 ft. 6 in., horseshoe, each	Linear feet	42 00	3,360	141,120	....	....
Concrete conduits, 18 ft. 10 in. x 12 ft., rectangular	"	42 00	1,170	49,140	....	....
Concrete conduits, 17 ft. 9 in. x 11 ft., rectangular	"	38 00	600	22,800	....	....
Concrete conduits, 14 ft. 3 in. x 11 ft., rectangular	"	32 00	600	19,200	....	....
Concrete conduits, 13 ft. 9 in. x 10 ft., rectangular	"	29 00	....	....	1,170	33,930
Concrete conduits, 11 ft. 9 in. x 10 ft., rectangular	"	26 00	600	15,600	600	15,600
Concrete conduits, 11 ft. x 9 ft., rectangular	"	23 00	....	....	600	13,800
Concrete conduits, 9 ft. x 8 ft., rectangular	"	19 00	600	11,400	600	11,400
Concrete conduits, 7 ft. 6 in. x 6 ft., rectangular	"	15 00	....	....	600	9,000
Concrete conduits, 7 ft. 6 in. x 7 ft. 6 in., horseshoe	"	10 00	430	4,300	430	4,300
Concrete conduits, 6 ft. 6 in. x 6 ft. 6 in., horseshoe	"	8 00	600	4,800	600	4,800
Concrete conduits, 5 ft. 6 in. x 5 ft. 6 in., horseshoe	"	6 00	1,030	6,180	1,030	6,180
Concrete conduits, 5 ft. x 5 ft., horseshoe	"	5 50	600	3,300	600	3,300
Concrete conduits, 4 ft. 6 in. x 4 ft. in., horseshoe	"	5 00	1,190	5,950	1,190	5,950
Concrete conduits, 4 ft. x 4 ft., horseshoe	"	4 50	3,490	15,705	4,090	18,405
Concrete conduits, 3 ft. 6 in. x 3 ft. 6 in., horseshoe	"	4 00	600	2,400	600	2,400
Concrete conduits, 3 ft. x 4 ft. 6 ins., egg shaped	"	6 00	600	3,600	600	3,600

Items.	Unit.	Price.	First Installation 50 Million Gallons Daily in 1905.		Deferred Installation 450 Million Gallons Daily, 1905–1924.	
			Quantity.	Amount.	Quantity.	Amount.
Concrete conduits, 2 ft. 8 in. x 4 ft., egg shaped	Linear feet	$5 00	600	$3,000	600	$3,000
8-inch vitrified pipe	"	25	1,800	450	....	....
Inlets	No.	50 00	2	100	18	900
Manholes on conduits and drains	"	75 00	38	2,850	38	2,850
Cast-iron water-pipe	Tons	40 00	2,800	112,000	8,950	358,000
Special castings, bell	"	70 00	170	11,900	1,000	70,000
" " flange	"	100 00	120	12,000	1,070	107,000
Riveted steel pipe	"	120 00	280	33,600	2,460	295,200
Malleable steel castings	"	200 00	10	2,000	80	16,000
Spiral riveted steel pipe	Linear feet	1 00	1,000	1,000	9,000	9,000
Gate valves, 48-inch (special)	No.	2,000 00	1	2,000	1	2,000
" 48-inch "	"	1,000 00	....	....	1	1,000
" 36-inch "	"	550 00	3	1,650	....	....
" 30-inch "	"	325 00	2	650	18	5,850
" 20-inch "	"	100 00	102	10,200	918	91,800
" 16-inch "	"	60 00	1	60	9	540
" 14-inch "	"	50 00	2	100	18	900
" 12-inch "	"	35 00	1	35	9	315
" 10-inch "	"	25 00	2	50	18	450
" 8-inch "	"	18 00	22	306	180	3,240
" 4-inch "	"	8 00	60	480	540	4,320
3-inch hose valves	"	6 00	300	1,800	2,700	16,200
3-inch round way cocks	"	6 00	300	1,800	2,700	16,200
36-inch check valve	"	600 00	1	600	....	....
Sluice gates, 5 ft. x 8 ft.	"	4,300 00	2	8,600	....	....
" " 5 ft. x 7 ft.	"	3,800 00	36	136,800	....	....
" " 5 ft. x 7 ft., horizontal	"	4,000 00	20	80,000	180	720,000
Sluice gates, 8 in. diameter	"	20 00	5	100	45	900
20-inch Venturi meters	"	350 00	20	7,000	180	63,000
Controllers for valves	"	150 00	100	15,000	900	135,000
Indicators	"	250 00	20	5,000	180	45,000
Portable ejectors	"	300 00	4	1,200	36	10,800
Sand receivers	"	1,000 00	4	4,000	36	36,000
Boosters	"	1,500 00	5	7,500	45	67,500
6-inch lateral collectors	Linear feet	15	67,200	10,080	604,800	90,720
Filter gravel	Cubic yards	2 50	34,400	86,000	309,600	774,000
" sand	"	2 50	85,400	213,500	768,600	1,921,500
Yellow pine timber	1,000 ft. B. M.	40 00	65	2,600	30	1,200
Switch gate-house	No.	50,000 00	1	50,000	....	....
Compensating gate-house	"	10,000 00	1	10,000	....	....
Regulating gate-house	"	15,000 00	1	15,000	....	....
By-pass gate house	"	25,000 00	1	25,000	....	....
Wash water reservoir gate-house	"	3,000 00	1	3,000	....	....
Operating station	"	35,000 00	1	35,000	9	315,000
Bacteriological Laboratory and Superintendent's office	"	50,000 00	1	50,000	....	....
Superintendent's residence	"	10,000 00	1	10,000	....	....
Barn	"	5,000 00	1	5,000	....	....
Pumping station, boiler-house and coal shed	"	150,000 00	1	150,000	....	....
Pumps and boilers	"	50,000 00	....	50,000	....	50,000
Electric lighting	"	....	....	19,000	....	87,000
Ventilating apparatus	"	1,500 00	2	3,000	18	27,000
Total estimated cost	....	....	....	$2,984,548	....	$12,205,097
Contingencies, 20 per cent.	....	....	....	596,909	....	2,441,019
Grand total	....	....	....	$3,581,457	....	$14,646,116

TABLE No. 2.

DETAILED ESTIMATE OF APPROXIMATE COST OF HIGH LEVEL RESERVOIR AT HILL VIEW, BETWEEN YONKERS AND MOUNT VERNON, N. Y.

No test pits or borings were obtained at this site and the estimate assumes the excavation as all rock and of such quality as to be available for concrete. If the excavation is all earth, a saving of about $1,000,000 may be made in the first installation and of about $3,000,000 in the deferred installations.

Items.	Unit.	Price.	First Installation Basin No. 1.		Deferred installations Basins Nos. 2, 3 and 4.	
			Quantity.	Amount.	Quantity.	Amount.
Land	Acres	$8,000 00	325	$2,600,000	....	....
Excavation, all rock	Cubic yards	1 00	2,600,000	2,600,000	6,200,000	$6,200,000
Puddle	"	2 25	27,500	61,875	64,300	144,675
Concrete, floors and walls	"	6 50	148,800	967,200	336,900	2,189,850
" piers and vaulting	"	8 00	97,800	782,400	234,700	1,877,600
Cyclopean concrete	"	5 00	66,500	332,500	77,000	385,000
Soil dressing	"	25	94,700	23,675	242,800	60,700
Sodding	Square yards	20	6,000	1,200	16,000	3,200
Rubble masonry	Cubic yards	4 50	....	....	9,500	42,750
Landscape, road building, gate-houses, etc.	....	....	....	150,000	....	35 000
Twisted steel for concrete	....	....	....	30,200	....	35,000
				7,549,050	....	10,973,775
Contingencies, 20 per cent	....	....	....	1,509,810	....	2,194,755
Total	....	......	....	$9,058,860	....	$13,168,530

RECAPITULATION.

First installation 600 million gallons in 1905	$9,058,860
Deferred installation for complete reservoir of 2,030 million gallons in 1924	13,168,530
Total cost	$22,227,390

PRELIMINARY DRAFT OF SPECIFICATIONS, SHOWING MANNER OF CONSTRUCTING THE HIGH LEVEL FILTER PLANT AT STORMVILLE, N. Y., RECOMMENDED BY COMMISSION ON ADDITIONAL WATER SUPPLY.

Excavation.

Clearing—The land shall be cleared of all refuse, brush, trees, stumps or rubbish. Under all fills or embankments the upper surface of the ground shall be removed to such a depth, which shall be determined by the Engineer, as may be necessary to obtain a suitable foundation for starting the embankments or fills.

Disposal of Materials—Such of the excavated materials as are suitable and are required shall be used in the various fills and embankments required by the specifications. All surplus material shall be permanently deposited at such point adjacent to the site of the work and graded to such lines as shall be given by the Engineer.

Materials Kept Separate—All materials encountered in the excavation and suitable for use in the various fills or embankments shall be kept separate for that purpose.

Borrowed Materials—Should a deficiency occur in the materials obtained from the excavation which are suitable for embankments or fills, the Contractor shall excavate suitable materials from borrow pits. The land for the borrow pits, which will be provided by the City, adjacent to the work, shall be cleared, and the pits excavated to the lines and grades given by the Engineer.

Unauthorized Excavation—Any excavation carried on outside of the lines and grades given by the Engineer, together with the removal of the excavated material, shall be at the Contractor's expense. All such space shall be refilled by the Contractor at his own expense, with concrete masonry or other suitable material as required.

Blasting—All blasting shall be done in a careful manner so as to not endanger life or the work of construction. All blasts shall be carefully covered with heavy timber or other material, satisfactory to the Engineer. The drilling shall be so done that in no case shall drill holes extend below the level of the sub-grade. All explosives shall be kept in a safe place at a sufficient distance from the work so that, in case of accident, no damage will occur to any part of the work.

Removal of Water—The Contractor shall, at all times during the construction, provide proper and suitable means and devices for the removal of all water from the excavation, and shall remove all water as fast as it may collect, in such a manner as will not interfere with the prosecution of the work or the proper laying of the masonry. The Contractor shall have sufficient pumping machinery on the ground ready for immediate use.

Timbering—The Contractor shall be responsible for properly supporting the sides of all excavations with timber or other supports. If, however, the Engineer is of the opinion that at any point sufficient or proper supports have not been provided, the Contractor shall provide additional or stronger supports at his own expense, but the furnishing of such further supports shall not relieve him of his responsibility for their efficiency. If required, all timber or other supports shall be removed, and upon their removal all voids shall be carefully filled as directed. If any timber is to remain in place, such timber shall be cut off so as not to project above the surface of the ground.

Excavation in Rock—When the excavation is in rock, any fissures which may be found shall be thoroughly filled with Portland cement grout mixed in the proportions of one part of cement to two parts of sand, after which the entire upper surface of the rock shall be leveled up to sub-grade with concrete, mixed and laid as specified under " Concrete."

Embankment and Filling.

Materials—The materials for use in fills and building embankments shall be that obtained from the excavation or from borrow pits as specified under Excavation.

Back Filling—The trenches shall be back-filled up to the original surface of the ground. This filling shall be made with the best material available, selected especially for the purpose, and free from stones over 3 inches in diameter. It shall be placed in thin layers, moistened and well tamped.

Rolled Embankments—All rolled embankments shall start from a base from which soil and other perishable material shall have been removed, and on sloping ground the base shall be stepped, if required. Embankments shall be built with carefully selected earth, free from all perishable matter and from stones over 3 inches in diameter. Material shall be deposited and spread in horizontal layers, not exceeding 3 inches in thickness; each layer to be sufficiently watered and thoroughly rolled with a heavy satisfactory grooved roller. From time to time during the construction of the embankments, and if so required, three times after their completion, they shall be so thoroughly saturated with water that water will stand upon the surface. Foundation embankments shall be built up to a level at least 6 inches above the outside bottom of the structures which are to be built upon them, and allowed to stand for six weeks after completion, unless otherwise directed. The tops of the embankments shall then be excavated to the required subgrade of the structures.

General Filling—The embankments around the filters in the east court and at such other places as are required shall be built of materials free from large stones. This filling need not be rolled.

Gravel Filling Above Vaulting—On top of the vaulting of the filters shall be placed a layer 4 inches in thickness of washed gravel. This gravel shall be graded in size from coarse sand to stones not exceeding 1 inch in diameter.

Filling Over Vaulting—The filling on top of the vaulting between the graded gravel and the loam shall be of light and porous material. Ashes, cinders or refuse matter will not be allowed for use in this filling. This filling shall not be rolled.

Loam—On top of the filling over the vaulting, on all embankments and on all fills shall be placed a dressing of loamy top soil. This soil shall be accurately graded to the proper lines and grades, and shall be rolled with a light roller to secure smoothness. Any sliding or settling which may occur before final acceptance of the work shall be repaired by the Contractor.

Settlement—In building all embankments and making all fills, such allowance for the probable settlement of the materials shall be made as the Engineer shall deem necessary.

Sodding and Seeding.

Sodding—The sod shall be of good quality of earth, covered with heavy grass, sound and healthy, free from weeds, at least 1 foot square and 2 inches thick, cut with a bevel on the sides, so that when laid they will lap at the edges. No poor, lean or broken sod will be allowed in the work. The sod shall be carefully set so as to have a full bearing on their whole lower surfaces, and shall be properly rammed and well rolled, and wherever required by the Engineer they shall be pinned down with wooden pins not less than twelve (12) inches long. The surface of the loam shall be dampened immediately previous to laying the sod. Care shall be taken to have all surfaces conform to the proper lines and grades, and any sliding or settling which may occur before the final acceptance of the work shall be repaired by the Contractor.

Seeding--The surfaces to be seeded shall be carefully prepared and raked over, and then seeded with a mixture of grass seed, or grass seed, Hungarian rye and clover seed mixed, where required by the Engineer, together with a sufficient amount of fertilizer, not less than six hundred (600) pounds per acre, and all well rolled. Care shall be taken to have all surfaces conform to the proper lines and grades, and any sliding or settling which may occur before the final acceptance of the work shall be repaired by the Contractor.

Maintenance—All sodded and seeded surfaces shall be carefully looked after and tended by the Contractor, shall be watered and the grass cut when necessary, and shall be turned over to the city in good condition on the final acceptance of the work.

Macadam.

Foundations—When the excavations or embankments have been finished to the proper sub-grade, they shall be thoroughly rolled with a suitable roller until approved by the Engineer. If any depressions or soft spots appear under the rolling, due to improper material or foundations, this material shall be removed and replaced with suitable material and the whole rerolled until it is perfectly solid.

Quality of Material—All material shall be of good, hard stone, and that for the second and surface courses shall be of the best trap-rock. Stone shall be crushed with approved machinery, and shall be as nearly cubical as possible, free from screenings, of the proper size, and shall be clean and free from foreign material.

Macadam—After the sub-foundation has been rolled, the first course of broken stone shall be placed. This shall consist of stone which will pass through a ring 3 inches in diameter and will not pass through a ring 2 inches in diameter. Stone shall be placed in a uniform layer 6 inches in thickness and thoroughly rolled. On this course shall be placed a binder of uniform thickness and the rolling continued until the stones cease to sink or creep in front of the roller. Above this binder shall be placed a second course of broken stone of such size that it will pass through a ring 2 inches in diameter but will not pass through a ring 1 inch in diameter. This course shall be spread in a uniform layer of 3 inches in thickness and thoroughly rolled, after which a binder course shall be applied as previously specified for the first course. The surface course shall consist of stones which will pass a ¾-inch ring and containing about 50 per cent. screenings. This course shall have a sufficient thickness, so that, when rolled, the road will have a smooth, hard and uniform surface. The upper surface of the road, when finished, shall be free from depressions and shall be at the proper grade and curvature. On each side of the road shall be excavated ditches or gutters. These shall be well paved with cobble-stones and so graded that the water will be removed from the road.

Puddle.

Materials—The puddle shall consist of a mixture of clay and gravel. The clay shall be of good quality, free from loam, mica or other objectionable matter. The gravel shall be graded in size. The clay and gravel before being used shall be approved by the Engineer.

Proportions—All puddle shall be mixed in general of 1 part of clay to 2 parts of gravel, but these proportions may be changed at any time by the Engineer, whenever in his opinion it may be necessary to, in order to secure water-tight work.

Mixing—The clay and gravel shall be mixed by machinery in a continuous mixer of type to be approved by the Engineer, water being added at the same time, and the mixing continued until the mixture has a proper consistency.

Placing—While the puddle is in a plastic condition, it shall be placed in a layer 6 inches in thickness over a large surface, and left to partially dry out. During the process of drying out, the puddle shall be thoroughly compacted by rolling or ramming until the entire mass has become thoroughly consolidated and made water-tight. Puddle shall be sprinkled with water during the process of compacting, or at any time when so directed by the Engineer.

Cast-Iron Water Pipe.

Quality—All cast-iron pipe and bell special castings shall conform to the standard specifications of the New England Water Works Association, adopted September 10, 1902. All flange special castings shall conform to the requirements just specified, in so far as those specifications apply.

Flanges and Drilling—All flanges shall be cast solid and faced and shall be drilled for bolts and studs as shall be indicated. All flanges and drilling shall correspond to dimensions furnished by the Engineer. Flanges shall be coated with white lead after they have been faced and drilled.

Laying—Suitable tools and appliances for the safe and convenient handling and laying of the pipes shall be used. Great care shall be taken to prevent the pipe from being damaged, particularly on the inside. The pipes shall be carefully examined for defects, and no pipe, casting or valve shall be laid which is known to be defective. If any defective pipe, special casting or valve shall be discovered after being laid, it shall be removed and replaced by the Contractor with a sound pipe, special casting or valve. The pipes shall be thoroughly cleaned before they are laid and shall be kept clean until they are accepted in the complete work, and when laid shall conform accurately to the lines and grades given by the Engineer.

Blocking—In all trenches and embankments, each valve, special casting and length of pipe shall be laid upon blocking set in at least two different places along its length. Blocking shall be of sound spruce planking of such dimensions as the Engineer shall determine. Spruce wedges of suitable size shall be placed on the blocking to hold the pipe in position. The blocking shall be bedded firmly and level across the bottom of the trench, and when any blocking has been sunk too deep, additional blocking shall be placed to bring the pipe to the required grade. In the pipe galleries and such other places as may be directed, the pipes, special castings and valves shall be supportd on concrete piers.

Cutting Pipe and Drilling Holes—Whenever pipes require cutting to fit in the line, it shall be done by a machine which will leave a smooth cut at right angles with the axis of the pipe and in a manner satisfactory to the Engineer. In all cases where it may be impracticable to have the holes drilled in the flanges in advance, the Contractor shall drill the holes necessary for making connections at the site of the work.

Lead Joints—In making all lead joints, the spigot end shall be properly seated in the adjacent bell and adjusted to give a uniform space for the joint which shall be made with twisted or braided hemp packing and soft packing lead. The packing shall be thoroughly driven into the bell so as to leave a space 2 inches deep for lead, for pipes 14 inches or less in diameter and 2¼ inches deep for pipes over 14 inches in diameter. The melting pot shall be kept near the joint to be poured. Dross shall not be allowed to accumulate in the pot and each joint shall be made at one pouring. The joints shall be thoroughly calked by competent mechanics in a manner to secure water-tight joints.

Flange Joints—The Contractor shall furnish and place all bolts, nuts, washers and gaskets for making flange connections. The bolts, nuts and washers shall be of quality equal to those made by Hoopes & Townsend.

Testing—When a section of pipe and appurtenances has been laid and before it is covered, the Contractor shall test the same by filling it with water under a hydrostatic head of at least 50 pounds per square inch for all systems, except the pressure supply system, which shall be tested under a hydrostatic head of at least 150 pounds per square inch. Should any defects be found in the joints they shall be promptly made good, and should any defective pieces be discovered they shall be removed and replaced by the Contractor with sound castings of equal quality, to the satisfaction of the Engineer.

Riveted Steel Pipes.

Quality of Steel—Steel plates and rivet steel shall meet the requirements of the Manufacturer's standard specifications for boiler steel and boiler rivet steel. They shall also meet such additional requirements for punching, drifting and scarfing as the Engineer shall determine.

Punching—The work shall be carefully and accurately laid out in the shop and the rivet holes punched. All holes shall be clean cut and shall be not more than 1-16 of an inch larger in diameter on the die side of the hole than that of the intended rivet. After the holes have been punched they shall be reamed for countersunk rivet heads on the inside of the pipe. When the work is assembled, rivet holes shall coincide with 1-32 of an inch, and any eccentricity greater than this shall be corrected by drilling or reaming. Drifting to force holes to coincide will not be allowed. When the eccentricity is so great that the joint is liable to be weakened by reaming, new and satisfactory plates shall be provided.

Shaping—All plates shall be shaped to the proper curvature by cold rolling; no heating or hammering will be allowed for straightening or curving. All scarfing shall be done when the steel is at a proper temperature. Parts of the plates which have been heated for scarfing shall be thoroughly annealed subsequently.

Construction of Pipes—All pipes shall be cylindrical and of the full diameter inside. Each course shall be made of one plate, and the pipes shall be made up in the shop in sections of four courses, having a total length of about 30 feet. All longitudinal and circular seams shall be butt joint with outside cover plates.

Riveting—All riveting in the shop shall be done by machinery, exerting a slow pressure which shall be maintained until the rivet head has lost its redness. All rivets shall be driven hot. In the field, all rivets shall be driven by pneumatic or other approved machinery; all rivet heads on the inside of the pipe shall be countersunk flush, with the face of the plate. All outside rivet heads shall be formed with a button set and shall be full and round and concentric with the shank of the rivet. All loose or otherwise defective rivets shall be removed and replaced in a satisfactory manner.

Calking—All seams and joints on the outside of the pipe shall be thoroughly calked, steel to steel, with a round-nosed calking tool. Split calking or calking of rivet heads will not be allowed.

Testing in Shop—Each section of pipe, after having been calked and before being coated, shall be filled with water and tested in the shop under a hydrostatic pressure of 50 pounds per square inch, and shall be made absolutely tight at this pressure.

Coating—After each section of pipe has been tested, it shall be immediately dried and cleaned and then heated uniformly to a temperature of 300 Fahr., after which it shall be dipped vertically in a bath of mineral rubber asphalt pipe coating, manufactured by the Commercial Asphalt Company of New York. Coating shall be durable, perfectly waterproof and adhere strongly to the metal. It shall have a smooth glassy surface, free from ridges and be practically of uniform thickness on all parts of the pipe. It shall be sufficiently hard and tough not to be easily abraded and shall show no tendency to flow when exposed to the sun in summer or to become so brittle in cold weather as to scale off. At each field riveted joint and at all other places where the coating may have become abraded the plate shall be properly recoated by the Contractor with the material above specified.

Transportation—In transporting all pipes especial care and provision shall be taken to prevent the pipes or the coating from being damaged in any way.

Special Work—At such points as shall be necessary, the pipes shall be made of such dimensions as to fit the line accurately.

Laying—The sections of pipe shall be so laid that the longitudinal seams shall be near the top and shall be spaced alternately approximately 1 foot each side of the middle. In connecting pipes together, great care shall be taken to prevent the edges of the sheets from being damaged. If rivet holes do not exactly match, they shall be slightly reamed or drilled by a pneumatic machine, in such a manner as may be indicated by the Engineer, so that the rivets may be inserted. Sections shall be securely bolted until the rivets are driven.

Protection of Coating During Laying—Great care shall be taken to prevent the coating from being damaged while the pipe is being laid. All persons walking in or upon the pipe shall have their shoes protected by soles of rubber or other suitable material.

Test After Laying—After the pipe has been riveted, calked and cleaned out, it shall be filled with water and tested under hydrostatic pressure of 50 pounds per square inch and made perfectly tight at this pressure.

Connections—Pipes shall be provided with manholes, blow-off connections and all valve connections. These manholes and all connections shall be made of malleable cast steel and shall be riveted to the pipes.

Workmanship—Workmanship shall be first-class in all respects.

Valves.

Waterway—All valves shall be provided with circular waterways through the bodies of the valves of the full diameters of the connecting pipes.

Quality of Materials—All materials shall be made of the best quality and suitable for the work required of them.

Workmanship—The workmanship shall be first class throughout.

Iron Castings—All iron castings shall be made of good quality soft gray iron, having a tensile strength of 22,000 pounds per square inch of section. All iron castings shall be smooth inside and out, free from sand and blowholes, scoriæ, cold shuts and spongy places. Plugged, filled or defective castings will not be accepted.

Composition Mountings—All valves shall be furnished with full composition mountings with bronze stems and with carefully and firmly fitted valve rings and seats.

Stuffing Boxes—All valves shall be provided with stuffing boxes, constructed with bolt followers and packed ready for use.

Flanges and Drilling—All flanges shall be cast solid, shall be faced and shall have holes for bolts and studs drilled to standards furnished by the City. Flanges shall be coated with white lead after they have been faced and drilled.

Bolts and Nuts—All bolts and nuts shall be of the best quality American refined bar iron, and shall be equal to those made by Hoopes & Townsend.

Controlling Device—Each valve shall be so constructed that it can be opened or closed by means of electricity. The apparatus for controlling the movement of the valve shall be placed in the operating station. This apparatus shall be so designed that when the valve is being opened the electrical current shall be broken automatically after the valve disk has traversed a distance of one-fiftieth of one inch, and that it will be necessary to close the circuit again before the valve can be still further opened. In closing the valve, the circuit shall not be broken automatically. It shall, however, be possible to make or break the circuit with the valve in any position.

Indicator—Each valve shall be provided with an indicator operated by electricity, showing the position of the valve disk, and which shall register in the operating station. This indicator shall be so designed that it will be operated by the movement of the valve disk and not by the device for controlling the opening and closing of the valve. Each valve shall be also provided with a suitable indicator registering at the valve and of a type to be approved by the engineer.

Coating—All cast-iron surfaces outside and inside shall be thoroughly cleaned and painted with two coats of asphaltum, or any other varnish to be approved by the City. All composition tool work shall be left bright.

Marking—Each valve body or cap shall have cast upon it in raised figures the name of the manufacturer, size of valve, date of casting, and such other initials as the engineer shall determine, in neat letters one-eighth of an inch high.

Hydrostatic Test for Valves—All valves except those in the high pressure system shall be tested with a hydrostatic pressure of 40 pounds per square inch. Valves in the pressure system shall be tested with a hydrostatic pressure of 150 pounds per square inch. All valves which show any defects under these tests will be rejected.

Test of Valves—After the valves have been placed, they will be tested for satisfactory operation. Any defects which may be found and which are due to the insufficiency of the materials or workmanship, at or within one year from the date of such test, shall be made good by the contractor at his own expense.

Sluice Gates.

Workmanship and Materials—All materials shall be of the best quality specially adapted to the service required. Workmanship shall be first class in all respects. All surfaces forming joints or bearing surfaces shall be machined. Iron castings shall be of the quality specified under Cast-iron. Composition castings shall be made of the proper mixture of copper, tin and zinc, and shall have ample strength for the work required of them.

Bolts—All bolts and nuts shall be made from the best quality American refined bar iron, with good, sound, well-fitting threads. Heads and nuts shall be hexagonal, shall be squared up and chamfered, and all heads, nuts and threads shall be of the United States standard dimensions.

Faces—All composition faces shall be securely fastened to the cast-iron and shall be hammered into place in a suitable groove, the back of this groove to be machined. All faces after they have been hammered and secured in place shall be scraped to a true bearing.

Wedges—Each gate shall be provided with suitable wedges of hard composition or bronze, and fastened by bolts and adjusting screws. Wedges are to be fitted and adjusted in position after the gate has been set and until it is water tight.

Concrete.

Sand—Sand shall be composed of sharp angular grains evenly graded from fine to coarse, thoroughly screened to reject all particles greater than one-fourth of an inch in diameter, and shall be clean and equal in quality to the best New Jersey bank sand. Any sand containing over 3 per cent. of very fine material or of loam, clay, or other impurities, may be rejected.

Ballast—Ballast shall be composed of gravel or broken trap, rock or other hard stone, to be approved by the engineer, carefully and finely graded from the size of ¼ inch to 1½ inches in diameter. This material shall be cleaned, and, if necessary, shall be washed when required by the engineer.

Cement—The cement shall be equal in quality to the best American Portland cement. It shall be delivered in such packages as may be approved by the engineer, and shall contain either 380 pounds or some even fraction of 380 pounds. The cement will be subject to inspection and rigorous tests of such character as the engineer shall determine. Only such cements as have a well-established reputation shall be used in the work; and the contractor shall submit to the engineer the brands of cement which he proposes to use. No cement shall be used which is not in all respects satisfactory to the engineer. The Contractor shall at all times keep in store at the site of the work a sufficient quantity of the cement to allow ample time for tests to be made without delay to the work of construction. The engineer shall be notified at once of each delivery. The cement shall be stored in a tight building having a floor.

Proportions—Concrete shall be mixed in the proportions of 1 part of cement to a total of 8 parts of sand and ballast. The sand and ballast shall be measured separately and mixed together in the proportions to be determined by the engineer. The proportions shall be fixed by volume, 100 pounds of cement being estimated to occupy 1 cubic foot of space. The sand and ballast shall be measured when not packed more closely than by throwing them in the usual way into barrels or boxes.

Mixing—Concrete shall be mixed by machinery in cubical box mixers or mixers of other types, if approved by the engineer. Measuring boxes or other approved apparatus shall be used so that the proportions can be accurately determined. Concrete shall be mixed very wet, except at such points where the engineer shall consider a drier mixture more desirable.

Depositing—After the concrete has been mixed it shall be deposited in place before it has time to obtain its initial set. No retempering will be allowed under any circumstances. The concrete shall be deposited and joggled or rammed into position in a satisfactory manner.

Centres and Forms—The Contractor shall provide the centres and forms required for placing the concrete. They shall be of the proper dimensions, smooth and sufficiently strong to withstand without movement the strains imposed upon them. The centres and forms for all surfaces which will be exposed in the finished work shall be so constructed or covered that when they are removed the exposed faces of the concrete will present a smooth, finished appearance, free from voids or stones. All centres and forms before being used shall be cleaned of all adhering substances, and shall be coated with petrolene, oil or other approved material, to prevent the concrete from adhering to them. Should the centres and forms lose their proper shape and dimensions or should the surfaces become unduly roughened or dented, satisfactory centres and forms shall be substituted for them. The directions of the engineer regarding the time of removing the centres and forms shall be followed, and their removal shall be done with care, so as not to injure any of the work.

Bonding—The Contractor shall make such provisions for bonding as the engineer shall direct, and, if required, shall step off joints between work done at different times. Where old work is joined to new the exposed surfaces shall be thoroughly cleaned with water and slushed with neat cement.

Protection of Masonry—The Contractor shall be responsible for the care and protection of the masonry at all times, and especially that laid during freezing weather; and if at any time sufficient protection has not been provided, the Contractor shall, at his own expense, provide such additional protection as shall be necessary. All injured work shall be made good by the Contractor in a satisfactory manner.

Not to Be Laid in Water—Concrete shall not be laid in water, nor shall water be permitted to rest on any concrete until the concrete has been set at least twenty-four hours.

Defective Work—Should any voids or other defects be discovered at any time, the defective work shall be repaired or removed and replaced with suitable material in a satisfactory manner, and at the Contractor's expense.

Care of New Work—The exposed surfaces of finished and unfinished work shall be kept constantly moist by sprinkling with water at short intervals, or by covering with moistened burlap, or by such other means as may be approved, and this moistening shall be continued until the permanent covering is in place, or until, in the opinion of the engineer, the concrete is sufficiently hardened.

Work in Storms—The mixing and placing of concrete shall be stopped through rainstorms, if required, and all freshly-laid concrete shall be protected by canvas in such a manner as to prevent running water from coming into contact with it. Sufficient canvas shall be provided and kept ready at hand for this purpose.

Floors—The upper surface of all floors in the filters, pipe galleries, conduits and other places shall be brought to the required dimensions by means of screeds, and screeded and troweled to a smooth surface, free from all appearance of stone. If necessary to secure this result, cement mortar mixed in the proportions of one volume of Portland cement and two volumes of sand shall be applied to it and troweled by the Contractor before the concrete has set.

Walls—The exposed faces of the outside and dividing walls of the filters below the sand line shall be plastered with Portland cement mortar mixed in the proportions of one part by volume of cement to two parts by volume of sand, and shall be roughened by stippling with a wire brush before the plaster has set.

Vaulting—The concrete in the vaulting shall be placed under all circumstances so that the section over each pier included between the centre lines of the adjacent arches will be a monolith. No other manner of making these joints will be allowed, except by direction of the engineer. The location of all other joints in the vaulting shall be subject to the approval of the engineer. The entire upper surface of the concrete in the vaulting shall be troweled to a smooth surface.

Piers—The concrete in each pier shall be laid without joints so as to make a monolith. The finishing of the outside of the piers below the sand line shall be the same as that heretofore specified for the walls of the filters.

Covers for Main Collectors—The covers for the main collectors in the filters shall be constructed in slabs of such dimensions as shall be approved by the engineer. These slabs shall be built in suitable forms and the under surface of each slab shall be perfectly smooth. Each slab shall be provided with two lifting rings.

Setting Iron and Steel Work—Such iron and steel fixtures as shall be furnished by the City shall be set in the concrete by the Contractor at his own expense.

Steel Reinforcements of Concrete.

All rods shall be twisted cold and shall meet such physical and chemical requirements as the engineer shall determine. In the vaulting over the pipe gallery the concrete shall be reinforced by steel sections of the "T" shape. This structural steel shall meet the manufacturers' standard specifications.

Drains in Piers and Walls.

In each pier and at points 20 feet apart in the dividing walls shall be placed a 2-inch drain. This drain shall be made of 2-inch wrought-iron pipe and fittings and shall extend from a point just above the sand line to flush with the top of the vaulting above. All drains which are in the walls shall be provided with a plug on one side. Over the top of each drain shall be placed a strainer of type to be approved by the engineer. Over this shall be placed 1 cubic foot of clean gravel or broken stone which will not pass the strainer. Any drains which become plugged up shall be opened before the final acceptance of the work.

Covers for Ventilator Shafts.

On the top of each ventilator shaft of the filters shall be placed a cast-iron frame with two steel covers. The frame shall be made of cast-iron and coated with coal-tar varnish. The covers shall be of sheet steel, the lower one being 1/8 of an inch thick and the upper one 1/4 of an inch thick, and painted with three coats of Smith's durable metal coating or other paint of equal quality to be approved. These covers shall be fastened together so as to provide an air space between them, and shall be hinged to the frame. Each cover will be provided with a device so that the cover can be raised from the inside of the filter and held in position after it has been opened, at an angle of 45 degrees.

Cast Iron.

Quality—All castings shall be of close-grained gray iron, having a tensile strength of not less than 20,000 pounds per square inch. All castings shall be sound, smooth, clean and free from blisters, sand holes and all defects. Castings shall be planed where necessary to secure perfectly flat and true surfaces. All bolt holes shall be drilled.

Painting—All castings shall be thoroughly painted with three coats of asphaltum or other approved varnish, one coat to be applied before the work leaves the shop and the other two coats after the castings have been set in place.

Structural Steel.

Quality—In quality and workmanship, all structural steel shall meet the Manufacturer's Standard Specifications.

Painting—All structural steel shall be thoroughly cleaned from all loose scale and given one coat of pure raw linseed oil before leaving the rolling mill, and before being exposed to the weather. Steel shall be thoroughly cleaned of all adhering substances and painted with one heavy coat of Smith's durable metal coating, or paint of equal quality. No painting shall be done after loading on cars, nor when work is exposed to freezing weather, nor unless the metal is perfectly dry, and whenever possible it shall be done under cover. All parts of members which are to be bolted or riveted together shall receive one heavy coat of paint immediately before being put together. After erection, the whole of the metal work shall be thoroughly cleaned and touched up to cover where the paint has been damaged, and finished with two additional coats of paint of the quality heretofore specified. All parts of the work which will be inaccessible in the complete structure shall receive two additional coats during erection.

Lateral Collectors.

Quality—Terra Cotta pipe shall be of standard quality, made of the best material, thoroughly and perfectly burned, of a homogeneous texture, with out cracks or imperfections, well glazed so that their inner and outer surfaces shall be smooth, hard and even.

Dimensions—All straight pipes shall be 2 feet in length; shorter lengths shall be used when necessary to secure the proper location of branches or bends. All pipes shall be straight or of the required curvature, true in form and full diameter throughout and 5/8 of an inch in thickness. All bends shall have a depth so as to allow an annular space of 1/2 an inch all around for the joints. In the manufacture of the pipes the bell shall be cut away on one side so that the barrel of the pipe shall rest for its entire length on the concrete floor.

Laying—All pipes shall be perfectly clean before being laid. They shall then be placed on the floors of the filters with open joints, the spigot end of one being placed in the bell of the next adjacent pipe, so that there will be an opening of 3/4 of an inch left between the spigot end and the seat of the bell. In the outer ends of the lateral collectors shall be placed vitrified terra cotta plugs to prevent the admission of gravel or other substances. All pipes shall be laid throughout to the proper lines. Any pipes which should be broken or found defective after having been laid shall be removed and replaced with sound ones. Should dirt or other foreign substances be allowed to enter any of the pipes, such pipes shall be taken up, thoroughly cleaned and relaid.

Filter Gravel.

Quality—Filter gravel shall be of rounded gravel, screened from deposits of a sandy nature. Schist, shale or limestone will not be accepted. Filter gravel shall not contain any dirt, clay or fine or foreign material of any kind, and when shaken with clear water shall leave it substantially clean and clear. No gravel shall contain more than 2 per cent. of lime or magnesia and other matter soluble in water or a weak solution of hydrochloric acid. Filter gravel shall be placed in layers of graded size and having a total thickness of

16 inches. The lower layer shall be 6 inches in thickness and shall pass through a sieve having a 3-inch clear mesh and shall be retained on a sieve having a 1¾-inch clear mesh. On this shall be placed a layer 4 inches in thickness, which shall pass through a sieve with a 1¾-inch clear mesh and be retained on a sieve with a ⅝-inch clear mesh. On this shall be placed a layer 3 inches in thickness which shall pass through a sieve with a ⅝-inch clear mesh and be retained on a sieve with a ¼-inch clear mesh. Above this shall be placed a layer 2 inches in thickness, which shall pass through a sieve with a ¼-inch clear mesh and be retained on a sieve having 14 meshes per lineal inch. Above this shall be placed the top layer 1 inch in thickness, which shall pass through a sieve having 14 meshes per lineal inch and be retained on a sieve having 20 meshes per lineal inch.

Placing—The gravel shall be carefully placed, and each layer shall be smoothed off to a true surface to the required depth. Any disturbances of any nature in the layers after being placed shall be corrected before the next layer above is placed. Around each of the joints of the lateral collector shall be placed at least 1 cubic foot of the large pieces of the gravel and those immediately adjacent to the joints shall be placed by hand.

Filter Sand.

Quality—Filter sand shall be of clean river, beach or bank sand (or crushed rock) with either sharp or rounded grains. It shall be entirely free from clay and organic impurities, and shall, if necessary, be screened and washed to remove such materials. All grains shall be of hard material, which will not disintegrate. Filter sand shall not contain more than 1 per cent. of lime or magnesia. Filter sand shall have an effective size of not less than 0.28 m.m. and not greater than 0.35 m.m. and shall have a uniformity coefficient not greater than 2.5. Any sand which contains particles larger in diameter than 5 m.m. or 0.5 of 1 per cent. of particles smaller in diameter than 0.16 m.m., will not be accepted.

Placing—Filter sand shall be placed in layers of such thickness as the engineer shall determine. The upper surface of the top layer only of filter sand shall be smoothed. Compacting of filter sand while being placed in the filters will not be allowed. Should any compacting take place, such sand shall be loosened up to the satisfaction of the engineer. Frozen sand shall not be placed in the filters.

Regulating and Indicating Apparatus.

On the outlet pipe of each filter shall be placed a Venturi meter for regulating the rate of filtration. The meter shall be connected to suitable apparatus which shall indicate the volume of water passing through the meter and the corresponding rate of filtration on the filter. This apparatus shall also be so connected with the water on the filter as to indicate the loss of head in passing through the sand of the filter. This indicating apparatus shall be placed in the operating station.

Sand Washing Apparatus.

Apparatus for the washing and transporting of filter sand shall be erected. This apparatus shall consist of portable ejectors, stationary boosters, and receiving tanks and the necessary piping.

Portable Ejector—Portable ejectors shall be so arranged that they may be easily moved from place to place by two men, and they shall be provided with suitable fittings, so that they may be connected with the pressure supply and sand discharge pipes in the filters.

Boosters—Each booster shall consist of three stationary hoppers, so arranged with suitable overflows and ejectors that sand which is delivered to them from the portable ejectors may be washed and then boosted to another booster or to the sand receiving tanks. Each booster shall have a suitable settling basin into which the surplus dirty water shall flow. Each basin shall have a connection with the wash water drain.

Sand Receiving Tank—Suitable sand receiving tanks shall be provided, so constructed that they may be easily moved from one filter to another and so arranged that they may be easily supported from the vaulting. Each tank shall have an overflow chamber at one end, from which shall be provided a suitable connection to the wash water pipe at the inlet chamber of the filter. In the bottom of each receiving tank shall be suitable openings, provided with easily operated valves through which sand may be discharged.

Quality of Materials—All materials used in the construction of the sand washing and transporting apparatus shall be of the best quality. All nozzles and throats shall be made of cast-steel and hardened. Workmanship shall be first class in all respects.

Painting—All cast-iron and steel work shall be coated with three coats of asphaltum or other approved varnish.

Buildings.

Construction—The buildings shall be built of brick masonry, finished with suitable pressed brick and granite trimmings. They shall be of pleasing architecture and suitable for the purposes for which they are intended.

Brick Masonry—The walls shall be built of brick masonry. The interior and exterior faces shall be of pressed brick, those on the exterior being of the Roman size. All other brick shall be of first quality building brick. Pressed brick shall be laid in mortar composed of one volume of Portland cement, one volume of lime paste and three volumes of sand. Lime paste shall be of first quality fresh burnt lime. Sand shall be of the quality specified under Concrete, and shall be screened to reject all particles greater than 1/8 of an inch in diameter. Mortar for brick backing shall be composed of one volume of Portland cement and three volumes of sand. Mortar for pressed brick shall contain a sufficient amount of mortar stain to produce the proper shade. All pressed bricks shall be gauged before being laid, and those in one course shall all have the same thickness. Joints shall not exceed 1/8 of an inch in thickness and shall be carefully jointed. Pressed brick shall be tied to the brick backing every sixth course. Brick backing shall be laid to line in running bond with every sixth course headers. All bricks shall be wet before laying and shall be laid in a full bed of mortar.

Stone Masonry—All stone masonry shall be of light grey Eastern granite. All stone shall be furnished from one quarry and shall be uniform in color throughout. The stones shall be of compact texture, free from streaks which show on the exposed faces. Joint surfaces for all horizontal joints shall be dressed for the full area of the joint faces, so that the thickness of the mortar joints shall not exceed 3/8 of an inch for a depth of 3 inches back from the exposed faces, and back of this limit shall not exceed 5/8 of an inch. Vertical joints shall be dressed for the mortar joint not exceeding 3/8 of an inch thick for a depth of 3 inches back from the exposed faces, and back of this limit shall not exceed 3 inches. All exposed faces shall be hand tool dressed, having eight cuts to the inch, and shall be flat and true, without depressions or cavities. Drips shall be cut on all projecting work where required. Stone masonry shall be laid in a full bed of mortar of the same quality as that specified for Brick Masonry. As soon as the masonry is set the exposed joints shall be cut out to a depth of 3/4 of an inch for pointing. Before completion of the work the joints shall be thoroughly wetted and pointed with mortar.

Carpenter Work and Lumber—All lumber shall be of first quality, free from knots, spots and imperfections of all kinds, and shall be extra well seasoned. All mitres shall be true and close, and the woodwork shall be kept free from all stains, lead pencil marks and other imperfections. All woodwork shall be properly secured with screws, nails, bolts, etc., as may be required. All interior woodwork shall be put up with wire nails. All interior moldings and linings shall be of well seasoned yellow pine.

Windows—All window frames, sashes, exterior sills and moldings shall be made of white pine. All window stools and aprons shall be made of yellow pine. Sashes shall be double hung with sash cord and cast-iron weights and pulleys. All sashes shall be glazed with first quality double strength American glass. All glass shall be imbedded in oil putty, bradded and back-stopped, and left clean and sound.

Doors—All doors, jambs and exterior moldings shall be of first quality, well seasoned white pine, and shall be paneled and molded. Doors shall be hung on three loose pin butts.

Hardware—All hardware shall be of first quality brass or bronze, of such sizes and located at such places as the Engineer shall determine.

Painting—All yellow pine shall receive three coats of hard oil finish, and all white pine shall be so finished or painted with three coats of pure white lead and linseed oil, the colors to be selected by the Engineer.

Roofs—All roof framing shall be of structural steel. The roofing shall consist of slate laid on terra cotta tiles. All terra cotta tiles shall be of standard dimensions and made from carefully selected clay and evenly burnt. Tiles shall be laid in and the joints filled with mortar of the quality specified for Brick Backing. All slate shall be equal to No. 1 Chapman slate, from Chapman quarries, Pennsylvania. Slate shall be 8 inches wide, and shall be laid with a lap of at least 3 inches of third on first. Each slate shall be drilled and nailed with two composition slater's nails. Slate shall be neatly cut at the valleys and the hips, and shall be laid double at the eaves and hips. Slate shall be laid in roofers' cement at the ridges, eaves, valleys and hips. All valleys, hips and openings in the roof shall be flashed with copper. All gutters and flashings shall be of 16-ounce soft copper, and all cornices, finials, ridge and hip rolls shall be of 16-ounce cold rolled copper. Rain water conductors shall be of ample size, shall be made of copper, rectangular in sections and properly crimped. They shall be supplied with suitable strainers and shall discharge into a cast-iron pipe extending 18 inches above the ground.

Plumbing—All plumbing shall be first-class; the fixtures to be selected by the Engineer. All plumbing shall conform to the rules and regulations of the Board of Health of The City of New York.

Heating—All buildings shall be heated by steam, furnished from a central plant at the boiler house. All steam pipe shall be properly covered to prevent loss of heat by radiation. Ample heating surfaces shall be provided so that the buildings may be maintained at a temperature of 70 degrees Fahr. in the coldest weather.

Railings—All railings and standards shall be of 2-inch wrought-iron pipe, the railing to be 3 feet above the floor. Standards and ends of railings shall be screwed into broad iron sockets well secured by bolts to the floors or walls. All joints shall be made with heavy iron balls, threaded to receive rails and standards. All railings, standards and connections shall be coated with a black, baked enamel coating.

Plastering—All outside walls shall be furred with 2 by 1 inch pine strips, set 16 inches centre to centre and securely nailed to wooden bricks built into the walls. All furring and partitions, which are to be plastered, shall be lathed, with best quality spruce lath, free from sap, bark or knots and of the full width and thickness for the full length. Lathes shall be put on horizontally, shall break joints every 18 inches and shall be not less than 3/8 of an inch apart. All plaster shall consist of three coats of Acme cement plaster; the first coat on the lath work to be of fibered material. The first coat shall be scratched to form a rough surface for the second coat, which shall be applied as soon as the first coat has set sufficiently to receive it, the mortar being brought out to a true surface. After the second coat has been on twenty-four hours the surface shall be finished with a sand finish of Acme cement, mixed with clean water only, and floated to a true surface, free from defects of any kind, with clear soft pine or cork-faced floats. All angles and corners in the plastering shall be finished round.

Electric Lighting.

Machinery—The engine shall be of the horizontal cross-compound type, direct connected to dynamo capable of generating direct current for supplying incandescent lights, and the motors for driving the ventilating fans. engine and dynamo shall be capable of operating economically at three-quarter load.

Wiring—All buildings shall be wired to correspond with the best current practice. In the filters and pipe galleries the wiring shall be done in accordance with the best marine practice. The wiring shall be of sufficient size so that the line losses will not exceed 5 per cent. The number and location of all lights and switches shall be determined by the Engineer.

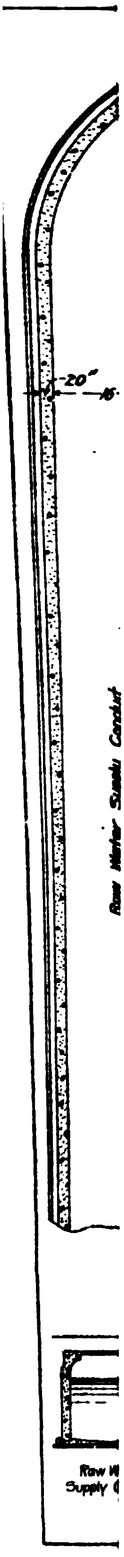
Ventilation.

In the basement of the operating station shall be placed, in duplicate, ventilating fans, electrically driven, for furnishing large volumes of air throughout the pipe galleries, so that when the filters are being cleaned they will be suitably ventilated by the discharge of this air from the pipe gallery through the filter.

Pumping Machinery.

Pumping Engines—Pumping engines shall be of the horizontal cross-compound fly wheel type, of modern construction in every particular. They shall be of sufficient size to pump easily 4 million gallons per 24 hours against a total suction and force main lift of 110 pounds per square inch, with a steam pressure of 150 pounds per square inch at the throttle. They shall be capable of showing on test of 24 hours duration a duty of not less than 135 million foot pounds of work for each 1,000 pounds of commercially dry steam, consumed by the engine and its auxiliaries. Workmanship shall be first class and equal to the best present practice.

Boilers—Boilers shall be of the horizontal water tube type, constructed for a working pressure of 150 pounds per square inch, with a factor of safety of not less than 5½, based on a minimum tensile strength of steel plate of 60,000 pounds per square inch. Each boiler shall contain not less than 10 square feet of heating surface per Centennial standard horse-power. No cast iron shall be used for the construction of any part which is under pressure.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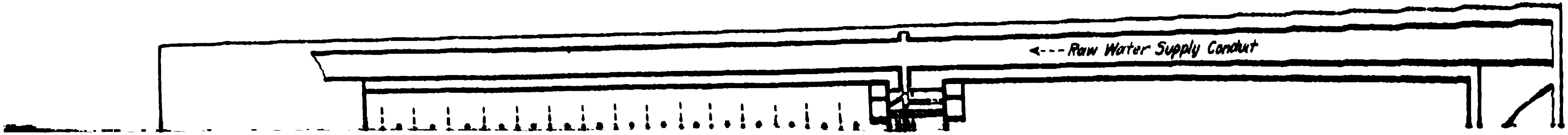

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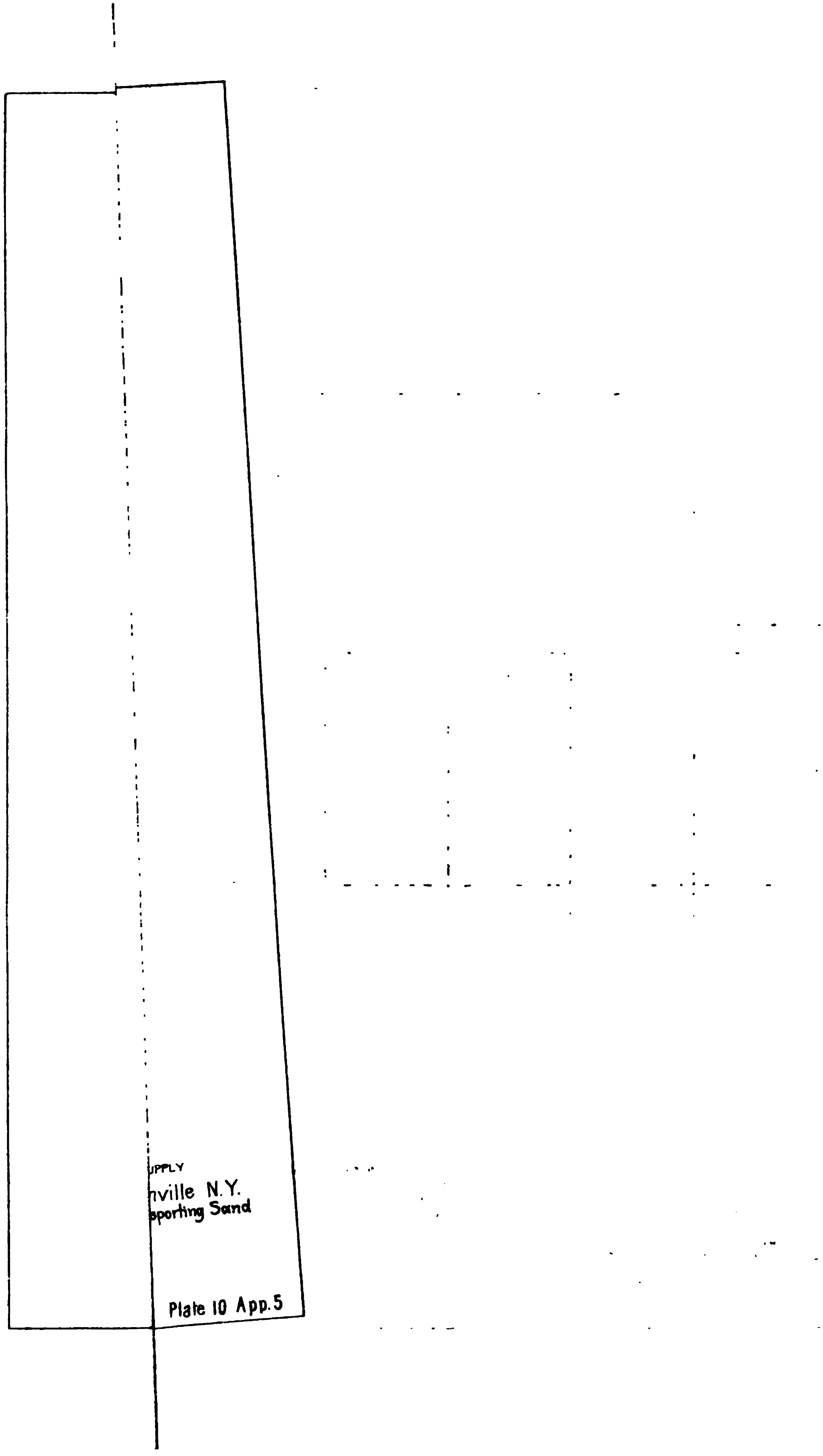

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APPENDIX VI.

Chemistry and Biology.

Appendix VI.

CHEMISTRY AND BIOLOGY.

GEORGE C. WHIPPLE, DEPARTMENT ENGINEER.

The work of the Department of Chemistry and Biology may be conveniently described under the following heads:

1st. Quality of the present water supplies of New York City;
2d. Stream investigations;
3d. Probable quality of the water supplies recommended;
4th. Hudson River studies;
5th. Ground water studies;
6th. Experiments on soil physics.

I. Quality of the Present Water Supplies of New York City.

I. INTRODUCTION.

The City of New York, with its five boroughs, with its 327 square miles of area, and its three and one-half million inhabitants, has eighty-two distinct sources of water supply. The City is an aggregate of many communities which were once independent and which once had their own systems of water works. (Consolidation affected these supplies but little.) In some cases the works of private companies were taken and operated by the City, and interconnections have been gradually established between adjacent distribution systems, but in general the old sources of supply continue in use.

The water supplies of the different portions of the city were developed according to local conditions. The smaller communities found supplies of ground water near at hand and utilized them by driving wells, while the larger communities, like Brooklyn and the old City of New York, were compelled to collect the surface water on distant watersheds and bring it to the city by aqueducts. Brooklyn later on reinforced its surface supply by driving wells. At the present time the citizens of Greater New York are supplied either with:

1. *Surface water*, collected and stored in impounding reservoirs; or

2. *Ground water*, obtained by driving wells to various depths between 20 and 200 feet; or

3. *Surface and ground water mixed.*

The number and varied character of the different sources of supply are shown in Tables IA and IB, and the districts which they supply are shown in Plate I.

These various sources of supply may be classified as follows, counting separately the different driven well stations and the most important lakes. ponds and reservoirs:

Borough.	Number of Ground Water Supplies.	Number of Surface Water Supplies.	Total.
Manhattan	..0	12	12
Bronx	2	4	6
Brooklyn	24	16	40
Queens	16	1	17
Richmond	7	..0	7
Entire City	49	33	82

It will be seen from these figures that of the eighty-two water supplies which The City of New York possesses, thirty-three are "surface water supplies" and forty-nine are "ground water supplies." If the quantity of water derived from these sources is considered, the following classification, based in part upon measurements and in part upon estimates, will give the relative amounts used in the different boroughs.

Borough.	Million Gallons per Day.		
	Ground Water.	Surface Water.	Total.
Manhattan	..0	260	260
Bronx	1	23†	24
Brooklyn	50	60	110
Queens	13	*	13
Richmond	6	..0	6
Total	70	343	413

In round numbers the present consumption of the city is 400 million gallons per day, and of this 83% is surface water and 17% ground water.

* Surface water supply is only occasionally used.

† 10 million gallons estimated as furnished by the Croton system.

In Brooklyn, and to some extent in The Bronx and in Queens, the surface waters and ground waters are mixed before they are distributed to the consumers. The following classification takes this into account:

Borough.	Number of Million Gallons per Day.			
	Surface Water.	Ground Water	Mixed Surface and Ground Water.	Total.
Manhattan	260	..0	..0	260
Bronx	22	1	1	24
Brooklyn	..0	19	91	110
Queens	..0	13	*	13
Richmond	..0	6	..0	6
Total	282	39	92	413

These figures show that 68% of the water supply is wholly surface water, 9% is wholly ground water, and 23% is mixed surface and ground water.

Filtration is used only to a very limited extent. No filtered surface water is served direct to consumers. Two mechanical filters purify the waters of Springfield and Baiseley's ponds, of the Ridgewood system, before they are turned into the conduit, and two sand filters are being constructed for Simonson's Pond and Hempstead Storage Reservoir of the same system, but these filter effluents are mixed with other waters before they are delivered to the consumers. The water from the driven wells of the Queens County Water Company, which supplies Far Rockaway, in the Borough of Queens, is filtered to remove the iron. Not any of the water supplied to Manhattan, Bronx or Richmond is filtered. Filters have been projected, however, at Lake Mahopac and elsewhere on the Croton Watershed.

* Very small amount.

TABLE IA.

Data Concerning the Surface Water Supplies of New York City.

Borough.	Name of Reserv ir, Lake or Pond.	Date When First Opened.	Drainage Area in Square Miles.	Area of Water Surface. Square Miles.	Maximum Depth in Feet (Approx.)	Capacity in Million Gallons.	Length Upper End to Outlet in Miles.	Distance Outlet G. H. to Upper End of Aqueduct.	Distance Outlet G. H. to Lower End of Aqueduct.	Estimated Population per Sq. M. on Each Watershed.	Aggregate Population Per Sq. M. Above Storage Reservoir.
Manhattan	Boyds Corner Reservoir.	1873	21.43	0.68	50	2,727	1.75	24.6	55.35	27	27
	West Branch Reservoir......	1895	18.83	2.07	46	10,070	3.00	21.0	51.75	24	32
	Lake Gleneida................................	1870	0.68	0.28	100	165	0.75	23.0	53.75	390	390
	Lake Gilead..............................	1870	0.65	0.19	100	380	0.80	19 0	49.75	61	61
	Kirk Lake......................................	1870	2.84	0.16	25	565	1 00	15.8	46.55	65	65
	Lake Mahopac..................................	1870	1.03	0.88	85	575	1.80	15.9	46.65	†126	126
	Muscoot Reservoir.............	1897	14.45	1.10	64	6,692	2.70	8.1	38.85	50	57
	Middle Branch Reservoir........................	1878	20.51	0.77	50	4,005	2.30	19.0	49.75	31	31
	Sodom Reservoir................................	1891	73.23	0.90	67	4,883	4.80	21.5	52.25	38	38
	Bog Brook Reservoir...........................	1891	3.67	0 64	50	4,145	1.70	21.4	52.15	56	56
	Titicus Reservoir	1893	22.80	1.30	75	7,167	2.70	14 3	45.05	47	47
	Croton Lake*	1842	158.70	1.75	90	2,000 (available)	4.80	0.0	30.75	74	....
	Total Croton Watershed above Old Croton Dam.		338.82				...	....	.....		52
Bronx.......... ...	Byram Lake...................................	1896	7.3	0.25	19	844	1.40	9.0	24.5	45	45
	Rye Pond......................................	1884	2.2	0.44	18	1,336	1.70	3.2	18.7	11	11
	Kensico Reservoir............................	1884	10.3	0.39	37	1,627	1.60	0 0	15.5	33	33
	Total Bronx and Byram Rivers............	....	19.88	1.08	...	3,807	....	....	.....		34
Brooklyn............	Massapequa Pond....................	1892	40.79	0.02	7	17	0.30	....	27.0	81	....
	Wantagh Pond.......	1892	17.6	0.05	9	44	0.40	....	20.0	126	....
	Newbridge Pond..............................	1892	3.3	0.01	4	12	0.10	....	18.3	148	....
	East Meadow Pond...........................	1892	31.0	0.13	8	19	0.20	....	17.0	99	....
	Millburn Pond.................................	1892	3.7	0.02	6	11	0.30	....	15.5	200	....
	Hempstead Storage Reservoir	1879	19.0	0.45	22	1,000	2.00	....	13.1	300	....
	Schodack Brook................................	....	1.0	....	...	......	....	....	13.1	250	....
	Hempstead Pond...............................	1862	0.5	0.04	8	27	0.30	....	12.6	200	....
	Pines Pond....	1859	5.5	0.01	7	9	0.20	....	12.5	240	....
	Smith Pond	1853	0.5	0.04	5	42	0.30	...	12.5	460	....
	Valley Stream Pond	1862	13.4	0.08	8	21	0.40	....	9.8	78	... .
	Watts Pond............................	1880	0.9	0.01	5	4	0.20	...	9.6	410	....
	Clear Stream Pond.....................	1852	1.6	0.002	5	1	0.07	....	8.4	60	....
	Simonson's Pond.............................	1862	9.2	0.02	7	10	0.30	....	8.0	130	....
	Springfield Pond..............................	1881	5 0	0.01	7	7	0.30	....	6.9	380	....
	Baiseley's Pond..	1858	9.2	0.06	9	42	0.40	....	5.4	1,250	....
	Total Ridgewood System	....	161.8	....	...	......	...	....	.....		208
Queens	Oakland Lake..................................	....	.....	....	...	.....	....	....	.....	....	....
Richmond..........	(No surface supplies.)............................	....	.....	....	...	......	....	....	.....	....	....

* Population per square mile on the Kisco river is 91; the population per square mile on the Cross river is 63.
† Increased during the summer to about 400 per square mile.

TABLE IB.

Data Concerning the Ground Water Supplies of New York City.

Borough.	Station.	Location.	Ownership	Driven Wells. Number.	Driven Wells. Diameter of Well Tubes in Inches.	Driven Wells. Depth in Feet.	Other Sources of Supply.	Estimated Average Daily Yield in Million Gallons.	Estimated Population per Square Mile on Adjacent Watershed.
Manhattan	(No ground-water supplies in the Borough of Manhattan.)								
Bronx..........	Pelham........	Near Third street..........	New York and Westchester Water Company	16	......	45	....	5.0	2,500
Brooklyn......	Massapequa...........	22.3 miles from Ridgewood	Municipal............	53	4.5	37 to 106	....	3.5	25
"	Wantagh...............	19.5 "	"	43 6	4.5 6	24 to 89 92	....	4.0	100
"	Matowa................	18.3 "	"	45	4.5	38 to 97	....	4.0	100
"	Merrick	17.5 "	"	62	4.5	40 to 110	....	3.5	150
"	Agawam	16.8 "	"	32	6	33 to 91	....	2.5	250
"	Watts Pond	9.1 "	"	12	6	50	Open well fed from Watts pond..........	......	175
"	Clear Stream............	8.5 "	"	150	2	38	....	3.0	150
"	Forest Stream.....	7.3 "	"	110	2	41	....	3.5	150
"	Springfield..............	6.5 "	"	20	8	170	....	2.5	......
"	Jameco (deep)........ .	4.9 "	"	16	8 and 10	160	....	4.00	......
"	Jameco (deep and shallow)................	4.9 "	"	183 7	2 4 and 6	27 to 73 153 to 160	....	2.50	860
"	Baiseleys...............	4.6 miles from Ridgewood	"	100	2	44	....	2.0	1,330
"	Oconee..........	3.8 "	"	12	8	195	....	2.0	......
"	Shetucket................	3.2 "	"	12	8	180	....	1.0	......
"	Spring Creek, old.........	1.0 "	"	100 8	2 6 and 8	36 150	....	4.0	2,600
"	Spring Creek, temporary.	1.0 "	"	13	6	42 to 75	....	3.00	2,600
"	New Lots..............	New Lots road and Fountain avenue, East New York.................	"	22 14	2 6	45 to 50 80 to 90	Open well, 29 inches diameter and 24 feet deep.....	4.5	10,000
"	German American.......	Penn. and Stanley avenues, East New York..	German-American Water Supply Company........	3	6	60 to 70	....	0.07	14,000
"	Flatbush	Avenue E, near New York avenue, Flatbush.....	Flatbush Water Company........	3 12 19	5 8 5	18 26 53	....	2.25	7,000

Table IB—*Continued.*

Borough.	Station.	Location.	Ownership.	Driven Wells.			Other Sources of Supply.	Estimated Average Daily Yield in Million Gallons.	Estimated Population per Square Mile on Adjacent Watershed.
				Number.	Diameter of Well Tubes in Inches	Depth in Feet.			
Brooklyn	Gravesend	East Seventeenth street, between Avenue R and Avenue S	Municipal	113	2	50	....	2.8	4,000
"	New Utrecht	East Fourteenth street, between Avenue U and Avenue V	"	120	2	30	....	1.5	3,000
"	Blythebourne	Eleventh avenue and Seventy-fourth Street	Blythebourne Water Co.	1 1	5 ft. 20 "	90 90	These are both open wells	0.20	3,000
"	Pfalzgraf West Brooklyn*	Sixtieth street, between Eleventh and Twelfth avenues Fort Hamilton avenue and Forty-second street	Pfalzgraf Water Supply Co West Brooklyn Water Supply Company	1	......	......	....	.006	4,000
Queens	Long Island City, Station No. 1	Van Dam street, Long Island City	Municipal	7	6	70	One open well, 47 inches diameter and 30 feet deep	0.68	1,800
"	Long Island City, Station No. 2†	Cabinet street, Long Island City	"	28	4	45	One open well, 16 inches diameter and 22 feet deep	0.80	2,400
"	Long Island City, Station No. 3	Grone street, Long Island City	"	12	4	41	....	0.62	2,800
"	Bayside	Broadway, Bayside	"	21	3 to 6	40	Also surface water from Oakland Lake	0.98	320
"	Flushing	Fresh Meadow road, Flushing	"	..	......	.....	Open infiltration basin	0.62	180
"	Whitestone No. 1	Lawrence avenue, Whitestone	"	17	4 and 6	55 to 75	....	0.18	1,330
"	" No. 2	Thirty-first street, Whitestone	"	5	3 and 4	80	....	Reserve Station	1,260
"	Citizens' Water Company, Station No. 1	No. 82 Cleremont avenue, Elmhurst	Citizens' Water Company	28	6	45 to 62	....	0.61	710
"	Citizens' Water Company, Station No. 2	Jackson avenue and Twelfth street, Woodside	Citizens' Water Company	78	4.5	45 to 80	....	1.51	1,130
"	Citizens' Water Company, Station No. 3	Union avenue, Flushing Creek	Citizens' Water Company	31	6	45 to 90	....	2.07	125

Queens........	Citizens' Water Company, Station No. 4.	....	Citizens' Water Company............	..	......	......	....	......	170
"	Citizens' Water Company, Station No. 5.	....	Citizens' Water Company...........	..	......	......	....	......	125
"	Jamaica Water Supply Company.....	Vine and Cumberland streets	Jamaica Water Supply Company....	7 12	10 5	50 to 60 50 to 60	....	1.50	1,800
"	Woodhaven	Thrall street, Woodhaven, Dunton Station.......	Woodhaven Water Supply Company	10 6	4 6	80 to 150 80 to 150	....	0.55	3,600
"	Montauk‡.	Van Wyck avenue, Jamaica	Montauk Water Company.............	17	10	30 to 50	....	1.80	2,200
"	Far Rockaway...........	2½ miles from Valley Stream...............	Queens County Water Supply Company........	16 45	3 and 4 3	145 to 180 30 to 50	Filtered through sand filter to remove iron...	1.00	......
Richmond.....	Staten Island Water Supply Company No. 1...............	Columbia street, West New Brighton.... ...	Staten Island Water Supply Company	156	6	100 to 120	Wells siphon into receiving well, 15 feet diameter, 25 feet deep.........	3.66	......
"	Staten Island Water Supply Company No. 2...............	Ridgewood place, Brighton Heights..........	Staten Island Water Supply Company	8	6	60	....	0.74	......
"	Staten Island Water Supply Company No. 3.....	Union avenue, New Springville.	Staten Island Water Supply Company	42	6	38 to 50	....	.08	......
"	Crystal Water Supply Company...........	Near head of Clove Lake.	Crystal Water Company.	52	6	60 to 120	....	1.20	......
"	Crystal Water Supply Company.	Linoleumville	Crystal Water Company	46	6	50 to 75	....	Reserve Station	.....
"	South Shore Water Works Company....	Beach avenue, New Dorp	South Shore Water Works Company	2	8	45	....	0.10	.....
"	Tottenville	Central avenue, Tottenville.	Municipal	1 1 1	6 8 10	60 85 85	Receiving well, 10 feet diameter and 20 feet deep.....	0.80	......

* Burned in 1899 and not rebuilt. † Station destroyed by boiler explosion in Nov., 1902. ‡ Not used for domestic purposes.

2. TYPHOID FEVER IN NEW YORK CITY.

There is no better index of the general sanitary condition of a public water supply than the typhoid fever death rate of the community supplied by it. This is especially true of large cities, where the rate is less likely to be influenced by local epidemics due to causes other than water. A study of the typhoid fever statistics of The City of New York furnishes an interesting and instructive commentary on the character of the water supply at different periods. These statistics, kindly furnished by the Department of Health, and for which I am indebted to Dr. Ernest J. Lederle, Health Commissioner; Dr. William H. Guilfoy, Registrar of Records, and Dr. J. S. Bryne, Assitant Registrar, are given in Tables 2 and 3, and are shown graphically on Diagrams 1 to 3.

Comparison with Other Cities.

In the first place it should be stated that The City of New York now has, and has had for a long time, a typhoid fever death rate which compares most favorably with the large cities of the United States.

In Table No. 4 will be found the typhoid fever death rate for all cities of the United States which had populations of more than 30,000 according to the United States census of 1900. The average annual death rate from typhoid fever for the 19,000,000 people there tabulated has varied during the past four years from 33 to 38, and has averaged 35 per 100,000. The average annual death rate for the years 1898 to 1901, inclusive, was 19.8 per 100,000 population for The City of New York, including all boroughs, while the extremes varied only between 16.3 and 21.0. In round numbers the typhoid fever death rate for New York City may be considered as 20 per 100,000 inhabitants ,or 0.20 per 1,000. Present indications are, however, that the rate for 1903 will be lower than this.

From Table 4 it will be seen that of the six cities which had populations of more than 500,000 in 1900, no city had as low a rate as New York. The nearest approach to it was St. Louis, which had an average rate of 25.4. Of the thirty-two cities which had populations between 500,000 and 100,000, only six had rates lower than New York. Of the forty cities which had populations between 100,000 and 50,000, only six had rates less than New York. Of the fifty-eight cities which had populations between 50,000 and 30,000, only eight had rates less than New York. Of all the one hundred and thirty-six cities which had more than 30,000 population, only twenty had rates lower than New York.

TABLE 2A.

TABLE SHOWING THE ANNUAL TYPHOID-FEVER DEATH RATES IN NEW YORK CITY, 1868–1902.

Boroughs of Manhattan and Bronx since 1898.

Year.	Population.	Number of Deaths from All Causes.	Number of Deaths from Typhoid Fever.	Typhoid-Fever Death Rate. Per 100,000 Inhabitants.	Typhoid-Fever Death Rate. Per Cent. of Total Deaths.
1868	851,137	24,889	329	38.9	1.32
1869	896,034	25,167	378	42.2	1.50
1870	943,300	27,175	422	44.7	1.56
1871	955,921	26,976	251	26.3	0.93
1872	968,710	32,647	386	39.8	1.18
1873	981,671	29,084	313	31.9	1.07
1874	1,030,607	28,727	305	29.6	1.03
1875	1,044,396	30,709	376	36.0	1.23
1876	1,075,532	29,152	325	30.2	1.11
1877	1,107,597	26,203	343	31.0	1.30
1878	1,140,617	27,008	321	28.1	1.19
1879	1,174,621	28,342	268	22.8	0.95
1880	1,209,196	31,937	372	30.8	1.19
1881	1,244,511	31,622	594	47.7	1.88
1882	1,280,857	37,924	516	40.3	1.40
1883	1,318,264	34,011	625	47.4	1.83
1884	1,356,764	35,024	476	35.1	1.35
1885	1.396,388	35,682	405	29.0	1.14
1886	1,437,170	37.351	433	30.1	1.16
1887	1,479,143	38,933	421	28.5	1.08
1888	1,522,341	40,175	364	23.9	0.91
1889	1,566,801	39,679	397	25.3	1 00
1890	1,612,559	40,103	352	21.8	0.88
1891	1,659,654	43,659	384	23.1	0.88
1892	1,708,124	44,329	400	23.4	0.90
1893	1,758,010	44,486	381	21.7	0.86
1894	1,809,353	41,175	326	18.0	0.79
1895	1,873,201	43,420	322	17.2	0.74
1896	1.906,139	41,622	297	15.6	0.71
1897	1,940,553	38,877	299	15.4	0.77
1898	1,976,572	40,438	376	19.0	0 93
1899	2,014,330	39,911	294	14.6	0.74
1900	2,053,979	43,227	372	18.1	0.86
1901	2,095,686	43,304	412	19.7	0.95
1902	2,139,632	41,704	399	18.6	0.96

Borough of Manhattan Alone.

Year.	Population.	Number of Deaths from All Causes.	Number of Deaths from Typhoid Fever.	Per 100,000 Inhabitants.	Per Cent. of Total Deaths.
1898	1,809,286	36,687	353	19.5	0.96
1899	1,830,462	36,191	278	15.2	0.77
1900	1,851,857	38,878	342	18.5	0.87
1901	1,873.562	38,507	380	20.3	0.99
1902	1,895,491	36,769	365	19.3	0.99
1903	1,917,676	......	...	15.0*	

* Approximately.

TABLE 2B.

Borough of Bronx.

Year.	Population.	Number of Deaths from all Causes.	Number of Deaths from Typhoid Fever.	Typhoid Fever Death Rate. Per 100,000 Inhabitants.	Typhoid Fever Death Rate. Per cent. of Total Deaths.
1898	167,286	3,751	23	13.8	0.61
1899	183,868	3,720	16	8.7	0.43
1900	202,092	4,349	30	14.8	0.69
1901	222,124	4,797	32	14.4	0.67
1902	244,141	4,935	34	13.9	0.69
1903	268,341			11.9*	

TABLE 2C.

Borough of Brooklyn.

Year.	Population.	Number of Deaths from all Causes.	Number of Deaths from Typhoid Fever.	Typhoid Fever Death Rate. Per 100,000 Inhabitants.	Typhoid Fever Death Rate. Per cent. of Total Deaths.
1868	354,421	8,750	103	28.5	1.18
1869	375,588	8,759	96	25.6	1.10
1870	397,404	9,546	111	28.0	1.16
1871	413,399	10,259	92	22.3	0.90
1872	430,038	10,648	149	34.7	1.40
1873	447,347	10,968	103	22.6	0.94
1874	465,352	11,011	81	17.4	0.74
1875	483,788	12,470	102	21.1	0.81
1876	499,600	12,334	97	19.4	0.79
1877	515,927	11,363	82	15.9	0.72
1878	532,789	11,975	59	11.1	0.53
1879	550,202	11,569	59	10.7	0.51
1880	568,622	13,222	71	12.4	0.54
1881	587,897	14,533	99	16.8	0.68
1882	607,898	15,024	93	15.2	0.62
1883	628,443	13,338	92	14.6	0.66
1884	649,715	14,116	107	16.4	0.76
1885	671,614	13,369	150	22.3	0.99
1886a	733,817	15,790	123	16.7	0.78
1887	758,650	17,078	143	18.8	0.84
1888	784,316	16,061	153	19.5	0.95
1889	810,850	18,480	161	19.8	0.87
1890	840,857	19,827	182	21.6	0.92
1891	869,083	21,349	180	20.7	0.85
1892	898,256	20,807	162	18.0	0.78
1893	928,408	21,017	179	19.2	0.85
1894b	959,572	21,183	159	16.5	0.75
1895	991,782	22,568	173	17.4	0.76
1896c	1,025,074	22,501	163	15.9	0.72
1897	1,060,483	20,674	173	16.2	0.83
1898d	1,095,047	21,989	270	24.6	1.21
1899d	1,131,805	21,649	206	18.1	0.95
1900d	1,169,796	23,507	301	25.7	1.28
1901d	1,209,064	23,271	272	22.5	1.18
1902d	1,249,650	22,344	322	25.7	1.45
1903d	1,291,597	......	....	20.8*	....

* Approximately.
a. New Lots annexed.
b. Flatbush, Gravesend and New Utrecht annexed.
c. Flatlands annexed
d. Borough of Brooklyn, City of New York.

TABLE 2D.

Borough of Queens.

1898	137,032	2,561	16	11.7	0.63
1899	145,143	2,510	27	18.6	1.08
1900	153,734	2,760	32	20.8	1.16
1901	162,834	2,800	27	16.6	0.96
1902	172,472	2,782	32	18.6	1.15
1903	182,681			17.6*	

TABLE 2E.

Borough of Richmond.

1898	63,767	1,306	14	22.0	1.07
1899	65,444	1,273	20	30.6	1.57
1900	67,166	1,378	13	19.4	0.94
1901	68,933	1,345	16	23.2	1.19
1902	70,747	1,282	11	15.5	0.86
1903	72,608			19.3*	

TABLE 2F.

TABLE SHOWING THE ANNUAL TYPHOID FEVER DEATH RATE IN GREATER NEW YORK FROM 1898 TO 1902.

Year.	Population.	Number of Deaths from all Causes.	Number of Deaths from Typhoid Fever.	Typhoid Fever Death Rate.	
				Per 100,000 Inhabitants.	Per cent. of Total Deaths.
1898	3,272,418	66,294	676	20.7	1.02
1899	3,356,722	65,343	546	16.3	0.83
1900	3,444,675	70,874	718	20.8	1.01
1901	3,536,517	70,720	728	20.6	1.03
1902	3,632,491	67,912	764	21.0	1.12

* Approximately.

TABLE 3.

Table Showing the Monthly Typhoid Fever Death Rate (per 100,000 Inhabitants) in New York City.

Place.	Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Old New York City.........	1891	0.85	0.66	1.02	0.78	1.21	1.38	1.68	3.43	3.92	3.37	3.07	1.75	23.12
	1892	0.88	1.46	0.99	1.11	1.35	1.35	3.04	3.10	3.34	3.22	1.81	1.76	23.41
	1893	1.25	1.02	1.65	1.42	1.65	1.31	1.19	1.99	2.39	3.98	2.33	1.48	21.66
	1894	1.22	0.61	0.94	0.99	0.61	0.77	1.55	2.32	3.15	2.54	1.77	1.55	18.02
	1895	0.91	0.85	0.43	0.75	0.69	1.23	1.44	1.98	2.46	2.56	1.98	1.92	17.20
	1896	1.05	0.89	0.58	0.63	0.52	0.68	1.31	2.20	2.00	2.05	1.79	1.89	15.59
	1897	0.98	0.77	0.46	0.52	0.72	0.98	1.49	2.06	1.65	2.06	1.44	2.27	15.40
Borough of Manhattan...	1898	0.44	0.55	0.77	0.44	0.44	0.94	1.05	2.93	5.20	3.10	2.10	1.55	19.51
	1899	0.60	0.44	0.65	0.82	0.98	0.54	1.15	1.47	2.13	2.68	2.35	1.36	15.17
	1900	1.40	0.75	0.48	0.48	0.86	1.08	1.51	1.67	2.85	2.54	2.22	2.64	18.49
	1901	2.14	0.96	1.07	1.01	0.85	0.69	1.60	1.92	3.04	3.10	1.92	1.97	20.27
	1902	1.21	0.52	0.90	0.96	0.95	0.95	1.37	2.27	2.22	3.48	2.74	1.79	19.36
	1903	....	....	....	....	....	....	....	....	....	....	....	....	.....
Borough of The Bronx.......	1898	0.00	1.19	0.00	0.00	1.79	1.19	0.59	1.79	1.19	1.79	2.39	1.79	13.71
	1899	2.18	0.54	1.09	0.00	0.00	0.54	0.00	1.63	0.54	1.63	0.00	0.54	8.69
	1900	0.49	2.47	0.49	0.49	0.99	0.49	0.99	2.97	1.48	2.47	0.49	0.99	14.81
	1901	0.45	0.45	0.45	1.35	0.90	0.45	0.45	1.80	3.15	2.70	1.35	0.90	14.40
	1902	0.41	0.00	0.00	1.64	0.41	1.28	2.45	1.64	0.00	1.64	1.23	3.27	13.92
	1903	....	....	....	....	....	....	....	....	....	....	....	....	.....
Borough of Brooklyn....	1892	0.89	0.67	0.78	0.78	0.33	0.56	1.67	3.34	4.23	1.67	1.88	1.11	17.91
	1893	0.97	1.19	1.51	0.97	0.75	0.75	1.08	2.81	2.27	2.37	2.69	1.51	19.20
	1894	1.15	0.83	0.42	0.52	1.04	0.63	1.04	2.19	2.19	3.02	2.29	1.15	16.47
	1895	1.01	0.71	0.20	0.91	1.11	0.81	1.92	2.42	2.63	2.10	1.71	2.10	17.42
	1896	1.95	1.07	0.58	0.29	0.58	0.19	1.27	2.72	2.44	2.73	1.56	0.49	15.87
	1897	1.13	0.37	0.66	0.57	0.75	0.28	1.13	1.88	2.65	2.93	1.70	2.27	16.22
	1898	1.19	0.82	1.19	1.00	0.64	0.73	1.28	3.29	5.30	4.11	3.29	1.83	24.67
	1899	0.71	0.62	0.53	0.97	0.71	1.15	1.94	2.39	2.66	2.03	2.12	2.30	18.13
	1900	2.05	1.03	1.45	1.19	1.28	1.03	1.37	2.23	3.25	3.33	4.02	3.51	25.74
	1901	1.41	1.49	1.41	1.74	0.66	0.91	1.57	2.48	2.57	3.15	2.57	2.57	22.53
	1902	2.00	0.96	0.64	1.12	1.36	1.84	2.00	2.96	3.60	3.60	3.36	2.32	25.76
	1903	0.93	1.55	1.55	1.16	1.47	....	....	....	....	....	....	....	.....
Borough of Queens......	1898	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.00	3.65	2.92	2.19	2.19	11.68
	1899	0.69	0.00	0.00	0.69	0.00	0.00	0.00	2.76	4.82	4.82	1.76	2.07	18.61
	1900	1.30	0.00	1.30	0.00	1.30	1.95	3.26	1.95	3.26	3.26	1.30	1.95	20.93
	1901	0.61	0.61	0.61	2.46	0.00	1.84	1.84	2.46	1.23	3.07	1.84	0.00	16.57
	1902	0.58	0.00	0.58	0.00	0.58	0.58	1.74	2.90	5.22	1.16	2.90	2.32	18.56
	1903	....	....	....	....	....	....	....	....	....	....	....	....	.....
Borough of Richmond...	1898	0.00	0.00	0.00	0.00	0.00	1.57	3.14	1.57	12.55	1.57	1.57	0.00	21.97
	1899	0.00	0.00	1.53	1.53	1.53	0.00	1.53	1.53	4.58	7.64	6.11	4.58	30.56
	1900	0.00	0.00	1.49	0.00	0.00	0.00	1.49	1.49	7.45	1.49	2.98	4.47	19.46
	1901	0.00	1.45	4.35	1.45	0.00	1.45	0.00	2.90	2.90	2.90	4.35	1.45	23.20
	1902	1.41	0.00	0.00	0.00	0.00	2.83	1.41	1.41	0.00	5.66	0.00	2.83	15.55
	1903	....	....	....	....	....	....	....	....	....	....	....	....	.....
Average.														
Old New York City	....	1.02	0.89	0.72	0.88	0.96	1.10	1.67	2.44	2.70	2.82	2.02	1.80	19.20
Manhattan.......	....	1.15	0.66	0.77	0.74	0.81	0.86	1.83	2.05	3.09	2.58	2.26	1.86	18.56
Bronx............	....	0.70	0.93	0.40	0.69	0.81	0.78	0.89	1.96	1.27	2.04	1.09	1.49	13.10
Brooklyn........	....	1.25	0.94	0.91	0.93	0.89	0.71	1.48	2.59	3.08	2.82	2.46	1.92	20.01
Queens..........	....	0.63	0.12	0.49	0.63	0.37	0.87	1.51	2.01	3.63	3.04	2.19	1.70	17.27
Richmond.......	....	0.28	0.28	1.47	0.59	0.30	1.17	1.50	1.74	5.49	3.85	3.00	2.66	22.43

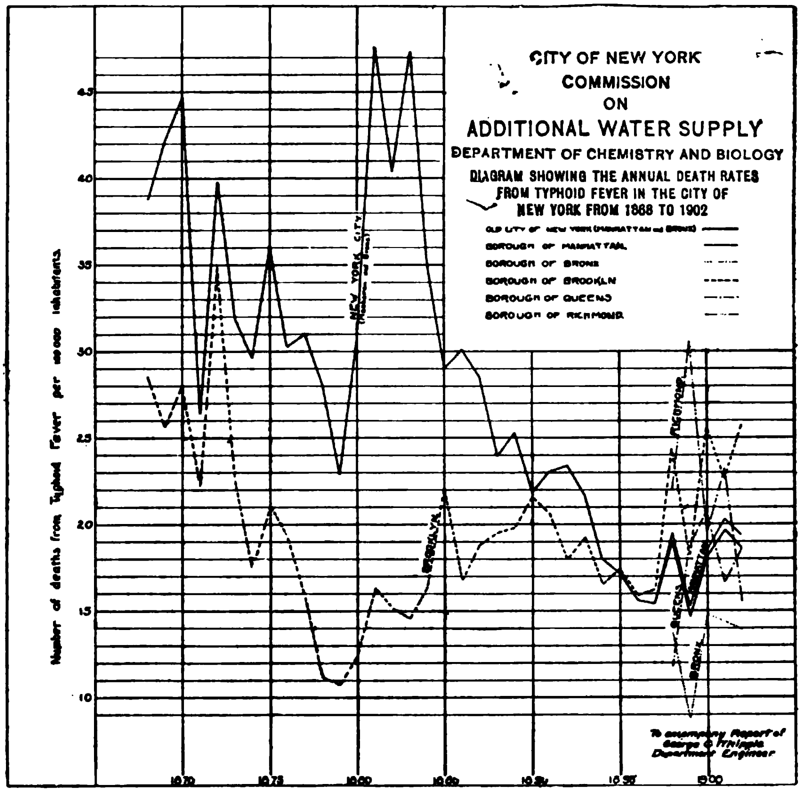


DIAGRAM I. APP. VI.

Manhattan—Although the typhoid fever death rate in New York is low in all the boroughs, it has not been always low and is now even slightly increasing. The available records for the old City of New York go back to 1868. In that year the death rate was 38.7 per 100,000 inhabitants, or 1.32% of the total mortality. In 1869 and 1870 there were severe droughts, and a water famine was prevented only by purchasing the right to use the water from Lake Gilead, Lake Glenida, Lake Mahopac, Kirk Lake, Barrett's Pond and China Lake (see "The Water Supply of the City of New York," by Edward Wegmann, C. E., New York, 1896, John Wiley & Sons). During this dry period the typhoid fever death rate increased to 44.7. There were high rates, however, in 1872 and 1875. 1872 was a very dry year, and the natural yield of the watershed was low. It is interesting to note, moreover, that the Boyd's Corner Reservoir was under construction in 1872 and the Middle Branch Reservoir in 1875. In those early days less attention was paid to the sanitation of camps than at present, and the possibility that workmen employed on these constructions may have contributed in some degree to raising the typhoid death rate is one which is within the limits of experience in other places, although it must be regarded as somewhat speculative.

In 1879 the typhoid death rate had fallen to 22.8 per 100,000 inhabitants, or 0.95% of the total mortality, because of the increased storage capacity on the watershed and to more favorable meteorological conditions. A very severe drought occurred in 1880, and the summer rainfall of 1881 was very low. These were, perhaps, the most severe droughts since 1842. The storage was drawn down almost to the vanishing point, and it was found necessary to throttle the outlet gates at Central Park Reservoir and to use extraordinary measures to curtail waste of water. The watershed had hardly regained its storage when another dry year occurred, in 1883, again depleting the supply. During this period, from 1880 to 1884, there was a marked increase in the typhoid fever death rate. It rose first to 30.8 and then to 47.7 per 100,000 inhabitants, the highest point reached within the period covered by the records. It fell somewhat in 1882, but increased again in 1883, the curve thus inversely following the rainfall.

Between 1883 and 1897 the typhoid rate steadily decreased. This may be attributed to the constantly increasing storage capacity to the generally more favorable meteorological condition and especially to the expedients adopted to protect the water supply from pollution. In 1888 the State Board of Health established rules and regulations relating to the pollution of the watershed, and in 1893 extensive purchases of land and buildings were begun along the stream courses and around the reservoirs. In 1893 a sewage purification plant was established on the watershed at Brewster.

TABLE 4.

Table Showing the Typhoid-Fever Death Rate in Cities of the United States Having More than 30,000 Inhabitants According to the Twelfth United States Census, 1900.

Number.	Name of City.	State.	Population According to Twelfth Census, 1900.	Typhoid-Fever Death Rate Per 100,000.				Average Death Rate For Four Years.
				1898.	1899.	1900.	1901.	
1	Pittsburg	Pennsylvania	321,616	68.0	106.9	144.2	124.7	110.9
2	Charleston	South Carolina	55,807	131.0	169.2	127.0	73.8	110.2
3	Youngstown	Ohio	44,885	....	120.2	87.0	118.0	108.4
4	Troy	New York	60,651	72.8	76.0	155.0	57.3	90.2
5	Allegheny	Pennsylvania	129,896	56.2	104.8	93.3	100.8	88.8
6	Johnstown	Pennsylvania	35,036	27.0	78.0	139.4	100.0	86.3
7	Wheeling	West Virginia	38,878	84.8	69.6	90.2	95.0	84.9
8	Knoxville	Tennessee	32,637	168.4	39.9	43.0	52.2	75.9
9	York	Pennsylvania	33,708	143.0	71.0	36.0	38.0	72.0
10	Atlanta	Georgia	89,872	62.4	85.7	61.3	61.7	67.7
11	Washington	Dist. of Columbia	278,718	60.6	60.7	77.8	67.3	66.6
12	Chattanooga	Tennessee	32,490	70.7	64.8	58.6	68.8	65.7
13	Albany	New York	94,151	100.0	87.1	51.0	24.0	65.5
14	Duluth	Minnesota	52,969	49.1	37.8	94.5	73.2	63.6
15	Mobile	Alabama	38,469	59.9	54.7	67.6	72.2	63.6
16	Norfolk	Virginia	46,624	64.4	77.2	45.0	58.2	61.2
17	Terre Haute	Indiana	36,673	40.9	57.4	71.0	67.5	50.2
18	Little Rock	Arkansas	38,307	65.3	54.7	47.0	67.5	58.6
19	San Antonio	Texas	53,321	....	43.2	89.9	41.5	58.2
20	Galveston	Texas	37,789	39.8	85.0	71.7	35.7	58.0
21	Chester	Pennsylvania	33,988	49.0	108.0	35.0	40.0	58.0
22	Louisville	Kentucky	204,731	57.7	59.8	57.8	56.3	57.9
23	McKeesport	Pennsylvania	34,227	43.8	40.9	67.3	77.3	57.3
24	Superior	Wisconsin	31,091	25.8	32.2	125.9	43.7	56.9
25	Kansas City	Kansas	51,418	31.1	....	60.4	78.9	56.8
26	Birmingham	Alabama	38,415	23.4	30.0	70.3	92.7	56.3
27	Spokane	Washington	36,848	51.6	46.2	65.3	47.5	52.6
28	Binghamton	New York	39,647	70.7	27.8	53.0	56.1	51.9
29	New Orleans	Louisiana	287,104	64.1	54.0	39.7	47.0	51.2
30	Evansville	Indiana	59,007	47.5	66.1	62.8	26.6	50.7
31	Richmond	Virginia	85,050	34.1	43.5	88.3	34.8	50.2
32	Lancaster	Pennsylvania	41,459	62.8	67.6	41.0	24.1	48.9
33	Philadelphia	Pennsylvania	1,293,697	49.4	73.4	34.7	33.3	47.7
34	Reading	Pennsylvania	78,961	64.7	33.0	49 5	42.7	47.5
35	Allentown	Pennsylvania	35,416	53.3	62.2	25.4	47.2	47.0
36	Montgomery	Alabama	30,346	48.0	57.0	56.0	25.0	47.0
37	Wilmington	Delaware	76,508	35.3	60.0	47.0	42.0	46.0
38	Nashville	Tennessee	80.865	27.2	61.9	48 3	45.5	45.8
39	New Haven	Connecticut	108,027	36.1	25.9	25.9	92.0	44.9
40	Dallas	Texas	42,638	47.0	51.6	41.2	34.0	43.7
41	Minneapolis	Minnesota	202,718	42.4	34.8	38.6	57.6	43.3
42	Topeka	Kansas	33,608	29.8	74.5	23.8	43.5	42.9
43	Hartford	Connecticut	79,850	45.	47.6	43.9	30.6	41.8
44	Quincy	Illinois	36,252	35.9	24.8	44.2	60.5	41.3
45	Cincinnati	Ohio	325,902	36.4	37.2	36.6	53.5	40.9
46	Portland	Maine	50,145	71.8	29.9	31.9	25.0	39.6
47	Denver	Colorado	133,859	30.6	38.1	41.8	47.9	39.6
48	Harrisburg	Pennsylvania	50,167	31.9	39.9	47 9	38.2	39.5
49	Covington	Kentucky	42.938	28.0	39.6	49.0	39.1	38.9
50	Elmira	New York	35,672	47 7	30.9	47.7	27.4	38.4

TABLE 4—*Continued.*

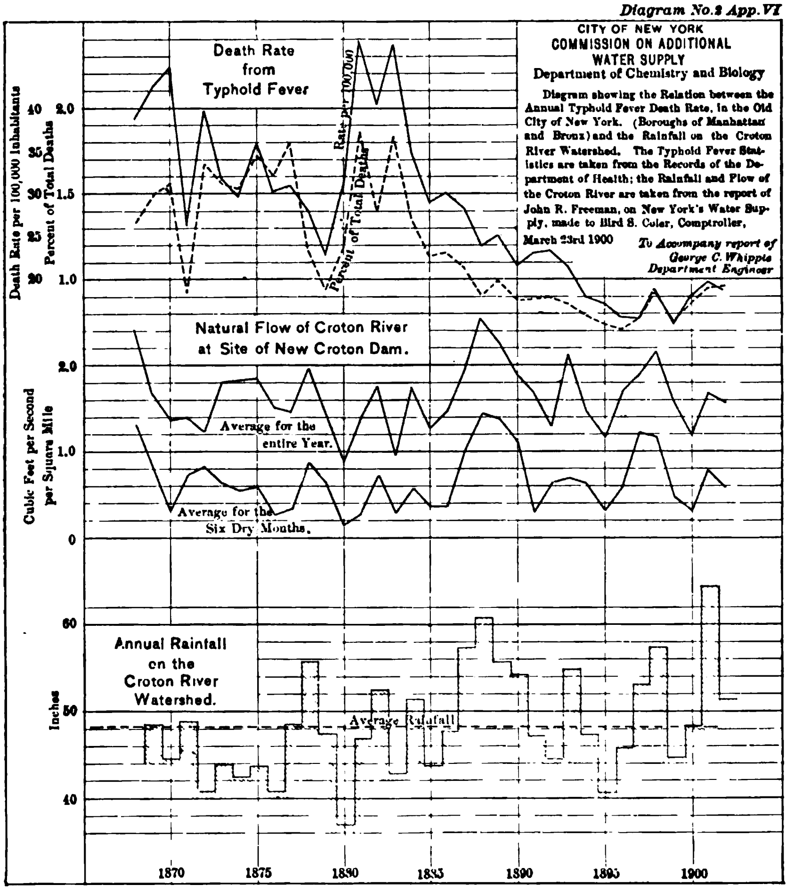
Number.	Name of City.	State.	Population According to Twelfth Census, 1900.	Typhoid-Fever Death Rate Per 100,000. 1898.	1899.	1900.	1901.	Average Death Rate For Four Years.
51	South Bend	Indiana	35,999	25.1	....	44.6	44.5	38.0
52	Los Angeles	California	102,479	40.9	39.1	42.0	29.1	37.8
53	Springfield	Ohio	38,253	23.6	62.8	44.5	20.0	37.7
54	Springfield	Illinois	34,159	41.0	58.6	29.3	22.2	37.7
55	Cleveland	Ohio	381,768	31.8	28.6	53.8	35.9	37.5
56	Waterbury	Connecticut	45,859	28.4	32.7	54.5	31.2	36.7
57	Houston	Texas	44,633	35.9	29.2	29.2	52.0	36.6
58	Grand Rapids	Michigan	87,565	32.0	29.7	42.3	34.7	34.8
59	Augusta	Georgia	39,441	20.2	45.7	35.5	36.6	34.5
60	Indianapolis	Indiana	169,164	28.4	37.8	43.7	27.4	34.3
61	Memphis	Tennessee	102,320	22.4	38.1	35.1	40.9	34.1
62	Butte	Montana	30,470	59.1	36.2	13.1	28.1	34.1
63	Kansas City	Missouri	163,752	25.1	30.6	36.0	42.9	33.6
64	Fort Wayne	Indiana	45,115	....	33.3	35.4	31.4	33.4
65	Baltimore	Maryland	508,957	37.2	30.1	37.1	27.3	32.9
66	Canton	Ohio	30,667	55.5	39.2	22.8	12.1	32.4
67	Paterson	New Jersey	105,171	33.3	46.5	22.8	27.0	32.4
68	San Francisco	California	342,782	16.7	51.2	41.3	20.0	32.3
69	Columbus	Ohio	125,560	26.3	22.3	42.4	35.5	31.6
70	Altoona	Pennsylvania	38,975	33.4	33.4	30.8	27.5	31.3
71	Trenton	New Jersey	73,307	30.0	45.0	31.4	18.7	31.2
72	Salt Lake City	Utah	53,531	43.0	20.6	26.2	34.5	31.1
73	Davenport	Iowa	35,254	8.5	42.6	42.3	30.2	30.9
74	Toledo	Ohio	131,822	23.6	30.4	38.7	30.0	30.7
75	Wilkesbarre	Pennsylvania	51,721	36.8	29.0	19.3	34.6	29.9
76	New Bedford	Massachusetts	62,442	27.3	25.6	35.2	28.8	29.2
77	Joliet	Illinois	29,353	42.3	22.8	....	21.9	29.0
78	Seattle	Washington	80,671	29.8	31.0	29.8	24.4	28.7
79	Dayton	Ohio	85,333	21.1	36.4	30.5	25.6	28.4
80	Camden	New Jersey	75,935	43.5	38.2	15.8	16.2	28.4
81	Boston	Massachusetts	560,892	33.0	29.4	25.6	24.8	28.2
82	Chicago	Illinois	1,698,575	57.6	26.0	19.9	28.3	27.9
83	Savannah	Georgia	54,244	36.9	35.1	29.6	9.7	27.8
84	Buffalo	New York	352,219	27.8	25.0	27.0	26.8	26.6
85	Portland	Oregon	90,426	22.1	23.2	26.6	24.5	26.6
86	Auburn	New York	30,345	13.2	23.1	46.2	22.9	26.3
87	Syracuse	New York	108,374	43.3	18.4	28.6	15.0	26.3
88	Saginaw	Michigan	42,345	14.2	26.0	35.5	28.9	26.1
89	Schenectady	New York	31,682	4.0	....	38.0	35.0	26.0
90	Tacoma	Washington	37,714	39.8	13.2	21.2	27.5	25.4
91	St. Louis	Missouri	575,238	16.5	22.8	29.2	33.3	25.4
92	Springfield	Massachusetts	62,059	24.2	24.2	27.4	24.6	25.1
93	Scranton	Pennsylvania	102,026	13.7	24.5	29.4	30.1	24.4
94	Providence	Rhode Island	175,597	22.2	24.5	23.4	26.4	24.1
95	Erie	Pennsylvania	52,733	13.3	34.2	34.2	14.5	24.0
96	Akron	Ohio	42,728	16.4	30.4	21.0	26.7	23.6
97	Peoria	Illinois	56,100	19.6	17.8	32.1	25.0	23.4
98	Taunton	Massachusetts	31,036	25.8	22.6	25.8	19.3	23.4
99	Omaha	Nebraska	102,555	31.2	25.4	23.4	21.8	22.9
100	Lawrence	Massachusetts	62,559	17.6	31.9	22.4	18.5	22.6
101	Chelsea	Massachusetts	34,072	20.6	29.4	20.6	19.8	22.6
102	Sioux City	Iowa	33,111	21.1	9.7	39.3	19.7	22.4
103	Jersey City	New Jersey	206,433	34.4	14.5	21.4	16.4	21.7
104	Newark	New Jersey	246,070	16.7	26.8	20.3	22.4	21.5
105	Fitchburg	Massachusetts	31,531	19.0	12.7	31.7	21.9	21.3
106	Dubuque	Iowa	36,297	22.1	16.6	27.6	18.7	21.2
107	Brockton	Massachusetts	40,063	7.5	17.5	45.0	14.1	21.0
108	Hoboken	New Jersey	59,364	13.5	30.4	16.8	23.0	20.9
109	Lincoln	Nebraska	40,169	17.5	22.4	14.9	28.2	20.8
110	Oakland	California	66,960	13.5	35.9	19.5	13.3	20.5

TABLE 4—*Continued.*

Number.	Name of City.	State.	Population According to Twelfth Census, 1902.	Typhoid-Fever Death Rate Per 100,000. 1898.	1899.	1900.	1901.	Average Death Rate For Four Years.
111	Pawtucket	Rhode Island	39,231	20.4	25.5	20.4	14.8	20.3
112	St. Paul	Minnesota	163,632	26.3	18.3	22.1	14.1	20.2
113	Lowell	Massachusetts	94,969	25.6	17.9	17.9	18.9	20.1
114	Des Moines	Iowa	62,139	37.0	14.5	9.6	18.6	19.9
115	Utica	New York	56,383	21.3	17.7	24.8	15.5	19.8
116	**NEW YORK**		**3,444,675**	**20.7**	**16.3**	**20.8**	**20.6**	**19.6**
	Borough of Manhattan		**1,851,857**	**19.5**	**15.2**	**18.5**	**20.3**	**18.4**
	Borough of The Bronx		**202,092**	**13.5**	**8.7**	**14.8**	**14.4**	**12.8**
	Borough of Brooklyn		**1,169,796**	**24.6**	**18.1**	**25.7**	**22.5**	**22.7**
	Borough of Queens		**153 734**	**11.7**	**18.6**	**20.8**	**16.6**	**16.9**
	Borough of Richmond		**67,166**	**22.0**	**30.6**	**19.9**	**23.2**	**23.9**
117	Haverhill	Massachusetts	37,175	21.6	13.5	16.2	26.9	19.5
118	Salem	Massachusetts	35.956	27.8	19.5	19.5	11.0	19.4
119	Holyoke	Massachusetts	45,712	17.5	24.1	19.7	14.7	19.0
120	Newton	Massachusetts	33,587	20.9	11.9	26.8	16.5	19.0
121	Somerville	Massachusetts	61,643	17.9	24.4	14.6	18.9	18.9
122	Worcester	Massachusetts	118,421	11.0	16.0	27.0	21.5	18.9
123	Manchester	New Hampshire	56,987	24.6	21.1	10.5	19 1	18.8
124	Milwaukee	Wisconsin	285,315	16.1	16.5	20.7	21.2	18.6
125	Lynn	Massachusetts	68,513	21.9	19.0	19.0	14.3	18.5
126	Malden	Massachusetts	33,664	14.9	11.9	20.8	26 0	18.4
127	St. Joseph	Missouri	102,979	11.6	34.0	6.7	19.3	17.9
128	Detroit	Michigan	285,704	16.9	19.3	18.2	15.7	17.5
129	Rochester	New York	162,435	13.5	18.5	18.5	18.2	16.6
130	Bayonne	New Jersey	32,722	43.0	4.0	15 0	6.0	17.0
131	Elizabeth	New Jersey	52.130	13.4	17.2	7.7	27.3	16.4
132	Fall River	Massachusetts	104.863	20.0	10.5	14.3	19.6	16.1
133	Cambridge	Massachusetts	91,885	15.2	21.8	16.3	10.6	15.9
134	Bridgeport	Connecticut	70,996	9.9	11.3	21.1	16.9	14.8
135	Yonkers	New York	47,931	12.5	10.4	10.4	11.8	11.2
136	Rockford	Illinois	31,051	3.2	9.7	3.2	6.2	5.6

NOTE.—The death rates for the years 1898, 1899 and 1900 are calculated using the population given in the 1900 census; for the year 1901 the estimated population given in the bulletins of the United States Labor Department. All deaths from Typhoid Fever are taken from the Labor Department bulletins.

Diagram No. 2 App. VI



The effect of the improved conditions was well illustrated in the year 1897, when, in spite of small rainfall and a very low stream flow, the typhoid fever rate did not materially increase.

The increase in 1898 was due to the soldiers returning from Cuba after the Spanish War. The rate for 1899 was only 14.6 per 100,000 inhabitants, the lowest during the period covered by the records. Since 1899, the rate has risen slightly, but has not gone above 20 per 100,000 inhabitants.

The influence of the rainfall upon the typhoid fever death rate in New York is quite marked. The larger the annual rainfall the smaller is the number of deaths from typhoid fever, other conditions remaining the same. It is not the total annual rainfall, however, which controls the rate so much as it is the summer rainfall and its distribution. Extreme conditions are dangerous. Prolonged periods of drought, followed by heavy rains, tend to increase stream pollution and to reduce the beneficial effects derived from sedimentation, long storage, etc.

Bronx—The old City of New York included what are now the Boroughs of Manhattan and The Bronx. Since consolidation, separate records have been kept for the different boroughs. They show that the typhoid fever death rate is considerably lower in The Bronx than in Manhattan. In 1889 it reached a phenomenally low rate, namely, 8.7 per 100,000 inhabitants.

Brooklyn—From 1868 to 1894 the typhoid fever death-rate was lower in Brooklyn than in New York; since 1894 it has been higher. In 1868, the date of the first available record, the rate was 28.5 per 100,000, or 1.18 per cent. of the total mortality. Between 1868 and 1879 there was a general decline in the rate, due in all probability to the order of the Board of Health closing hundreds of polluted wells within the city limits. The decline was not continuous, however, and during the dry years of 1870, 1872 and 1875 there were reactions. This was especially true of the year 1872, when the rate increased to 34.7 per 100,000 inhabitants, the highest point reached within the history of the records. In 1879 the rate dropped to 10.7, the lowest point reached.

Between 1880 and 1890 there was a gradual increase in the number of deaths from typhoid fever. During this period the draught upon the watershed was constantly increasing. The " pond pumping stations " were started in 1879, and about this time the storage reservoir at Hempstead was put into use, thus adding a supply of water which was considerably more open to pollution than most of the sources of supply then in use. The year 1883 was a very dry year, but at that time there was no increase in the typhoid death-rate, although during the year 1885, which was also a very dry year, there was a considerable increase. During this year there was a shortage of water in the city.

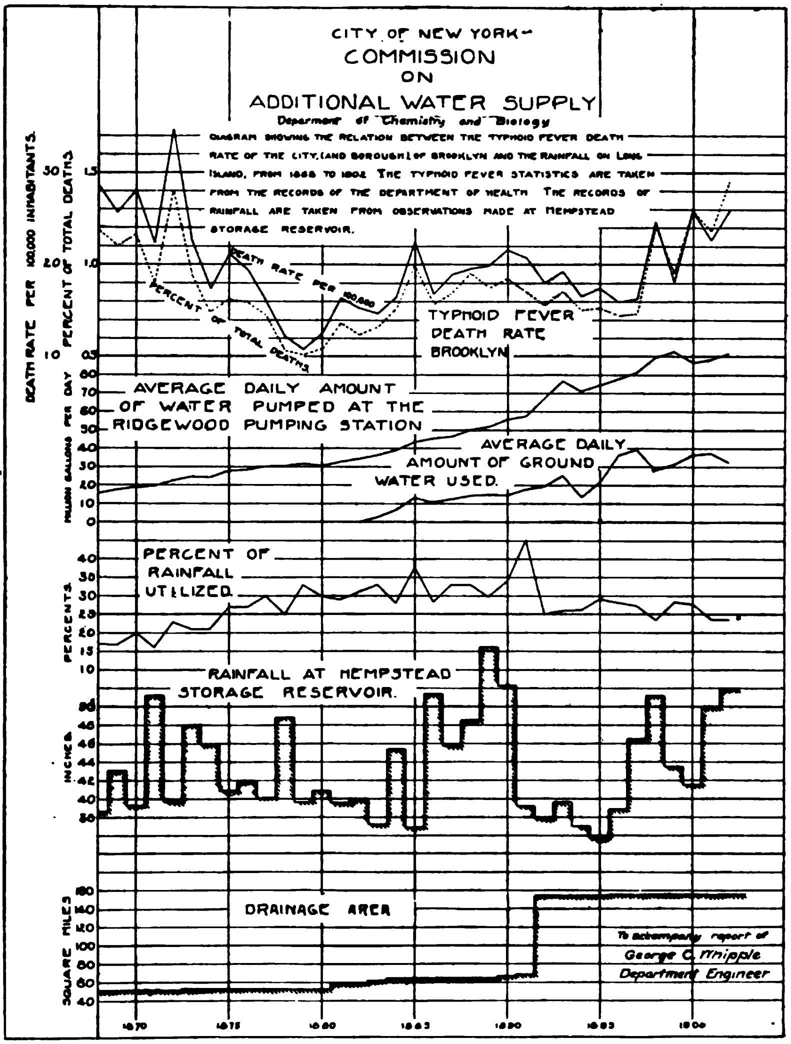


DIAGRAM III. APP. VI.

Between 1890 and 1897 several causes contributed to lower the rate. The new watershed, east of Millburn, was drawn upon in 1891, and this added a considerable volume of relatively pure water. In 1892 Basin 3 was added to Ridgewood Reservoir, thus increasing the storage capacity of the distribution reservoir. In 1893 the water-closets of the Village of Hempstead were panned and taken care of by a private company, while in 1894-5 this work was assumed by the Water Department and its scope extended to other portions of the watershed. The towns of Flatbush, Gravesend and New Utrecht were annexed in 1894. These towns were all supplied with water of good quality, and this additional increase of population in itself tended to lower the death-rate. In 1896 Flatlands was annexed. Baiseley's Pond was cut off from the supply in 1894 on account of pollution, and in 1897 Springfield Pond was cut off for the same reason.

In 1898 came the Spanish War. Many of the soldiers, returning from Cuba ill with typhoid fever, were carried to the hospitals in Brooklyn, where they died, and this naturally increased the rate. A study of the hospital records during that year showed that, if the soldier cases had been excluded, the annual typhoid fever death-rate, instead of being 24.6, would have been about 19 per 100,000 inhabitants. Since 1889 the rate has been rising with irregular steps. This can be attributed to no other cause than the depletion of the water supply, which has made it impossible to adequately guard against pollution. During the present year the rainfall has been greater and there have been fewer deaths from typhoid fever. During the past two years the succession of droughts and freshets have not been favorable to furnishing a good water supply from a watershed so nearly exhausted in its capacity and provided with such small storage reservoirs as exist on the Ridgewood system. The population on the watershed, moreover, is steadily increasing.

The frequent occurrence of growths of microscopic organisms in Ridgewood and Mt. Prospect Reservoirs, due to the mixing of the ground water with the surface water, has rendered it imperative to isolate these reservoirs at times and pump the water around them through the by-passes directly into the mains. This has prevented much unpalatable water from being sent to the city, but it has reduced the time required for the water to reach the consumers by about two days, and to that extent has rendered the water less safe should it become infected in any of the streams.

While it is true that there appears to be a general inverse ratio between typhoid fever morbidity and the rainfall, it must not be forgotten that the effects of the meteorological condition are not confined to the watersheds which supply water to the city. In great measure they also affect country wells, and water supplies elsewhere in the region surrounding the metropolitan district, thus increasing the possibilities of typhoid being brought to the city by agencies other than water, and by persons who contracted the disease elsewhere.

Queens—The water supplies of the Borough of Queens are taken from driven wells, and these may be practically excluded as sources of typhoid fever in that borough. For thirteen years before consolidation the typhoid fever death-rate was approximately 20 for Long Island City, 12 for Newtown and 15 for Flushing. Since 1898 the death-rate for the borough has varied from 11.7 in 1898 to 20.8 in 1900. Typhoid fever in this borough is probably due almost entirely to local causes, one illustration of this being the epidemic at Bayside in 1902, which was found to be due to infected milk furnished by a certain dealer.

It is worth noting that since 1885, the year of the earliest available records, the death-rates in Long Island City, Flushing and Newtown have not fluctuated synchronously with the rates in either Brooklyn or New York, and have shown no relation to the rainfall.

Richmond—The average typhoid fever death-rate in the Borough of Richmond since 1898 has been higher than that in any borough except Brooklyn. In 1899 it rose to 30.6 per 100,000, but since then it has fallen, until in 1902 it was 15.5 The public water supplies of the borough are all taken from underground sources, and it is probable that they are in no way responsible for the typhoid fever in this borough.

The general low death-rate from typhoid fever is a fact which reflects creditably upon the City. It is true, of course, that in a large city there is difficulty in obtaining accurate statistics, and the actual death-rate is probably larger than that reported, but after making all due allowance for errors, the fact remains, that the annual number of deaths from typhoid fever is surprisingly small. This could not be so if the public water supplies were other than reasonably safe from the sanitary standpoint.

It has been shown that 17 per cent. of the water supplied to the city is taken from driven wells. All of this ground water may be considered as entirely safe from the sanitary standpoint; and while the waters from the different well stations vary in many of their characteristics, not in a single instance is there reason to suppose that they were unhealthful. This is a fact generally true of driven well water, but it is doubly true where the wells are driven in such sandy material as is found on Long Island.

Eighty-three per cent. of the water supplied to the City, however, is collected from the surface of the ground and is used practically without filtration; and while the influence of the surface waters upon the amount of typhoid fever in the City is probably very small indeed, yet it cannot be considered as a negligible factor. It must be admitted that all of this water is open to possible infection, the danger of which must vary according to the amount of direct or indirect pollution from the population dwelling upon the watersheds. The watersheds of the Croton, Bronx, Bryam and Ridgewood systems are by no means unpolluted, although for the most part the direct pollution of the water is prevented. There must be some meaning, however, in the following figures:

	Bronx.	Manhattan.	Brooklyn.
Typhoid fever death rate, 1902, per 100,000.	13.9	19.3	25.8
Estimated population per square mile on the watersheds which form the chief sources of supply....................	34	52	208

While there is no general artificial system of purification for any of the surface waters, save in a few instances on the Ridgewood system, there are certain natural agencies of purification which deserve consideration, and which are described beyond.

(3) SANITARY SUPERVISION OF THE PUBLIC WATER SUPPLIES.

The practical measures which are being taken to eliminate the sources of pollution on the various watersheds are described on a later page. They include the abatement of industrial nuisances, the establishment of local systems of sewage disposal and local filter plants, and a sanitary patrol of the watersheds. These are measures which are all immediately and continuously necessary. The end will not be reached, however, until all of the water for the supply of Manhattan and The Bronx is filtered before delivery to the consumers and not until all the surface supplies on Long Island have been replaced by ground water sources. Meanwhile, it is necessary to keep a constant watch on the quality of the water by means of physical, chemical and biological analyses, and for this purpose samples of water are collected every day from the terminus of the Croton Aqueduct at One Hundred and Thirty-fifth Street, Manhattan, and from the terminus of the Brooklyn Aqueduct at the Ridgewood Pumping Station, besides several taps in Manhattan and Brooklyn. Once a week samples are collected from all the distribution reservoirs, supply ponds and storage reservoirs. Once a month or once a quarter every driven well supply is analyzed. This work is done chiefly at Mt. Prospect Laboratory, but the samples from the Croton Watershed intended for biological examination are sent to the branch laboratory at Katonah. These laboratories are referred to on other pages, and the work of Mt. Prospect Laboratory has been described in several of the scientific journals (see "Proceedings Brooklyn Engineers' Club," vol. IV., p. 106). The steady growth of this system of analyses is shown by the following table, which gives the number of samples analyzed each year from the time when Mt. Prospect Laboratory was established in 1897 to the present date:

Year.	Laboratories.	Scope of the Analyses.	Number of Samples.
1897..	Mt. Prospect	City of Brooklyn	1,240 (6 mos.)
1898..	"	Boroughs of Brooklyn and Queens..........	2,180
1899..	"	"	2,393
1900..	"	"	2.707
1901..	"	"	3,029
1902..	"	Boroughs of Brooklyn, Queens and Manhattan.	6,021
1903..	Mt. Prospect, Katonah, Poughkeepsie........	Entire City of New York, Special Investigations for Com. on Add. Water Supply..	16,000 { 10 mos. Approx.

In addition to the analyses made in the laboratories of the Department of Water Supply, Gas and Electricity, analyses are regularly made by the Department of Health, in continuation of their work which began long before the Department of Water Supply took up the matter. Their analyses, however, are made with reference simply to the sanitary quality of the water, their field of operations being logically limited to the character of the water in its relation to the public health.

To publish the results of all the analyses which have been made would be to fill several volumes, but inasmuch as there are no complete published records of analyses showing the general characteristics of all the various sources of supply of the City, it has been thought best to present summaries of the most important results. These are given in Tables 5 to 8. Before describing them, however, it may not be out of place to offer a few words in explanation of the character of the analyses made and the meaning of the results.

4. REQUISITE QUALITIES OF A PUBLIC WATER SUPPLY.

The requisite qualities of a water to be used for purposes of public supply are as follows:

1. It should be free of organisma capable of producing disease and of all irritating or poisonous substances, whether organic or inorganic.

2. It should have an agreeable appearance, that is, it should be practically clear and colorless.

3. It should be odorless and tasteless.

4. It should not be too hard for domestic or industrial uses, and it should be practically free of iron.

5. It should not contain substances in solution liable to corrode metal work either in boilers or in the distribution or service pipes.

6. It should perferably have a cool and equable temperature.

These requisites differ in their relative importance. First, and before everything else, a public water supply must be safe from the sanitary standpoint. It must not, by scattering the germs of disease, be a menace to the health and the lives of the consumers. In so far as a water supply is open to pollution, it is dangerous to use.

It is, perhaps, unfortunate that the characteristics of a water which make it unsafe do not at the same time render it unpalatable; but it is true to a very great extent that safety and palatability of water are independent of each other. Those characteristics which render a water distasteful are recognizable by the senses, but the presence of disease germs is not. For example, a water which is colored or turbid, and especially a water which has a bad odor, is naturally repellent, while a hard water has objectionable qualities which are evident in every household and boiler-room; yet a water may possess all these objectionable features and be perfectly safe. On the other hand, a water may be clear and cold, and in every respect pleasant to drink, and yet contain disease-producing germs or poisonous metallic salts. Thus it is that public opinion as to the sanitary value of a water supply is often fallaceous. The brown color of water is due almost invariably to harmless vegetable matter in solution; turbidity is due to clay or iron or other matter in suspension, while most of the bad odors are produced by microscopic organisms, not disease germs. Upon these æsthetic qualities, as such, the consumer is a good judge, and they are proper subjects of complaint, but high color, turbidity and odor are usually wrongly interpreted by the ordinary citizen. They do not in themselves indicate pollution. The characteristics which render a water unsafe from the sanitary standpoint can be detected only by the expert using the most delicate chemical and biological tests.

The other characteristics mentioned, such as hardness, the presence of corrosive substances, etc., are by no means unimportant. They detract from the general acceptability of a water and have an important bearing upon its industrial value, as will be pointed out later.

5. WATER ANALYSES.

A complete sanitary water analysis, as made in the modern laboratory, consists of four parts: the physical examination, the chemical analysis, the microscopical examination and the bacteriological examination. For a complete understanding of the quality of the water, all of these analyses are required and are usually sufficient, but in special cases it is necessary to proceed further and make what is termed a mineral analysis. Fifteen years ago the only analysis made was the chemical analysis, but the development of the science of bacteriology has made a change in many of our ideas concerning the quality of drinking water, so that at the present time the bacteriological examination ordinarily gives more practical results from a sanitary point of view than the chemical analysis. The microscopical examination is of still more recent origin. Its principal function is that of ascertaining the presence of those microscopic organisms which impart a bad taste and odors to drinking water. Strangely enough, the physical examination was the last one to take definite shape. The old methods of stating the amounts of turbidity and odor in indefinite phrases have been replaced by more accurate and convenient forms of expression. It has been found that these different parts of the complete sanitary analysis are interlocking, and often the results of a microscopical examination are necessary in order to properly interpret the figures obtained by the chemical analysis. The up-to-date analyst, however, can usually tell what portions of the analysis may be omitted without loss of any important information. It is fortunate that this is so, because it is found that in the work of routine supervision of water supplies more can be learned about the general condition of the water by making partial analyses of samples frequently collected than by making more complete analyses of samples taken only occasionally, and thus it is that the daily samples which are taken from the terminals of the aqueducts are given only a partial analysis.

Physical Examination.

The physical examination includes the determination of those qualities of water which are evident to the senses, such for example, as its temperature, turbidity, color and odor. The temperature of the water needs no comment. The odors of water are variously described as vegetable, aromatic, fishy, moldy, disagreeable, etc. The vegetable odors are due largely to organic matter in solution. The aromatic, grassy and fishy odors are caused almost entirely by microscopic organisms. Different organisms give rise to different odors, and often the organisms present can be detected simply from the odor of the water. The microscopical examination, however, serves to give all necessary details as to the character and number of these organisms, hence the relation between the microscopical examination and the determination of odor is very intimate. The odors which are termed moldy, musty, disagreeable, etc., are due largely to organic matter in decomposition, and their presence has a bearing upon the sanitary character of the water.

The estimate of the intensity of the different odors is naturally very indefinite, and is one where the personal equation plays a very large part. It has been found practical, however, to grade the odors on a scale of numbers which may be defined substantially as follows:

Numerical Value	Term.	Approximate Definition.
0	None........	No odor perceptible.
1	Very faint....	An odor that would not be ordinarily detected by the average consumer, but that could be detected in the loboratory by an experienced observer.
2	Faint........	An odor that the consumer might detect if his attention were called to it, but that would not otherwise attract attention.
3	Distinct......	An odor that would be readily detected, and that might cause the water to be regarded with disfavor.
4	Decided	An odor that would force itself upon the attention, and that might make the water unpalatable.
5	Very strong..	An odor of such intensity that the water would be absolutely unfit to drink (a term to be used only in extreme cases).

By using simple abbreviations for the quality of the odors, and by rating the intensity of the odors on a numerical scale, the records are much simplified. Ordinarily, the taste of water is about the same as its odor. In fact, many of the so-called tastes are really odors. Certain tastes, however, are independent of odor, such for example, as that of brackish water, or of a water which contains a large amount of iron in solution. In by far the great majority of cases, however, it is unnecessary to make a record of the taste, independent of the odor.

The color of water is due to vegetable matter in solution. It is acquired largely from swamp land on the watershed, and is practically an extract of the leaves, bark, twigs, etc., which accumulate upon the surface of the ground. Ground waters ordinarily have no color, and the amount of color in surface waters is dependent upon the character of the watershed. The color of water is measured by comparing it with certain artificial tints imparted to distilled water by adding to it measured amounts of certain salts of platinum and cobalt. The figure which represents the color is the number of parts per million of the platinum salt used to obtain that color. A water which, like distilled water, has no color, is regarded as 0: As soon as the color reaches 15 or 20, it begins to be noticeable in a porcelain bathtub or a washbowl, but not until the color is above 30 does it attract much attention in a glass tumbler upon a white cloth. If the color rises to 40 or 50, it has a brownish cast in a tumbler, while if it reaches 75 it has the appearance of very weak tea. The color of the water in swamps frequently rises to more than 100, and in the Dismal Swamp of Virginia samples have been collected which had a color of more than 800. It should be noted that the color of water is due to substance in solution, and is to be distinguished from the apparent color which water sometimes has, due to matter in suspension. This leads to the subject of turbidity.

The turbidity of water is caused by matter in suspension. Sometimes suspended matter is in a very finely divided condition, as clay. At other times it consists of very much larger particles, each of which may be easily seen with the naked eye. The turbid waters of the southern and western rivers are due largely to the very fine clay and river silt which they contain. Such substances settle slowly in water, and the turbidity produced by them is, therefore, quite permanent. Most of the waters of New England and New York, however, are relatively clear in their normal condition. They become turbid only after heavy rains, when they receive the wash from the surface of the ground. Much of this material is comparatively coarse, and settles rapidly. Some of it is organic in character. The waters of lakes sometimes become turbid from the presence of microscopic organisms. The waters in the pipe distributing systems sometimes contain large amounts of suspended matter, derived from the pipes or aqueducts. This is usually present in flakes of considerable size so that the water may be said to be " dirty " rather than turbid. It is convenient, however, to apply the word " turbidity " to all these forms of suspended matter, and it has been found that for all practical purposes they may be measured by the same standard. The standard used for measuring turbidity is that known as the silica standard, the basis of which is an artificial preparation of diatomaceous earth so prepared for use by washing and grinding that the silicious material is in an extremely finely divided state. The figure for turbidity given in the record means that the water under examination is as turbid as distilled water would be if that number of parts per million of the standard silica was added to it. A water which has a turbidity of 3 or over is noticeably turbid. It seldom becomes offensively turbid under 5 or 10, although this varies more or less according to the character of the suspended matter. Furthermore, people of certain sections of the country become accustomed to turbid streams, and waters which New England people would call turbid others might consider reasonably clear.

Chemical Analysis.

The chemical analysis of water consists of determining the chemical character of the foreign substances present. Some of the determinations are made for the purpose of ascertaining the sanitary quality of the water. These constituents are usually of little importance in themselves, and are chiefly valuable as indicating the past history of the water. Other constituents are determined for the sake of their own influence upon the quality of the water. Prior to the advent of bacteriology the chemical analysis was the most reliable means one had for ascertaining the safety of water for drinking purposes, but to-day the chemical results form only a part of the necessary analytical data. It is useful, however, to know the amount and character of the nitrogenous matter present. The nitrogen is usually expressed as being present in four forms—either as albuminoid ammonia, free ammonia, nitrites, or nitrates. The expression "nitrogen as albuminoid ammonia" refers to the nitrogen present in organic matter before any decomposition has taken place. The "free ammonia" represents the nitrogen set free from the organic matter by initial decomposition; and the "nitrogen as nitrites" represents a later stage in that process. The "nitrogen as nitrates" represents the final mineralized condition of the nitrogen in which it is no longer organic matter. These four forms of nitrogen, therefore, serve to indicate the state of the organic matter present with reference to its decomposition. They do not show whether the original organic matter was or was not derived from dangerous sources. Taken in connection with the rest of the analysis, however, these findings are of importance. The chlorine found in water has little sanitary significance in itself, but, inasmuch as salt is an accompaniment of sewage and domestic wastes, its presence in water is indicative of pollution. All natural waters situated reasonably near the sea coast, however, contain, even when unpolluted, a certain amount of chlorine, which varies according to their distance from the sea, and it is necessary to subtract this "normal chlorine" from the figure obtained in order to estimate how much of the chlorine was due to pollution. The amounts of normal chlorine have been carefully determined for some of the New England and Middle States, so that the normal may be readily obtained for any given locality.

By the hardness of water is meant the presence of those salts of lime and magnesia which decompose soap, a phenomenon well understood in every household and which is referred to at length elsewhere. The alkalinity represents that portion of the hardness due to the carbonates and bicarbonates of calcium and magnesium, while the difference between the alkalinity and the hardness is practically a measure of the sulphates, nitrates, etc., of the same elements. The amount of iron present is of little importance, except where it amounts to more than about 0.5 parts per million. From there up it is liable to render the water objectionable by causing stains of iron-rust when used in the laundry. The "total solids," or, as they are sometimes called, "residue on evaporation," include practically all of the constituents above mentioned. The loss of weight when this residue is heated gives a rough measure of the organic matter present, but the determination of this "loss on ignition" is subject to so many errors that it is often omitted from the analysis in the case of ground waters. The results of the chemical analysis are best expressed in parts per million by weight, which is practically equivalent to milligrams per liter. The method of expressing results in grains per gallon is now antiquated, but it may not be out of place to state that results given in parts per million may be transferred to grains per gallon by dividing the figures by 17.1.

Microscopical Examination.

Surface waters contain many forms of animal and vegetable life, which are too small to be observed with the naked eye, but which are very much larger in size than the bacteria. These microscopic organisms, as they are conveniently called, may be studied directly by means of the microscope. Examination is made by first collecting them upon the surface of a tiny sand filter, and then transferring them from this in concentrated form to the stage of a microscope, where they are identified and counted. It is customary to express the results in number of standard units of organisms per cubic centimeter. A standard unit is the unit of size used for measuring them, and is practically equivalent to a surface area of 400 square microns (1 micron equals 0.001 millimeter). It is the microscopic organisms which give rise to the aromatic, grassy and fishy odors above mentioned.

Bacteriological Examination.

The number of bacteria in water is ascertained by a process known as cultivation on nutrient gelatin, the details of which need not be here described. The result is simply the determination of the number of bacteria of all kinds present in the water, which will grow, upon that medium, in 48 hours at a temperature of 20 degrees centigrade. No distinction is made between harmful and harmless bacteria, and the result does not actually state the total number of bacteria present. The method is one of some crudity, and is far from being what is desired, yet the results are of considerable value, although they ought to be considered merely as relative. Unfortunately, there is no practical method by which the presence of dangerous disease germs in water can be detected. Not even can the germ of typhoid fever be isolated from water by means of practical laboratory methods, although there seems to be a popular impression that it can be. In the intestines of man and warm-blooded animals generally there dwells a bacterium, however, known as Bacillus coli, and this organism fortunately can be detected in water with a reasonable degree of precision.

We have in this determination, therefore, one of the most reliable and practical methods of ascertaining the sanitary character of the water, and the test becomes of especial value when it is made quantitatively. On account of the labor involved in ascertaining the presence of this germ, an exact quantitive result cannot be secured; but if different quantities of water are used in making the qualitative test, the data obtained approach in value the results which would be obtained if the determination were more exactly quantitative. In Mount Prospect Laboratory it has been customary to make the test in three different quantities of water—namely, 0.1, 1 and 10 cubic centimeters. These quantities were selected after a long series of experiments, in which it was found that only water suspicious in character constantly gave positive tests in 0.1 cubic centimeters, while perfectly safe waters occasionally gave positive tests in 10 cubic centimeters. The determination of the total number of bacteria and the test for Bacillus coli made upon three different quantities of water, constitute the bacteriological examination made in the laboratory.

Only in rare instances is it deemed necessary to proceed further with the qualitative study of the different species of bacteria present.

RESULTS OF ANALYSES.

In Tables 5 to 8, which follow, are given summaries of analyses for all the sources of water supply of the city, compiled from the records of Mount Prospect Laboratory. They represent the results obtained in the course of the regular analytical supervision of the water supplies. From 1897 to 1902 the work was done under the direction of Mr. I. M. de Varona, Chief Engineer, and in 1903 under the direction of Mr. I. M. de Varona and Mr. Nicholas S. Hill, Chief Engineer.

TABLE 5A.

SUMMARY OF ANALYSES OF SAMPLES OF

Borough of

Sample.	Period Covered by Analyses.	Physical Examination. Turbidity (Parts per Million of Silica).	Color (Parts per Million of Platinum).	Odor.
BOROUGH OF MANHATTAN.				
SOURCES OF SUPPLY.				
Surface Waters.				
White Lake	1903	1	11	3v.
Cold Spring Brook	"	1	50	3v.
Black Pond	"	1	52	3v.
Boyd's Corner Reservoir (Surface)	"	1	29	3v.
West Branch " "	"	3	22	3v.
Lake Gleneida (Surface)	"	2	6	2v.
Lake Gilead "	"	2	6	2v.
Kirk Lake "	"	4	23	3v.
Lake Mahopac "	"	2	9	3v.
Muscoot Reservoir (Surface)	"	2	16	2v.
Middle Branch Reservoir (Surface	"	3	22	3v
East Branch Stream, Deforest Corner	"	3	28	3v.
Sodom Reservoir (Surface)	"	3	24	3v.+1g.
Tog Brook Reservoir (Surface)	"	2	20	2v.+1g.
East Branch Stream above Tonetta Brook	"	3	24	3v.
Tonetta Brook	"	3	35	2v.+2m.
East Branch Stream below Brewster	"	3	29	2v.
Croton River above Titicus Stream	"	4	24	2v.
Titicus Reservoir (Surface)	"	4	21	3v.+1g.
Cross River at Katonah	"	2	22	3v.
Branch Brook below Mount Kisco	"	3	26	3v.+1m.
Croton Lake (Surface)	"	6	27	3v.+1g.
Ground Waters.				
(There are no ground water supplies in the Borough of Manhattan.)				
Distribution System—				
One Hundred and Thirty-fifth Street Gatehouse	1903	5	24	3v.+1m.
High Bridge Reservoir*	"	4	25	3v.+1g.
Central Park, New Reservoir (Efflux)	"	3	21	3v.+1g.
Central Park, Old Reservoir, North Basin (Efflux)	"	4	20	3v.+1g.
Central Park, Old Reservoir, South Basin (Efflux)	"	4	21	3v.
Tap, City Hall Square	"	3	23	3v.

* A single analysis July 24.

TABLE 5A.

WATER FROM VARIOUS SOURCES OF SUPPLY.

Manhattan.

Chemical Analysis (Parts per Million).												Microscopical Examination.	Bacteriological Examination.	
Nitrogen as						Total Solids.	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopical Organisms. Standard Units per c. c.	Number of Bacteria per c. c. 48 hours at 20° C.	Percent. of Positive Tests for B. Coli in 1 c. c.
Albuminoid Ammonia			Free Ammonia	Nitrites.	Nitrates.									
In Solution.	In Suspension.	Total.												
.138	.022	.160	.043	.001	.00	32.0	1.6	14.9	13.0	1.9	.14	....	....	....
.087	.018	.105	.023	.001	.08	43.4	0.9	26.2	23.3	2.9	.08	....	....	....
.120	.010	.130	.026	.002	.07	53.0	0.9	33.0	30.0	3.0	.04	....	....	....
.102	.010	.112	.031	001	.04	43.3	0.9	20.4	17.1	3.3	.07	287	....	....
.104	.042	.146	.059	.001	.03	41.0	1.3	22.8	17.3	5.5	.08	732	....	....
.109	.018	.127	.042	.001	.00	68.0	4.1	41.5	38.0	3.5	.05	180	....	....
.107	.015	.122	.059	.001	.00	43.1	2.2	23.7	21.0	2.7	.06	52	....	....
.131	.042	.173	.080	.001	.07	52.0	1.4	28.8	22.0	6.8	.07	654	....	....
.106	.018	.124	.038	.002	.07	43.3	2.8	24.5	16.8	8.7	.10	283	....	....
.138	.030	.168	.043	.001	.10	59.0	2.0	31.7	27.6	4.1	.27	885	....	....
.114	.019	.133	.066	.002	.05	48.7	1.4	27.3	20.4	6.9	.10	1004	...	....
.122	.022	.144	.060	.004	.07	98.3	1.4	66.4	62.5	3.9	.16	....	....	....
.134	.069	.203	.058	.002	.06	77.2	1.2	47.6	44.0	3.6	.08	824	....	....
.152	.049	.201	.087	.002	.04	68.0	1.6	43.8	41.3	2.5	.11	794	....	....
.120	.033	.153	.035	.004	.05	75.3	1.2	49.5	44.0	5.5	.22	....	....	....
.136	.028	.164	.058	.005	1.11	108.0	5.8	55.5	41.7	13.8	.25	....	....	....
.132	.034	.166	.047	.004	.05	78.0	1.5	45.0	41.0	4.0	.22	....	....	....
.105	.024	.129	.042	.002	.09	70.2	1.4	37.8	34 0	3.8	.41	....	....	....
.123	.043	.165	.048	.002	.04	65.0	1.7	38.0	34.4	1.6	.18	680	....	....
.069	.005	.074	.035	.003	.16	75 0	2.1	39.6	36.2	3.4	.29	....	....	....
.087	.014	.101	.050	.008	1.29	120.6	5 7	61.7	53.3	8.4	.26	....	....	....
.142	.049	.191	.077	.002	.10	71.0	1.7	39.4	31.0	8.4	.23	675	....	....
.129	.028	.157	.032	.004	.14	71.5	2.0	37.4	32.7	4.7	.28	1058	1848	18.7
.112	.028	.140	.132	.010	.20	91.0	1.8	41.5	40.0	1.5	.30	....	....	....
....	....	.160	.045	.005	.13	52.5	1.6	32.5	29.0	3.5	.15	13 9	645	8.0
....	....	.165	.037	.004	.07	61.0	1.6	33.8	30.6	3.2	.08	2682	450	15.6
....	....	.169	.0[illegible]3	.004	.08	51.0	1.6	34.3	31.0	3.3	.12	1753	655	11.7
....	....	.123	.016	.003	.14	65.5	1.8	35.4	30.0	5.4	.15	832	551	5.9

TABLE 5B.

SUMMARY OF ANALYSES OF SAMPLES OF

Borough of

Sample.	Period Covered by Analyses.	Physical Examination. Tur-bidity (Parts per Million of Silica).	Color (Parts per Million of Pla-tinum.)	Odor.
BOROUGH OF BRONX.				
SOURCES OF SUPPLY.				
Surface Waters.				
Byram Lake (Surface)	1903	3	9	2v.
Rye Pond (Surface)	"	3	16	3v.
Kensico Reservoir (Surface)	"	4	25	3v.
Grassy Sprain Reservoir (Yonkers)	"	2	10	2v.
Ground Waters.				
Westchester Water Works	"	1	..	....
Tube Wells (Yonkers)	"	..	3	....
Distribution System—				
Glen Park Pumping Station*	"	5	24	2v.
Williamsbridge Reservoir, Influx	"	3	20	2v.
Williamsbridge Reservoir, Efflux	"	3	18	2v.
Tap, Manor Hall, Yonkers	"	2	15	2v.

* 6 samples only.

TABLE 5B.

WATER FROM VARIOUS SOURCES OF SUPPLY.

The Bronx.

Chemical Analysis (parts per million). Nitrogen as Albuminoid Ammonia. In Solution.	In Suspension.	Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopical Examination. Microscopic Organisms Standard Units per cc.	Bacteriological Examination. Number of Bacteria per cc. 48 hours at 20° C.	Percent. of Positive Tests for B. coli in 1 cc.
.097	.043	.140	.030	.001	.05	47.0	2.8	21.5	15.0	6.5	.13	225	....	....
.125	.030	.155	.038	.001	.00	58.0	2.4	28.9	24.7	4.2	.10	418	....	....
.087	.054	.141	.057	.003	.05	62.0	2.1	25.5	20.6	4.9	.15	555	....	....
....	....	.113	.048	.002	.06	67.0	2.8	34.5	32.3	2.2	.13	1011	....	0
.020	.002	.022	.023	.002	1.75	277.7	53.0	122.6	79.7	42.9	.06	0	6	0
....	....	.018	.003	.001	1.49	202.5	4.1	148.1	116.5	31.6	.01	0	4	0
.100	.012	.112	.036	.002	.07	56.0	2.1	26.2	21.2	5.0	.17	313	267	330
.097	.017	.114	.040	.003	.10	58.5	2.2	25.8	20.4	5.4	.15	179	148	139
....	....	.106	.017	.005	.09	54.0	2.6	23.5	17.0	6.5	..	154	154	93
....	....	.091	.014	.002	.27	85.0	3.0	53.2	43.0	10.2	.21	516	....	0

Table 5c.

SUMMARY OF ANALYSES OF SAMPLES OF

Borough of

Sample.	Period Covered by Analysis.	Physical Examination.		
		Turbidity. (Parts per Million of Silica).	Color. (Parts per Million of Platinum.	Odor.
BOROUGH OF BROOKLYN.				
SOURCES OF SUPPLY.				
Surface Waters.				
Massapequa Pond	1897–1902	1	37	2v.
Wantagh Pond	"	2	17	"
Newbridge Pond	"	1	25	"
East Meadow Pond	"	2	23	"
Millburn Pond	"	2	18	"
Millburn Pumping Station	"	2	18	"
Hempstead Stream, Franklin street	"	5	10	2t.+2d.
Hempstead Storage Reservoir	"	3	8	2v.+1m.
Schodack Brook	"	2	11	2v.
Hempstead Pond	"	3	11	"
Pine's Pond	"	3	16	"
Smith's Pond	"	3	19	"
Valley Stream Pond	"	3	21	"
Watts Pond	"	4	20	"
Clear Stream Pond	"	4	12	"
Simonson's Pond	"	10	11	2v.+1m.
Springfield Pond	"	6	23	2v...1m.
Baiseley's Pond	"	15	31	3v.+2m.
Ground Waters.				
Massapequa, deep and shallow	1898–1902	1	4	None.
Wantagh, deep and shallow	1897–1902	1	3	"
Matowa, deep and shallow	"	1	2	"
Merrick, shallow wells	"	3	2	"
Agawam, shallow wells	"	1	3	"
Watts' Pond, shallow wells	"	3	4	"
Clear Stream, shallow wells	"	1	2	"
Forest Stream, shallow wells	"	2	7	"
Springfield, deep wells	"	7	21	"
Jameco, deep wells	"	1	7	"
Jameco, deep and shallow	"	9	31	"
Baiseley's, shallow wells	"	0	2	"
Oconee, deep wells	"	1	6	"
Shetucket, deep wells	"	10	25	"
Spring Creek, old plant, deep wells	"	1	12	"
" " shallow wells	"	0	..	"
" new plant, shallow wells	"	0	1	"
" Pump No. 1	1901–1902	0	1	"
" Pump No. 3	"	1	6	"
New Lots Pumping Station	1898–1902	0	1	"
German American Water Company	1897–1902	0	1	"
Flatbush Water Company	"	0	1	"
Gravesend Wells	"	0	0	"
New Utrecht Wells	"	0	0	"
Blythebourne Water Company	1898–1902	0	0	"
Pfalzgraf Water Company	"	0	1	"
DISTRIBUTION SYSTEM.				
Ridgewood Basin, No. 1 and 2, Influx	"	4	13	2v.
" " 3, Influx	"	3	13	"
" " 1, Efflux	"	3	12	2v.+1a.
" " 2, "	"	3	13	"
" " 3, "	"	4	14	"
Mt. Prospect Reservoir	"	5	12	3v.+2a.
Tap in Laboratory	"	3	13	2v.
" at Flushing and Cleremont avenues	"	3	13	"
" at Flatbush and Seventh avenues	"	3	13	2v.+1a.

Table 5c.

WATER FROM VARIOUS SOURCES OF SUPPLY.

Brooklyn.

Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. In Solution.	In Suspension.	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopic Examination. Microscopical Organisms Standard Units per C.C.	Bacteriological Examination. Number of Bacteria per C.C. 48 Hours at 20° C.	Per cent. of Positive Tests for B. Coli in 1 C.C.
.073	.010	.083	.010	.001	.32	38.4	5.3	10.5	5.8	4.7	.08	47	434	4.3
.057	.013	.072	.010	.001	.40	38.2	5.6	13.1	4.6	8.5	.21	41	385	5.5
.056	.007	.063	.007	.001	.41	43.5	5.9	12.2	4.4	7.8	.18	21	172	5 0
.056	.009	.065	.016	.001	.51	37.1	5.4	14.7	4.1	10.6	.51	33	469	7.6
.047	.007	.054	.009	.002	.01	52.0	6.7	17.7	5.3	12.4	.18	30	417	11.3
.035	.005	.040	.006	.001	3.88	41.7	5.7	14.5	5.4	9.1	.25	19	278	7.1
.078	.021	.099	.826	.022	3.19	95.3	18 6	33.7	13.3	20.4	.31	45	3,010	30.0
.064	.028	.092	.026	.006	1.09	50.0	6.4	20.4	8.0	12.4	.27	903	658	8.0
.035	.008	.043	.020	.003	1.10	49.1	6.0	18.0	5.6	12.4	.24	28	664	13.9
.059	.013	.072	.037	.003	.26	45.1	6.0	17.3	6.3	11.0	.33	118	448	6.2
.053	.017	.070	.019	.004	.97	53.6	6.2	21.1	7.3	13.8	.40	219	522	6.9
.055	.015	.070	.024	.003	.55	46.2	5.8	17.2	6.2	11.0	.55	189	492	7.3
.065	.005	.080	.014	.005	1.58	62.9	6 5	25.4	7.5	17.9	.34	87	571	4.5
.056	.012	.068	.020	.004	1.43	65.2	6.6	24.4	7.8	16.6	.41	77	847	10.5
.047	.011	.058	.018	.009	4.80	93.0	9.0	29.3	8.7	20.6	.14	149	903	9.4
.041	.020	.061	.025	.012	4.16	90.9	8.8	31.7	8.5	23.2	.26	45	2,171	9.8
.078	.036	.114	.044	.012	2.84	112.7	12.4	35.9	15.0	20.9	.81	754	1,337	17.0
.090	.197	.287	.072	.010	1.78	127.7	9.9	50.4	28.6	21.8	1.26	5,252	1,168	10.6
....	....	.024	.013	....	.17	43.9	5.5	20.8	11.4	9 4	.45	16	15	0
....	....	.015	.006	.001	.06	26.1	3.7	6.7	1.7	5.0	.51	3	21	0
....	....	.030	.008	.001	.08	34.4	4.2	9.3	2.1	7.2	.45	0	15	0
....	....	.014	.004	.001	.37	46.0	5.3	16.4	5.0	11.4	.67	38	31	0
....	....	.015	.003	.001	.13	34.2	5.0	8.4	1.4	7.0	.27	61	32	0
....	....	.019	.026	.002	2.29	74.1	7.5	28.2	8.3	19.9	.64	16	83	0
....	....	.011	.005	.001	2.03	70.2	6.3	28.1	7.1	21.0	.30	1	30	0
....	....	.012	.025	.003	.54	56.6	6.0	24.4	9.5	14 9	1.18	8	64	0
....	....	.008	.007	.001	.03	50.0	3.9	15.7	4.0	11.7	3.53	100	37	0
....	....	.013	.368	.001	.01	113.3	4.8	88.2	84.8	3.4	.63	57	67	0
....	....	.018	.242	.009	.78	146.2	25.7	73.8	48.4	25.4	3.37	57	66	0
....	....	.008	.025	.003	1.84	340.5	114.9	111.0	26.4	84.6	.20	....	73	0
....	....	.020	.265	.001	.01	148.7	4.8	106.0	101.0	5.0	.57	2	33	0
....	....	.015	.402	.012	.01	713.5	264.2	240.0	80.6	159.4	2.02	16	50	0
....	....	.005	.005	....	.06	183.7	7.1	123.6	122.7	.9	.70	5	27	0
....	....	.011	.013	.002	3.00	517.9	139.1	161.1	89.7	71.4	.06	....	66	0
....	....	.013	.009	.002	6.47	334.9	55.2	166.2	100.0	66.2	.13	....	25	0
....	....	.012	.012	.003	4.20	645.8	197.7	250 4	99.3	151.1	.14	....	59	0
....	....	.011	.010	.002	1.65	378.1	106.3	196.7	122.0	74.7	.40	....	76	0
....	....	.012	.002	.004	10.15	296.5	21.4	167.8	102.6	65.2	.04	....	136	0
....	....	.010	.007	.003	8.50	307.7	27.1	174.0	103.0	71.0	.03	....	60	0
....	....	.010	.002	.001	5.48	181.3	13.1	105.4	60.0	45.4	.02	....	32	0
....	....	.008	.002	.001	4.05	153.3	13.1	93.2	57.4	35.8	.01	....	81	0
....	....	.008	.002	.001	3.11	255.1	64.1	128.7	61.8	66 9	.08	....	82	0
....	....	.011	.001	.002	5.36	162.8	8.1	93.1	63.6	29.5	.04	2	51	0
....	....	.019	.003	.004	8.36	261.8	15.3	162.4	101.5	60.9	.25	....	112	0
.037	.007	.044	.029	.003	1.14	102.2	19.6	38.1	17.8	20.3	.58	144	375	5.9
.038	.007	.045	.019	.002	1.00	83.1	15.7	33.2	15.6	17.6	.45	112	320	5.2
.045	.021	.066	.018	.004	1.08	106.1	21.4	30.5	21.7	17.8	.38	2,097	379	5.5
.055	.026	.061	.019	.003	1.07	104.9	20.9	38.7	21.6	17.1	.37	1,634	399	9.3
.046	.019	.065	.012	.003	.96	89.9	17.6	34.6	18.2	16.4	.33	1,954	329	4.5
.063	.045	.128	.013	.009	.82	99.1	19.7	36.4	21.3	15.1	.22	6,088	208	1.5
.039	.011	.055	.005	.002	1.08	99.9	19.8	38.6	19.6	19.0	.41	850	291	3.4
.041	.011	.054	.005	.002	1.04	94.5	18.7	35.6	18.1	17.5	.37	855	217	3.9
.050	.021	.065	.006	.003	1.00	97 5	19.9	37.2	19.1	18.1	.37	2,362	314	1.4

TABLE 5D.

SUMMARY OF ANALYSES OF SAMPLES OF

Borough of

Sample.	Period covered by Analyses.	Physical Examination. Turbidity (Parts per million of Silica).	Color (Parts per million of Platinum).	Odor.
BOROUGH OF QUEENS.				
SOURCES OF SUPPLY.				
Surface Waters.				
Bayside—Oakland Lake	1903	2	12	3v.
Ground Waters.				
Long Island City, Pump No. 1	1898–1902	0	1	0
" " 2	"	0	1	0
" " 3	"	0	2	0
Citizens Water Co., Station No. 1	"	0	0	0
" " 2	"	0	0	0
" " 3	1909–1902	0	1	0
" " 4	1900–1902	0	0	0
" " 5	1901–1902	0	0	0
Flushing Water Works	1898–1902	0	5	0
Whitestone Water Works, Station No. 1	1903	2	2	0
" " 2	1898–1902	0	1	0
Bayside Water Works	"	0	3	0
Jamaica Water Supply Co.	"	0	2	0
Woodhaven "	"	0	0	0
Montauk "	"	0	0	0
Queens County Water Supply Co. (Unfiltered)	"	0	6	0
" (Filtered)	"	0	1	0

TABLE 5E.

Borough of

BOROUGH OF RICHMOND.				
SOURCES OF SUPPLY.				
Ground Waters.				
West New Brighton Station, Staten Island Water Supply Co.	1903	5	16	0
New Springville Station, "	"	0	2	0
Crystal Water Supply Co., Clove Station	"	0	0	0
Crystal Water Supply Co., Reservoir	"	1	2	0
South Shore Water Works at New Dorp	"	0	0	0
Tottenville Water Supply Co.	"	0	26	0

TABLE 5D.

WATER FROM VARIOUS SOURCES OF SUPPLY.

Queens.

Chemical Analysis (parts per million). Nitrogen, as Albuminoid Ammonia. In Solution.	Albuminoid Ammonia. In Suspension.	Albuminoid Ammonia. Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopical Examination. Microscopic Organisms. Standard Units per C.C.	Bacteriological Examination. Number of Bacteria per C.C. 48 hours at 20° C.	Bacteriological Examination. Per cent. of Positive Tests for B. coli in 1 c. c.
..	..	.122	.056	.012	1.91	109.6	6.8	53.0	36.6	16.4	.12	1365	2575	0
..	..	.015	.004	.092	3.44	259.4	73.4	185.9	91.5	90.4	.06	22	280	..
..	..	.016	.005	.001	3.66	1322.1	481.3	418.2	145.2	273.0	.05	..	..	..
..	..	.022	.001	.000	3.72	305.1	15.3	199.8	134.9	64.9	.08	1	49	..
..	..	.016	.003	.002	8.76	322.2	11.8	206.1	142.0	64.1	.03	3	101	0
..	..	.012	.000	.055	6.96	277.9	13.6	177.6	109.9	67.7	.03	2	46	0
..	..	.008	.094	.008	.91	150.3	7.6	107.5	92.7	14.8	.08	4	28	0
..	..	.005	.001	.002	5.78	192.2	9.0	130.4	97.3	33.1	.05	0	31	0
..	..	.108	.001	.002	5.85	195.4	7.6	124.3	95.8	28.5	.00	0	..	..
..	..	.033	.008	.010	2.98	96.0	6.8	51.9	31.5	20.4	.18	48	370	0
..	..	.024	.006	.002	5.39	241.2	12.5	152.2	102.7	49.5	.04	0	13	0
..	..	.009	.000	.001	4.23	205.7	10.9	140.0	107.3	32.7	.03	2	..	..
..	..	.018	.004	.003	2.59	92.8	6.3	49.2	35.3	13.9	.11	24	450	0
..	..	.011	.015	.007	6.01	161.1	13.5	81.8	38.7	43.1	.15	3	..	0
..	..	.008	.001	.001	2.83	179.5	8.1	128.3	109.4	18.9	.05	205	..	0
..	..	.010	.008	.004	4.59	180.1	16.5	107.9	75.8	32.1	.03	0	..	0
..	..	.013	.018	.001	.01	45.2	32.6	15.2	8.7	6.5	2.57	275	..	0
..	..	.011	.007	.000	.00	39.8	33.6	14.2	9.3	4.9	.01	47	..	0

TABLE 5E.

Richmond.

..	..	.018	.065	.006	2.66	441.5	132.6	177.5	76.0	101.5	.78	37	..	..
..	..	.022	.065	.002	2.66	168.5	11.9	144.6	77.6	67.0	.01	3	..	..
..	..	.023	.025	.002	.83	139.6	6.9	138.5	97.4	41.1	.03	6	..	..
..	..	.042	.035	.006	.78	143.7	7.2	163.0	97.3	65.7	.07	76	..	..
..	..	.015	.006	.002	3.30	236.6	9.4	179.0	143.4	35.6	.03	8	..	..
..	..	.035	.064	.003	.01	209.8	8.5	168.0	134.6	33.4	1.15	55	..	..

TABLE 6A.

BOROUGH OF BROOKLYN—SUMMARY OF ANALYSES BY YEARS—RIDGEWOOD SYSTEM, SURFACE WATERS.

Massapequa Pond.

Year.	Physical Examination.		Chemical Analysis (Parts per Million).														Bacteriological Examination.				Microscopical Examination Number of Standard Units, per c.c.	
			Nitrogen as															B. coli in 1 cc.				
			Albuminoid Ammonia.																			
	Turbidity. (Parts per Million of Silica)	Color. (Parts per Million of Platinum)	In Solution.	In Suspension.	Total.	Free Ammonia	Nitrites	Nitrates.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c. c. 48 hours at 20° C.	Number of Samples Tested.	Number of Positive Tests.	Per Cent. of Positive Tests.	Total Microscopic Organisms.	Amorphous Matter.
1897	..	*46	.091	.008	.099	.004	.000	.25	40.4	13.3	27.5	5.8	12.8	....	.05	....	....	..	....	....	....
1898	..	45	.070	.008	.078	.006	.001	.33	37.7	13.5	24.2	5.5	11.2	....	.13	375	12	0	.0	41	175
1899	..	32	.071	.010	.081	.007	.001	.32	33.9	12.0	21.9	5.5	8.4	....	.08	336	37	1	2.7	72	378
1900	..	31	.062	.017	.079	.006	.001	.25	39.1	....	....	5.2	9.9	5.6	.08	411	50	1	2.0	43	168
1901	1	38	.069	.002	.071	.011	.001	.28	35.6	....	....	5.2	10.6	7.5	.07	550	44	2	4.5	22	318
1902	1	37	.095	.013	.108	.020	.001	.41	42.9	....	....	5.1	12.3	4.2	.06	499	41	4	9.8	58	202
Average....	†1	37	.073	.010	.083	.010	.001	.32	37.8	†12.7	†23.0	5.3	10.5	‡5.8	.08	434	184	8	4.4	47	248

Wantagh Pond.

Year.	Turbidity.	Color.	In Solution.	In Suspension.	Total.	Free Ammonia	Nitrites	Nitrates.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria	Number of Samples Tested.	Number of Positive Tests.	Per Cent. of Positive Tests.	Total Microscopic Organisms.	Amorphous Matter.
1897	..	*22	.082	.004	.086	.006	.000	.45	38.7	11.2	27.5	5.5	14.6	....	.30	....	....	..	....	....	....
1898	..	18	.064	.008	.072	.005	.001	.48	38.8	11.9	26.9	5.0	13.8	....	.27	269	12	2	1.7	38	169
1899	..	15	.057	.006	.063	.005	.001	.46	34.7	11.3	23.4	4.7	8.9	....	.16	342	40	0	0.0	23	333
1900	..	18	.046	.011	.065	.015	.001	.35	41.2	....	....	4.6	11.0	4.9	.20	440	50	1	2.0	126	304
1901	1	17	.053	.009	.062	.006	.000	.33	35.3	....	....	4.4	15.1	4.0	.22	451	51	2	3.9	7	305
1902	2	18	.068	.030	.098	.018	.001	.40	41.2	....	....	4.5	16.6	5.0	.20	422	46	6	13.0	16	175
Average....	†2	17	.057	.015	.072	.010	.001	.40	38.2	†11.5	†25.1	4.6	13.1	‡4.6	.21	385	199	11	5.57	42	257

Newbridge Pond.

1897..............	..	*29	.064	.002	.066	.008	000	.75	47.5	15.2	32.2	6.4	11.5	....	.35	....	....	..	....	....	....
1898..............	..	24	.052	.006	.058	.007	.000	.45	41.7	14.1	27.6	6.2	18.5	....	.22	213	12	0	.0	24	168
1899..............	..	22	.047	.008	.055	.001	.001	.42	38.9	13.0	25.9	6.2	9.2	....	.12	291	40	1	2.5	21	324
1900..............	..	26	.050	.007	.057	.009	.001	.37	49.1	....	....	5.9	9.6	5.1	.14	430	50	2	4.0	6	304
1901..............	1	26	.055	.005	.060	.007	.000	.38	41.4	....	....	5.6	14.7	3.7	.25	463	51	1	1.9	25	298
1902..............	1	27	.075	.008	.083	.009	.001	.44	46.6	....	....	5.7	15.8	4.5	.19	551	45	6	13.3	28	193
Average....	†1	25	.056	.007	.063	.007	.001	.41	43.5	†13.5	†26.7	5.9	12.2	‡4.4	.18	372	198	10	5.00	21	259

East Meadow Pond.

1897..............	..	*29	.060	.003	.063	.005	.003	1.22	38.7	12.5	26.2	6.0	11.9	....	.52	....	....	..	....	....	....
1898..............	..	25	.057	.006	.068	.010	.000	.49	39.7	13.7	26.0	5.5	12.0	..	.58	290	12	0	.0	50	202
1899..............	..	24	.051	.010	.061	.005	.001	.51	36.1	12.9	23.2	5.3	8.8	....	.40	375	39	4	10.3	26	368
1900..............	2	21	.062	.005	.067	.020	.002	.51	43.9	....	....	5.5	13.1	4.6	.36	449	50	2	4.0	30	303
1901..............	2	23	.048	.013	.061	.018	.001	.54	38.6	....	....	5.3	15.2	3.8	.42	501	51	3	5.9	43	481
1902..............	2	23	.060	.008	.058	.025	.001	.52	38.3	....	....	5.2	14.6	4.0	.76	530	45	6	13.3	18	362
Average....	‡2	23	.056	.009	.065	.016	.001	.51	39.3	†13.3	†24.6	5.4	12.7	‡4.1	.50	429	197	15	7.6	33	343

Millburn Pond.

1897..............	..	*20	.062	.007	.069	.018	.001	.79	47.2	16.2	31.0	7.1	15.8	....	.30	....	....	..	....	....	....
1898..............	..	23	.048	.008	.056	.008	.001	.95	52.2	17.4	34.8	6.9	16.8	....	.27	388	12	0	.0	56	194
1899..............	..	16	.039	.005	.044	.005	.002	.96	48.7	16.7	32.0	6.9	15.3	....	.14	347	40	2	5.0	25	375
1900..............	2	16	.045	.003	.048	.007	.002	.83	59.2	....	....	6.8	17.6	6.8	.16	456	50	5	10.0	28	359
1901..............	1	16	.044	.005	.049	.010	.003	.88	47.7	....	....	6.3	19.0	4.5	.22	442	51	6	11.7	18	288
1902..............	2	17	.061	.013	.074	.013	.004	.91	52.2	....	....	6.5	19.6	4.5	.13	455	42	9	21.2	16	270
Average....	‡2	18	.047	.007	.054	.009	.002	.91	52.0	†17.0	†33.4	6.7	17.7	5.3	.18	417	195	22	11.3	28	297

* Average for 3 months. † Average for 2 years. ‡ Average for 3 years.

The results of 1897 were not used in computing the averages as they represented only three months' records

Table 6a—*Continued.*

Millburn Pumping Station.

Year.	Physical Examination: Turbidity (Parts per Million of Silica)	Physical Examination: Color (Parts per Million of Platinum)	Nitrogen as Albuminoid Ammonia, In Solution.	Nitrogen as Albuminoid Ammonia, In Suspension.	Nitrogen as Albuminoid Ammonia, Total.	Nitrogen as Free Ammonia	Nitrogen as Nitrites.	Nitrogen as Nitrates	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c. 48 hours at 20° C.	B. coli in 1 cc.: Number of Samples Tested.	B. coli in 1 cc.: Number of Positive Tests.	B. coli in 1 cc.: Per Cent. of Positive Tests.	Microscopical (Standard Units per c.c.): Total Microscopic Organisms.	Microscopical: Amorphous Matter.
1897	..	..	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	....	....
1898	..	21	.039	.004	.043	.005	.001	.068	44.3	13.3	31.0	6.1	14.7	....	.34	215	7	0	.0	32	180
1899	..	18	.032	.003	.035	.003	.001	.073	41.8	13.9	27.9	5.9	12.0	....	.22	216	40	6	15.0	15	386
1900	2	15	.020	.015	.035	.007	.001	.580	40.2	....	....	5.5	13.1	5.8	.26	244	50	2	4.0	17	359
1901	1	16	.034	.003	.037	.007	.001	.600	41.1	....	....	5.6	17.2	5.5	.21	323	51	2	3.9	17	341
1902	2	18	.048	.002	.050	.009	.001	.620	41.3	....	....	5.3	15.3	5.0	.21	380	48	4	8.3	14	189
Average....	‡2	18	.035	.005	.040	.006	.001	.388	41.7	†13.6	†29.4	5.7	14.5	‡5.4	.25	275	196	14	7.1	19	291

Hempstead Stream, Franklin Street.

Year.	Turbidity	Color	Albuminoid Ammonia, In Solution.	Albuminoid Ammonia, In Suspension.	Albuminoid Ammonia, Total.	Free Ammonia	Nitrites.	Nitrates	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c. 48 hours at 20° C.	Number of Samples Tested.	Number of Positive Tests.	Per Cent. of Positive Tests.	Total Microscopic Organisms.	Amorphous Matter.
1897	..	*14	.190	.028	.218	1.890	.047	4.07	185.5	49.5	135.0	36.4	53.3	....	.62	....	....	..	....	....	....
1898	..	10	.079	.027	.106	.507	.015	2.61	103.7	28.2	75.7	14.8	29.8	....	.57	6,029	34	21	61.9	54	216
1899	..	9	.060	.019	.079	.452	.010	2.52	82.5	24.6	57.9	12.8	26.5	....	.18	1,846	47	17	36.4	20	318
1900	5	11	.087	.013	.100	1.595	.042	3.55	122.9	....	....	21.5	41.2	14.0	.31	4,176	50	13	26.0	36	123
1901	5	9	.085	.018	.103	.878	.029	4.48	92.0	....	....	22.2	38.9	17.0	.25	1,649	51	5	9.8	38	737
1902	4	12	.078	.029	.107	.637	.010	2.77	75.5	....	....	11.5	32.2	9.0	.22	1,359	45	9	20.0	78	510
Average....	‡5	10	.078	.021	.099	.826	.022	3.19	95.3	†26.4	†66.8	16.6	33.7	‡13.3	.31	3,010	227	65	30.0	45	381

Springfield Pond.

1897............	..	*28	.054	.059	.113	.063	.006	2.25	96.3	30.0	66.3	10.4	30.7	....	1.17	....	....	..	....	....	....
1898............	..	25	.071	.023	.094	.041	.009	2.44	99.6	30.7	68.9	11.2	35.3	....	.91	1,187	14	6	18.0	305	513
1899............	..	21	.074	.025	.093	.034	.012	3.08	104.3	36.9	67.4	11.4	35.7	....	.59	1,036	39	7	19.8	220	875
1900............	8	26	.082	.047	.129	.072	.015	2.49	150.3	...	....	10.7	37.3	15.5	1.25	2,927	51	10	0.0	2054	1,021
1901............	5	19	.086	.027	.113	.046	.010	3.18	101.8	....	....	10.4	38.7	14.1	.55	827	30	0	....	359	1,407
1902............	6	25	.091	.032	.136	.046	.016	3.03	107.4	....	....	18.4	31.3	15.3	.77	706	33	7	....	790	733
Average....	‡6	23	.078	.031	.114	.044	.012	2.84	112.7	†33.8	†68.1	12.4	35.9	‡15.0	.81	1,337	167	30	17.0	754	910

Baiseley's Pond.

1897............	..	*39	.183	.426	.609	.030	.004	.84	143.0	58.4	84.6	10.6	45.1	....	1.70	....	....	..	....	....	....
1898............	..	35	.127	.159	.286	.037	.005	1.18	123.0	35.8	87.2	9.7	48.1	....	1.86	1,331	2	1	50.0	4,280	1,280
1899............	..	30	.109	.261	.370	.035	.008	1.61	123.7	38.9	84.8	10.2	46.7	...	1.25	589	27	3	21.2	7,332	870
1900............	27	31	.121	.312	.433	.090	.007	1.39	137.1	....	....	9.7	47.1	29.5	1.23	1,039	51	4	7.9	12,148	15,625
1901............	8	25	.094	.062	.156	.073	.013	2.26	131.2	....	....	10.4	61.0	25.8	1.13	932	43	5	11.6	1,029	5,574
1902............	9	32	.144	.050	.192	.125	.016	1.96	133.5	....	....	9.7	49.2	30.4	.85	1,958	9	1	11.1	1,471	617
Average....	‡15	31	.119	.169	.287	.072	.010	1.68	127.7	†37.3	†36.0	9.9	50.4	‡28.6	1.26	1,170	132	14	10.6	5,252	4,393

* Average for 3 months. † Average for 2 years. ‡ Average for 3 years.
The results for 1897 were not used in computing the averages as they represented only three months' records.

TABLE 6A—*Continued.*

Hempstead Pond.

Year.	Physical Examination. Turbidity. (Parts per Million of Silica)	Physical Examination. Color. (Parts per Million of Platinum)	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. In Solution.	Nitrogen as Albuminoid Ammonia. In Suspension.	Nitrogen as Albuminoid Ammonia. Total.	Nitrogen as Free Ammonia	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c.c. 48 hours at 20° C.	B. coli in 1 cc. Number of Samples Tested.	B. coli in 1 cc. Number of Positive Tests.	B. coli in 1 cc. Per Cent of Positive Tests	Microscopical Examination. Number of Standard Units, per c.c. Total Microscopic Organisms.	Amorphous Matter.
1897	..	*2	.083	.010	.093	.020	.002	.37	41.2	9.5	31.7	6.8	9.0	....	.27	....	....	..	....	...	....
1898	..	12	.053	.006	.059	.030	.002	.25	41.8	9.3	32.5	6.1	15.6	....	.34	224	15	1	6.7	106	251
1899	..	12	.053	.009	.062	.022	.003	.26	41.6	11.5	30.1	6.2	15.3	....	.32	279	43	5	11.6	74	443
1900	3	9	.055	.016	.071	.050	.004	.36	53.6	...	....	6.0	22.5	6.2	.28	713	50	4	8.0	326	1,115
1901	3	7	.056	.003	.059	.054	.002	.27	45.2	....	....	5.9	17.0	6.2	.28	569	51	3	5.9	60	866
1902	2	16	.080	.031	.111	.028	.003	.13	43.1	....	....	5.8	16.3	6.5	.42	453	50	0	.0	26	271
Average	‡3	11	.059	.013	.072	.037	.003	.26	45.1	10.4	†31.3	6.0	17.3	‡6.3	.33	448	209	13	6.2	118	589

Pines Pond.

Year.	Turbidity.	Color.	Albuminoid Ammonia In Solution.	In Suspension.	Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c.	Number of Samples Tested.	Number of Positive Tests.	Per Cent of Positive Tests	Total Microscopic Organisms.	Amorphous Matter.
1897	..	*5	.048	.009	.057	.029	.003	.65	45.2	12.8	32.3	6.1	12.2	....	.23	....	...	..	....	....	....
1898	..	15	.054	.011	.065	.010	.004	.85	48.8	14.4	34.4	6.4	18.6	....	.45	359	15	2	13.3	40	273
1899	..	15	.050	.008	.058	.014	.004	1.09	53.0	17.4	35.6	6.3	18.0	....	.31	443	43	3	7.0	60	489
1900	3	14	.055	.013	.068	.016	.004	.90	55.0	....	....	6.0	25.1	7.9	.39	739	51	0	0.0	198	267
1901	2	14	.049	.012	.061	.021	.003	.94	54.0	....	....	6.2	20.0	6.5	.38	578	51	4	7.8	9	433
1902	4	21	.057	.040	.097	.033	.007	1.09	57.3	....	....	6.3	24.0	7.7	.46	493	45	5	11.1	790	531
Average	‡3	16	.053	.017	.070	.019	.004	.97	53.6	†15.9	†35.0	6.2	21.1	‡7.3	.40	542	205	14	6.9	219	399

TABLE 6B—*Continued.*

Agawam Deep and Shallow Wells.

Year.	Physical Examination: Turbidity (Parts per Million of Silica)	Physical Examination: Color (Parts per Million of Platinum)	Chemical Analysis (Parts per Million): Nitrogen as Albuminoid Ammonia, Total	Nitrogen as Free Ammonia	Nitrogen as Nitrites	Nitrogen as Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteriological Examination: Number of Bacteria per c. c. 48 hrs. at 20° C.	Microscopical Examination (Number of Standard Units per c. c.): Total Microscopic Organisms	Amorphous Matter
1897*	..	0	.006	.000	.000	.15	43.8	10.5	8.3	....	.15	....	....	....
1898	..	0	.006	.000	.000	.04	33.3	5.7	6.7	....	.38	5	0	78
1899	..	0	.008	.000	.000	.17	35.5	5.2	6.7	....	.10	0	0	50
1900	0	3	.026	.007	.000	.19	34.8	5.1	8.0	0.0	.13	4	0	20
1901	1	9	.024	.005	.001	.17	38.8	4.9	10.2	2.0	.33	75	170	388
1902	1	3	.013	.005	.003	.06	30.8	4.3	10.2	2.4	.39	77	133	440
Average.	‖1	3	.015	.003	.001	.13	34.6	5.0	8.4	‖1.4	.27	32	61	195

Watts Pond Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia, Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897†	..	3	.028	.024	.001	1.26	62.9	7.2	22.8	....	.30	....	....	....
1898	..	2	.016	.033	.002	1.86	72.6	7.5	23.6	..	.38	293	16	171
1899	..	3	.011	.019	.001	2.46	68.3	7.4	24.2	....	.25	24	1	74
1900	1	4	.017	.027	.003	2.25	69.3	7.6	28.3	7.5	.64	12	15	56
1901	1	5	.023	.020	.001	2.41	74.4	7.4	31.3	7.8	.76	30	20	92
1902	6	8	.030	.032	004	2.47	85.9	7.8	33.4	9.7	1.15	58	27	240
Average.	‖3	4	.019	.026	.002	2.29	74.1	7.5	28.2	‖8.3	.64	83	16	127

Clear Stream Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia, Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897†	..	1	.019	.017	.001	1.80	69.8	6.8	21.6	....	.28	....	....	....
1898	..	2	.013	.009	.001	1.68	68.3	6.5	25.1	....	.28	30	2	175
1899	..	3	.005	.002	.000	2.22	68.0	6.6	22.9	....	.23	17	1	76
1900	1	2	.012	.006	.001	2.06	68.9	5.9	29.1	7.0	.35	22	0	63
1901	1	2	.011	.004	.000	2.25	70.9	6.4	31.1	7.3	.32	54	3	33
1902	0	1	.012	.005	.002	1.93	74.9	6.3	32.5	7.0	.32	27	0	77
Average.	‖1	2	.011	.005	.001	2.03	70.2	6.3	28.1	‖7.1	.30	30	1	85

Forest Stream Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia, Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897†	..	6	.017	.051	.000	.64	53.3	5.8	21.0	....	1.13	....	....	....
1898	..	7	.011	.031	.001	.34	53.4	5.6	19.8	....	1.49	75	2	228
1899	..	6	.005	.020	.003	.59	56.1	6.1	19.9	....	.87	147	5	162
1900	3	10	.015	.027	.004	.57	60.8	6.0	27.0	8.0	1.37	35	10	100
1901	2	6	.011	.022	.002	.59	58.0	6.1	28.9	9.0	.88	12	13	100
1902	2	8	.016	.026	.004	.63	56.9	6.4	26.3	11.5	1.29	51	8	123
Average.	‖2	7	.012	.025	.003	.54	57.0	6.0	24.4	‖9.5	1.18	64	8	143

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years.

TABLE 6A—*Continued.*

Clear Stream Pond.

Year.	Physical Examination. Turbidity. (Parts per Million of Silica)	Physical Examination. Color. Parts per Million of Platinum)	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. In Solution.	Albuminoid Ammonia. In Suspension.	Albuminoid Ammonia. Total.	Free Ammonia	Nitrites.	Nitrates	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c. c. 48 hours at 20° C.	B. coli in 1 cc. Number of Samples Tested.	B. coli in 1 cc. Number of Positive Tests.	B. coli in 1 cc. Per Cent. of Positive Tests.	Microscopical Examination. Number of Standard Units, per c.c. Total Microscopic Organisms.	Amorphous Matter.
1897	..	*12	.076	.004	.080	.024	.006	2.83	83.5	37.7	46.2	7.5	26.0	....	.15	....	....	..	....	....	....
1898	..	12	.041	.010	.051	.010	.004	3.95	90.9	35.1	55.8	8.2	28.9	....	.20	630	13	1	7.7	85	335
1899	..	12	.045	.009	.054	.009	.009	4.54	89.6	40.3	49.3	9.4	28.0	....	.10	884	39	5	12.8	64	494
1900	5	14	.051	.016	.067	.021	.015	4.60	99.2	....	....	9.3	32.1	12.2	.12	1,585	51	7	13.7	115	341
1901	3	11	.050	.004	.054	.017	.007	5.47	92.1	....	....	9.1	31.1	7.5	.15	716	51	2	3.9	478	741
1902	3	12	.051	.016	.067	.032	.009	5.44	93.1	....	....	8.9	26.2	6.5	.11	701	48	4	8.3	14	594
Average	‡4	12	.047	.011	.058	.018	.009	4.80	93.0	†37.7	†52.4	9.0	29.3	‡8.7	.14	903	202	19	9.4	151	501

Simonson's Pond.

Year.	Turbidity	Color	Alb. Amm. In Solution	Alb. Amm. In Suspension	Alb. Amm. Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Loss on Ignition	Fixed Solids	Chlorine	Hardness	Alkalinity	Iron	Number of Bacteria	Samples Tested	Positive Tests	Per Cent. Positive	Total Microscopic Organisms	Amorphous Matter
1897	..	*7	.047	.001	.048	.007	.006	2.89	86.8	35.5	51.5	8.1	24.7	....	.18	....	....	..	....	....	....
1898	..	9	.038	.008	.046	.011	.008	3.35	88.3	31.2	57.1	8.6	31.4	....	.32	778	15	3	20.0	37	272
1899	..	9	.036	.012	.048	.008	.009	3.95	88.2	36.1	52.1	8.6	28.5	....	.25	1,223	39	7	18.0	37	544
1900	9	10	.036	.018	.054	.024	.019	4.03	90.8	....	....	9.0	29.3	8.1	.24	6,971	51	5	9.8	21	410
1901	4	11	.019	.013	.062	.037	.013	4.38	92.4	....	....	8.9	34.5	8.3	.25	1,029	51	2	3.9	98	544
1902	18	15	.047	.050	.097	.045	.009	5.05	94.6	....	....	8.8	34.9	9.0	.25	854	49	3	6.1	30	366
Average	‡10	11	.041	.020	.061	.025	.012	4.16	90.9	†33.6	†54.6	8.8	31.7	‡8.5	.26	2,171	205	20	9.8	45	427

Table 6B—*Continued.*

Oconee Deep Wells.

Year.	Physical Examination: Turbidity (Parts per Million of Silica).	Physical Examination: Color (Parts per Million of Platinum).	Chemical Analysis (Parts per Million): Nitrogen as Albuminoid Ammonia, Total.	Nitrogen as Free Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination: Number of Bacteria per c. c. 48 hrs. at 20° C.	Microscopical Examination. Number of Standard Units per c. c.: Total Microscopic Organisms.	Amorphous Matter.
1897†	..	4	.013	.395	.000	.08	144.6	4.1	96.4	....	.54	....	....	....
1898	..	8	.011	.256	.000	.00	142.2	4.2	97.6	....	.71	13	0	70
1899	..	9	.008	.245	.000	.00	143.0	4.3	100.9	....	.48	8	0	43
1900	3	4	.029	.263	.001	.00	143.0	4.4	107.7	100.0	.67	8	0	25
1901	1	5	.033	.277	.001	.00	154.1	4.3	108.1	100.2	.50	66	9	57
1902	0	4	.020	.282	.002	.00	145.4	4.2	115.9	103.0	.50	72	0	29
Average.	‖1	6	.020	.265	.001	.00	145.5	4.3	106.0	‖101.1	.57	33	2	45

Shetucket Deep Wells.

1897‡	..	6	.015	.322	.000	.04	139.8	4.2	96.7	....	.62	....	....	....
1898	..	10	.016	.237	.005	.03	188.6	25.7	107.5	....	.90	15	2	110
1899	..	20	.015	.313	.007	.00	534.0	185.0	164.4	....	1.51	47	6	258
1900	11	33	.013	.403	.040	.00	762.4	288.0	243.6	81.0	2.73	20	17	190
1901	9	30	.013	.487	.002	.00	986.9	368.6	324.6	81.3	2.38	120	30	400
1902	11	32	.017	.570	.003	.01	1095.5	433.7	360.0	79.5	2.59	47	37	320
Average.	‖10	25	.015	.402	.012	.01	713.5	264.2	240.0	‖80.6	2.02	50	18	255

Spring Creek, Old Plant, Deep Wells.

1897†	..	6	.006	.005	.000	.43	222.5	12.8	137.0	....	.50	....	....	....
1898	..	16	.004	.006	.000	.02	189.1	8.7	114.5	....	.99	16	11	92
1899	..	16	.004	.003	.000	.07	183.0	5.8	125.1	....	.64	35	0	64
1900	1	3	.007	.006	.001	.10	178.9	6.9	131.3	122.7	.46	31	3	60
Average.	§1	12	.005	.005	.000	.07	183.7	7.1	123.6	§122.7	.70	27	5	71

Spring Creek, Old Plant, Shallow Wells.

1897*	..	0	.018	.000	.000	1.59	696.7	228.0	161.9	....	.10	....	....	....
1898	..	1	.009	.003	.001	2.68	482.1	125.2	151.5	....	.04	120	0	79
1899	..	0	.011	.006	.001	3.35	516.8	136.4	165.3	....	.03	35	0	44
1900	0	0	.013	.030	.005	2.98	524.7	155.7	166.5	89.7	.12	42	0	28
Average.	§0	0	.011	.013	.002	3.00	517.9	139.1	161.1	§89.7	.06	66	0	50

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years.

Table 6b.

BOROUGH OF BROOKLYN—SUMMARY OF ANALYSES—RIDGEWOOD SYSTEM, GROUND WATERS.

Massapequa Deep and Shallow Wells.

Year.	Physical Examination. Turbidity (Parts per Million of Silica)	Physical Examination. Color (Parts per Million of Platinum).	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. Total.	Chemical Analysis. Nitrogen as Free Ammonia.	Chemical Analysis. Nitrogen as Nitrites.	Chemical Analysis. Nitrogen as Nitrates.	Chemical Analysis. Total Solids.	Chemical Analysis. Chlorine.	Chemical Analysis. Hardness.	Chemical Analysis. Alkalinity.	Chemical Analysis. Iron.	Bacteriological Examination. Number of Bacteria per c. c. 48 hrs. at 20° C.	Microscopical Examination. Number of Standard Units per c. c. Total Microscopic Organisms.	Microscopical Examination. Amorphous Matter.
1898	..	1	.036	.016	.000	.40	36.5	5.7	22.1	....	.55	6	4	40
1900	0	3	.022	.019	.000	.08	42.3	5.3	18.7	8.3	.42	12	50	75
1901	1	6	.024	.012	.000	.09	50.3	5.2	27.3	18.0	.46	35	13	60
1902	1	7	.015	.007	.002	.27	46.7	5.0	15.0	8.0	.35	7	0	40
Average.	‖1	4	.024	.013	.000	.21	43.9	5.3	20.8	‡21.4	.45	15	16	54

Wantagh Deep and Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897*	..	6	.005	.004	.000	.23	31.7	4.2	6.6	....	1.08	....	....	....
1898	..	2	.006	.008	.000	.04	25.0	3.8	9.5	....	.70	12	0	50
1899	..	3	.017	.003	.001	.07	28.7	4.0	5.2	....	.37	3	0	35
1900	1	4	.024	.010	.000	.01	24.6	3.7	3.9	1.0	.39	14	0	23
1901	0.5	3	.018	.004	.001	.00	26.0	3.5	6.4	1.0	.50	40	0	30
1902	1	3	.008	.004	.002	.02	26.2	3.3	8.3	3.0	.58	34	17	83
Average.	‖1	3	.015	.006	.001	.03	26.1	3.7	6.7	‖1.7	.51	21	3	44

Matowa Deep and Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897†	..	..	.005	.003	.000	.21	39.0	5.0	7.9	....	.63	....	....	....
1899	..	3	.056	.003	.000	.18	39.5	4.7	8.8	....	.35	5	0	35
1900	1	1	.027	.011	.000	.05	36.0	3.7	7.8	1.3	.48	27	0	13
1901	0.5	2	.028	.012	.000	.07	32.3	3.8	10.6	1.8	.52	7	0	18
1902	0	2	.007	.004	.002	.03	29.9	3.5	10.1	3.3	.43	21	0	33
Average.	‖1	2	.030	.008	.001	.08	34.4	3.9	9.3	‖2.1	.45	15	0	25

Merrick Deep and Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897*	..	0	.009	.001	.000	.50	41.8	6.3	14.3	....	.13	....	....	....
1898	..	0	.013	.003	.000	.57	43.5	6.3	16.5	....	.23	12	0	48
1899	..	0	.008	.002	.000	.42	42.0	5.2	8.0	....	.05	....	....	....
1000	0	1	.014	.005	.000	.41	43.2	5.1	17.3	5.2	.13	15	0	18
1901	3	3	.028	.008	.001	.25	56.8	5.0	25.2	3.8	1.55	50	125	1,269
1902	5	4	.008	.003	.003	.22	44.6	4.9	14.8	6.0	1.38	48	67	357
Average.	‖3	2	.014	.004	.001	.37	46.0	5.3	16.4	‖5.0	.67	§31	48	§423

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years.

TABLE 6B—*Continued.*

Agawam Deep and Shallow Wells.

YEAR.	Physical Examination.		Chemical Analysis (Parts per Million).									Bacteriological Examination.	Microscopical Examination. Number of Standard Units per c. c.	
			Nitrogen as											
	Turbidity (Parts per Million of Silica).	Color (Parts per Million of Platinum).	Albuminoid Ammonia. Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c. c. 48 hrs. at 20° C.	Total Microscopic Organisms.	Amorphous Matter.
1897*	..	0	.006	.000	.000	.15	43.8	10.5	8.3	....	.15	....	....	....
1898	..	0	.006	.000	.000	.04	31.3	5.7	6.7	....	.38	5	0	78
1899	..	0	.008	.000	.000	.17	35.5	5.2	6.7	....	.10	0	0	50
1900	0	3	.026	.007	.000	.19	34.8	5.1	8.0	0.0	.13	4	0	20
1901	1	9	.024	.005	.001	.17	38.8	4.9	10.2	2.0	.33	75	170	388
1902	1	3	.013	.005	.003	.06	30.8	4.3	10.2	2.4	.39	77	133	440
Average.	‖1	3	.015	.003	.001	.13	34.6	5.0	8.4	‖1.4	.27	32	61	195

Watts Pond Shallow Wells.

YEAR.	Turbidity.	Color.	Albuminoid Ammonia.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteria.	Total Microscopic Organisms.	Amorphous Matter.
1897†	..	3	.028	.024	.001	1.26	62.9	7.2	22.8	....	.30	....	....	....
1898	..	2	.016	.033	.002	1.86	72.6	7.5	23.6	..	.38	293	16	171
1899	..	3	.011	.019	.001	2.46	68.3	7.4	24.2	....	.25	24	1	74
1900	1	4	.017	.027	.003	2.25	69.3	7.6	28.3	7.5	.64	12	15	56
1901	1	5	.023	.020	.001	2.41	74.4	7.4	31.3	7.8	.76	30	20	92
1902	6	8	.030	.032	004	2.47	85.9	7.8	33.4	9.7	1.15	58	27	240
Average.	‖3	4	.019	.026	.002	2.29	74.1	7.5	28.2	‖8.3	.64	83	16	127

Clear Stream Shallow Wells.

YEAR.	Turbidity.	Color.	Albuminoid Ammonia.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteria.	Total Microscopic Organisms.	Amorphous Matter.
1897†	..	1	.019	.017	.001	1.80	69.8	6.8	21.6	....	.28	....	....	....
1898	..	2	.013	.009	.001	1.68	68.3	6.5	25.1	....	.28	30	2	175
1899	..	3	.005	.002	.000	2.22	68.0	6.6	22.9	....	.23	17	1	76
1900	1	2	.012	.006	.001	2.06	68.9	5.9	29.1	7.0	.35	22	0	63
1901	1	2	.011	.004	.000	2.25	70.9	6.4	31.1	7.3	.32	54	3	33
1902	0	1	.012	.005	.002	1.93	74.9	6.3	32.5	7.0	.32	27	0	77
Average.	‖1	2	.011	.005	.001	2.03	70.2	6.3	28.1	‖7.1	.30	30	1	85

Forest Stream Shallow Wells.

YEAR.	Turbidity.	Color.	Albuminoid Ammonia.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteria.	Total Microscopic Organisms.	Amorphous Matter.
1897†	..	6	.017	.051	.000	.64	53.3	5.8	21.0	....	1.13	....	....	....
1898	..	7	.011	.031	.001	.34	53.4	5.6	19.8	....	1.49	75	2	228
1899	..	6	.005	.020	.005	.59	56.1	6.1	19.9	....	.87	147	5	162
1900	3	10	.015	.027	.004	.57	60.8	6.0	27.0	8.0	1.37	35	10	100
1901	2	6	.011	.022	.002	.59	58.0	6.1	28.9	9.0	.88	12	13	100
1902	2	8	.016	.026	.004	.63	56.9	6.4	26.3	11.5	1.29	51	8	123
Average.	‖2	7	.012	.025	.003	.54	57.0	6.0	24.1	‖9.5	1.18	64	8	143

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years.

TABLE 6B—*Continued.*

Springfield Deep Wells.

Year.	Physical Examination. Turbidity (Parts per Million of Silica)	Physical Examination. Color (Parts per Million of Platinum).	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia Total.	Nitrogen as Free Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c. c. 48 hrs. at 20° C.	Microscopical Examination. Number of Standard Units per c. c. Total Microscopic Organisms.	Amorphous Matter.
1897†	..	13	.006	.012	.000	.13	47.2	3.6	12.8	....	1.97	....	...	....
1898	..	22	.006	.010	.001	.02	49.7	3.6	12.8	....	3.70	82	9	357
1899	..	25	.004	.005	.000	.01	51.1	4.2	15.0	....	3.62	30	16	168
1900	4	15	.014	.009	.001	.00	50.2	3.8	20.5	4.0	3.89	13	125	288
1901	7	21.7	.007	.006	.000	.00	48.1	3.8	17.0	3.0	2.66	7	388	250
1902	10	19	.008	.007	.001	.02	50.7	3.9	13.2	5.0	3.80	51	13	90
Average.	‖7	21	.008	.007	.001	.01	49.7	3.9	15.7	‖4.0	3.53	37	110	213

Jameco Deep Wells.

1897†	..	5	.014	.550	.000	.57	121.9	6.5	80.2	....	.50	....	....	....
1898	..	7	.012	.329	.001	.01	117.2	5.5	78.4	....	.68	62	276	224
1899	..	6	.010	.348	.001	.00	121.0	5.0	82.2	....	.49	60	1	108
1900	1	9	.014	.355	.001	.01	122.0	4.7	90.1	84.5	.72	36	0	113
1901	1	6	.011	.396	.001	.00	119.8	4.5	93.3	83.3	.65	94	0	45
1902	1	9	.017	.412	.003	.01	85.7	4.5	92.1	86.6	.63	83	6	44
Average.	‖1	7	.013	.368	.001	.01	113.1	4.8	88.2	‖84.8	.63	67	57	107

Jameco Deep and Shallow Wells.

1897†	..	51	.026	.497	.010	.39	188.8	22.8	70.7	....	2.63	....	....	....
1898	..	27	.023	.220	.011	.87	154.1	24.3	67.5	....	3.02	36	28	903
1899	..	29	.014	.246	.006	.65	144.4	26.6	62.6	....	2.53	66	12	366
1900	9	30	.018	.236	.008	.70	135.0	16.1	85.0	49.4	3.55	32	14	137
1901	10	33	.014	.232	.013	.89	158.3	29.4	76.6	46.0	4.73	106	200	723
1902	9	35	.022	.276	.007	.59	139.1	22.1	77.4	49.7	3.00	90	31	538
Average.	‖9	31	.018	.242	.009	.71	146.2	23.7	73.8	‖48.4	3.37	66	57	533

Baiseley's Shallow Wells.

1897†	..	0	.012	.038	.003	1.48	352.2	117.7	119.0	....	.22	....	....	....
1898	..	4	.005	.022	.001	.79	333.5	114.2	109.9	....	.36	18	0	76
1899	..	1	.009	.018	.001	1.87	300.0	97.8	95.3	....	.09	37	0	45
1900	0	1	.011	.022	.003	1.69	378.2	127.6	111.3	26.0	.03	30	0	22
1901	0	0	.007	.024	.003	2.35	377.6	135.0	133.6	26.0	.26	127	0	23
1902	0	1	.009	.041	.006	2.52	313.4	100.0	105.1	27.2	.22	152	0	48
Average.	‖0	2	.008	.025	.003	1.84	340.5	114.9	111.0	‖26.4	.20	73	0	43

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years.

TABLE 6B—*Continued.*

Oconee Deep Wells.

Year.	Physical Examination. Turbidity (Parts per Million of Silica)	Physical Examination. Color (Parts per Million of Platinum).	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. Total	Nitrogen as Free Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c. c. 48 hrs. at 20° C.	Microscopical Examination. Number of Standard Units per c. c. Total Microscopic Organisms.	Amorphous Matter.
1897†	..	4	.013	.395	.000	.08	144.6	4.1	96.4	....	.54	....	....	....
1898	..	8	.011	.258	.000	.00	142.2	4.2	97.6	....	.71	13	0	70
1899	..	9	.008	.245	.000	.00	143.0	4.3	100.9	....	.48	8	0	43
1900	3	4	.029	.263	.001	.00	143.0	4.4	107.7	100.0	.67	8	0	25
1901	1	5	.033	.277	.001	.00	154.1	4.3	108.1	100.2	.50	66	9	57
1902	0	4	.020	.282	.002	.00	145.4	4.2	115.9	103.0	.50	72	0	29
Average.	‖1	6	.020	.265	.001	.00	145.5	4.3	106.0	‖101.1	.57	33	2	45

Shetucket Deep Wells.

Year.	Turbidity	Color	Albuminoid Ammonia, Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897‡	..	6	.015	.322	.000	.04	139.8	4.2	96.7	....	.62	....	....	....
1898	..	10	.016	.237	.005	.03	188.6	25.7	107.5	....	.90	15	2	110
1899	..	20	.015	.313	.007	.00	534.0	185.0	164.4	....	1.51	47	6	258
1900	11	33	.013	.403	.040	.00	762.4	288.0	243.6	81.0	2.73	20	17	190
1901	9	30	.013	.487	.002	.00	986.9	368.6	324.6	81 3	2.38	120	30	400
1902	11	32	.017	.570	.003	.01	1095.5	433.7	360.0	79.5	2.59	47	37	320
Average.	‖10	25	015	.402	.012	.01	713.5	264.2	240 0	‖80.6	2.02	50	18	255

Spring Creek, Old Plant, Deep Wells.

Year.	Turbidity	Color	Albuminoid Ammonia, Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897†	..	6	.006	.005	.000	.43	222.5	12.8	137.0	....	.50	....	....	....
1898	..	16	.004	.006	.000	.02	189.1	8.7	114.5	....	.99	16	11	92
1899	..	16	.004	.003	.000	.07	183.0	5.8	125.1	....	.64	35	0	64
1900	1	3	.007	.006	.001	.10	178.9	6.9	131.3	122.7	.46	31	3	60
Average.	§1	12	.005	.005	.000	.07	133.7	7.1	123.6	§122.7	.70	27	5	71

Spring Creek, Old Plant, Shallow Wells.

Year.	Turbidity	Color	Albuminoid Ammonia, Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Total Microscopic Organisms	Amorphous Matter
1897*	..	0	.018	.000	.000	1.59	696.7	228.0	161.9	....	.10	....	....	....
1898	..	1	.009	.003	.001	2.68	482.1	125.2	151.5	....	.04	120	0	79
1899	..	0	.011	.006	.001	3.35	546.8	136.4	165.3	....	.03	35	0	44
1900	0	0	.013	.030	.005	2.98	524.7	155.7	166.5	89.7	.12	42	0	28
Average.	§0	0	.011	.013	.002	3.00	517.9	139,1	161.1	§89.7	.06	66	0	50

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years.

TABLE 6B—*Continued.*

Spring Creek, New Plant, Shallow Wells.

YEAR.	Physical Examination.		Chemical Analysis (Parts per Million).									Bacteriological Examination.	Microscopical Examination. Number of Standard Units per c. c.	
	Turbidity (Parts per Million of Silica)	Color (Parts per Million of Platinum).	Nitrogen as				Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c. c. 48 hrs. at 20° C.	Total Microscopic Organisms.	Amorphous Matter.
			Albuminoid Ammonia. Total.	Free Ammonia.	Nitrites.	Nitrates.								
1897*	..	1	.009	.002	.002	6.91	245.5	22.0	144.8	....	.09	....	....	....
1898	..	1	.007	.003	.002	3.60	319.6	52.8	129.6	....	.10	109	0	92
1899	..	2	.011	.004	.001	5.32	324.7	57.0	140.8	....	08	17	0	55
1900	0	0	.014	.010	.002	6.28	289.9	35.5	175.8	98.6	.07	18	0	32
1901	0	0	.013	.016	.002	7.33	295.6	37.2	181.6	101.0	.14	42	0	23
1902	0	1	.019	.010	.005	9.83	444.5	103.4	203.1	100.5	.25	30	0	14
Average.	‖0	1	.013	.009	.002	6.47	334.9	57.2	166.2	‡100.0	.13	43	0	43

Spring Creek, Pump No. 1.

1901	0	1	.012	.019	.003	4.05	653.3	203.2	257.5	96.3	.15	36	0	22
1902	0	0	.011	.005	.002	4.35	638.2	192.2	243.3	102.3	.12	82	0	57
Average.	0	1	.012	.012	.003	4.20	645.8	197.7	250.4	99.3	.14	59	0	39

Spring Creek, Pump No. 3.

1901	1	8	.012	.009	.001	1.52	324.4	72.9	189.6	124.0	.54	61	0	39
1902	0	3	.010	.011	.002	1.78	431.7	139.6	203.7	120.0	.25	50	0	28
Average.	1	6	.011	.010	.002	1.65	378.1	106.3	196.7	122.0	.39	76	0	33

* Two months. † Three months. ‡ Four months. § One year. ‖ Three years

TABLE 6c.

BOROUGH OF BROOKLYN—SUMMARY OF ANALYSES BY YEARS—DISTRIBUTION SYSTEM.

Ridgewood Basin 1 *and* 2, *Influx.*

Year.	Physical Examination.		Chemical Analysis (Parts Per Million).												Bacteriological Examination.			Microscopical Examination. Number of Standard Units, Per c.c.		
	Turbidity (Parts Per Million of Silica).	Color (Parts Per Million of Platinum).	Nitrogen As: Albuminoid Ammonia: In Solution.	Nitrogen As: Albuminoid Ammonia: In Suspension	Nitrogen As: Albuminoid Ammonia: Total.	Nitrogen As: Free Ammonia.	Nitrogen As: Nitrites.	Nitrogen As: Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria Per c.c. 48 Hours at 20° C.	In 1 c.c.: Number of Samples Tested.	In 1 c.c.: Number of Positive Tests.	Per Cent. of Positive Tests.	Total Microscopic Organisms.	Amorphous Matter.
1898	....	14	.034	.003	.039	.036	.002	.89	89.7	13.9	35.7	....	.72	253	4	0	0.0	105	428
1899	....	13	.034	.007	.041	.025	.002	1.18	96.2	18.3	35.4	25.6	.48	282	201	12	5.9	97	282
1900	5	12	.038	.009	.047	.030	.003	1.18	107.2	20.7	39.6	23.0	.62	545	291	13	4.5	114	625
1901	3	13	.034	.006	.040	.031	.003	1.22	111.0	23.2	41.1	21.7	.53	453	269	7	2.6	55	459
1902	3	14	.045	.010	.055	.024	.003	1.23	107.0	22.1	38.9	18.4	.49	341	273	27	9.9	51	353
Average	†4	13	.037	.007	.044	.029	.003	1.14	102.2	19.6	38.1	*22.2	.58	375	1,041	59	5.7	144	429

Ridgewood Basin 3, *Influx.*

Year.	Turbidity	Color	In Solution	In Suspension	Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Number of Bacteria	Number of Samples Tested	Number of Positive Tests	Per Cent. of Positive Tests	Total Microscopic Organisms	Amorphous Matter
1898	....	15	.037	.005	.042	.024	.002	.81	76.8	12.3	31.9	....	.54	237	4	0	0	102	337
1899	....	13	.033	.007	.040	.017	.022	1.03	82.3	15.9	31.0	16.8	.36	267	204	6	2.9	76	468
1900	4	13	.040	.005	.045	.017	.002	1.00	81.8	14.6	32.7	15.7	.43	398	266	12	4.2	251	570
1901	2	12	.033	.007	.040	.018	.002	1.03	83.5	17.2	34.9	14.7	.46	371	267	12	4.5	55	506
1902	3	14	.049	.010	.059	.021	.003	1.12	91.1	18.3	35.5	15.4	.44	327	269	25	9.3	74	438
Average	†3	13	.038	.007	.045	.019	.002	1.00	83.1	15.7	33.2	*15.6	.45	320	1,030	55	5.3	112	464

† Average for 3 years. * Average for 4 years.

TABLE 6c—*Continued.*

Ridgewood Basin 1, Efflux.

Year.	Physical Examination.		Chemical Analysis (Parts Per Million).												Bacteriological Examination.			Microscopical Examination. Number of Standard Units, Per c. c.		
			Nitrogen As													In 1 c. c.				
			Albuminoid Ammonia.																	
	Turbidity (Parts Per Million of Silica).	Color (Parts Per Million of Platinum).	In Solution.	In Suspension	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria Per c. c. 48 Hours at 20° C	Number of Samples Tested.	Number of Positive Tests.	Per Cent. of Positive Tests.	Total. Microscopic Organisms.	Amorphous Matter.
1898	....	13	.043	.022	.065	.021	.003	.79	91.9	15.0	37.0	....	.45	246	....	....	....	3,433	346
1899	....	11	.042	.038	.080	.014	.005	1.02	103.9	20.7	38.5	23.7	.32	284	46	3	6.5	4,782	611
1900	5	13	.048	.016	.064	.016	.003	1.17	112.3	22.8	41.2	24.0	.45	579	54	1	1.9	1,426	550
1901	2	11	.042	.013	.055	.022	.005	1.18	110.8	25.1	41.2	21.7	.36	459	52	2	3.8	608	521
1902	3	14	.051	.012	.063	.017	.005	1.22	111.6	23.6	39.6	17.6	.34	329	49	5	10.2	238	369
Average	†3	12	.045	.021	.066	.018	.004	1.08	106.1	21.4	39.5	*21.7	.38	379	201	*11	5.5%	2,097	479

Ridgewood Basin 2, Efflux.

Year.	Turbidity	Color	In Solution	In Suspension	Total	Free Ammonia	Nitrites	Nitrates	Total Solids	Chlorine	Hardness	Alkalinity	Iron	Bacteria	Samples Tested	Positive Tests	Per Cent.	Total Microscopic Organisms	Amorphous Matter
1898	....	14	.093	.057	.150	.033	.004	.62	88.9	12.9	35.2	....	.37	271	....	....	....	3,669	328
1899	....	12	.036	.018	.054	.014	.003	1.13	102.8	20.5	36.8	22.7	.33	336	46	8	17.4	1,115	533
1900	5	13	.049	.020	.069	.017	.003	1.17	108.7	22.7	40.3	23.5	.41	621	54	1	1.8	1,387	581
1901	2	12	.041	.016	.057	.016	.003	1.24	113.9	24.9	41.8	22.3	.40	421	52	3	5.7	740	590
1902	3	14	.056	.018	.074	.018	.004	1.20	110.5	23.4	39.4	17.8	.33	344	47	6	12.8	1,261	437
Average	†3	13	.055	.026	.061	.019	.003	1.07	104.9	20.9	38.7	*21.6	.37	399	199	*18	9%	1,634	494

Ridgewood Basin 3, Efflux.

898	....	15	.039	.016	.055	.010	.002	.76	80.7	13.2	32.3	....	.41	241	....	....	....	1,823	364
899	....	11	.038	.020	.058	.014	.005	.93	88.6	18.4	32.9	20.1	.26	275	46	3	6.5	1,872	508
900	6	14	.058	.025	.083	.010	.003	.95	92.4	17.5	34.9	20.0	.36	349	50	3	6.0	3,372	608
901	2	13	.041	.015	.055	.009	.003	1.04	80.1	18.5	36.1	16.0	.34	430	52	1	1.9	790	492
902	3	14	.056	.019	.076	.017	.004	1.10	97.8	20.5	36.7	16.8	.29	348	51	2	3.9	1,915	397
Average	†4	14	.046	.019	.065	.012	.003	.096	89.9	17.6	34.6	*18.2	.33	379	199	*9	4.5%	1,954	654

Mt. Prospect Reservoir.

1898	....	10	.101	.048	.149	.013	.007	.52	86.5	13.8	34.4	....	.24	113	....	....	....	8,188	481
1899	....	11	.060	.041	.101	.012	.007	.88	96.5	19.0	34.2	26.5	.17	196	44	0	0	8,891	602
1900	6	12	.063	.037	.100	.009	.007	.90	103.8	20.8	37.8	21.7	.26	199	54	3	5.6	6,536	615
1901	4	12	.084	.046	.130	.016	.007	.91	105.2	22.6	38.6	20.0	.23	279	53	0	0.0	3,891	554
1902	5	14	.009	.052	.101	.013	.015	.91	103.4	22.4	36.8	17.0	.21	255	56	0	0.0	2,935	830
Average	†5	12	.063	.045	.128	.013	.009	.82	99.1	19.7	36.4	*21.3	.22	208	207	*3	1.1%	6,088	616

Tap in Laboratory.

1898	....	12	.038	.012	.050	.005	.001	.80	90.8	14.7	36.6	....	.64	150	....	....	....	1,173	477
1899	....	13	.030	.016	.046	.005	.001	1.07	95.8	19.1	36.3	19.5	.36	235	83	0	0	859	574
1900	4	14	.046	.010	.056	.004	.002	1.03	103.1	21.0	41.1	21.4	.37	433	279	12	4.3	1,330	477
1901	2	13	.039	.004	.043	.005	.003	1.21	103.9	22.5	40.3	20.3	.31	370	284	11	3.8	461	514
1902	4	14	.044	.011	.055	.005	.002	1.30	106.2	21.9	38.8	17.3	.36	269	283	16	5.7	426	384
Average	†3	13	.039	.011	.050	.005	.002	1.08	99.9	19.8	38.6	*19.6	.41	291	929	*39	4.2%	850	485

† Average for 3 years. * Average for 4 years.

Table 6c—*Continued.*

Tap at Flushing and Clermont Avenues.

Year.	Physical Examination. Turbidity (Parts Per Million of Silica).	Physical Examination. Color Parts Per Million of Platinum).	Chemical Analysis (Parts Per Million). Nitrogen As Albuminoid Ammonia. In Solution.	Albuminoid Ammonia. In Suspension	Albuminoid Ammonia. Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine,	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria Per c. c. 48 Hours at 20° C.	In 1 c.c. Number of Samples Tested	In 1 c.c. Number of Positive Tests.	Microscopical Examination. Number of Standard Units, Per c.c. Per Cent. of Positive Tests	Total Microscopic Organisms.	Amorphous Matter.
1898	....	13	.040	.010	.050	.005	.001	.78	85.0	13.6	34.5	....	.52	179	....	....	....	1,266	382
1899	....	13	.027	.015	.042	.003	.001	1.05	88.7	17.9	32.4	20.1	.30	242	41	0	0	863	490
1900	4	13	.061	.010	.071	.005	.002	1.02	103.8	19.1	35.7	18.4	.38	515	50	2	4.0	1,337	519
1901	2	13	.037	.013	.050	.009	.003	1.15	96.5	21.8	37.6	16,5	.38	361	52	1	1.9	328	513
1902	4	15	.040	.005	.058	.005	.001	1.18	98.6	20.9	37.7	17.4	.27	287	53	5	9.4	449	341
Average	†3	13	.041	.011	.054	.005	.002	1.04	94.5	18.7	35.6	*18.1	.37	317	196	*8	5.1%	848	449

Tap at Flatbush and Seventh Avenues.

Year.	Turbidity	Color	In Solution.	In Suspension	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine,	Hardness.	Alkalinity.	Iron.	Number of Bacteria	Number of Samples Tested	Number of Positive Tests.	Per Cent. of Positive Tests	Total Microscopic Organisms.	Amorphous Matter.
1898	....	12	.050	.029	.079	.010	.003	.75	85.1	14.1	35.0	....	.57	235	....	....	....	3,571	578
1899	....	13	.032	.019	.051	.003	.002	1.05	94.3	19.1	35.0	20.5	.89	287	41	0	0	1,786	490
1900	4	13	.060	.005	.065	.006	.003	.99	98.6	21.1	40.1	20.6	.31	352	50	0	0	3,614	563
1901	2	12	.048	.030	.056	.005	.003	1.06	102.5	22.7	38.4	20.0	.34	414	52	1	1.9	1,713	667
1902	4	14	.061	.012	.074	.006	.003	1.16	107.3	22.6	37.4	16.5	.35	282	55	1	1.8	1,125	458
Average	†3	13	.060	.021	.065	.006	.003	1.00	97.5	19.9	37.2	*19.4	.37	314	198	*2	1.8	2,362	551

† Average for 3 years

* Average for 4 years.

TABLE 7.

BOROUGH OF BROOKLYN—SUMMARY OF ANALYSES BY YEARS—INDEPENDENT WATER SUPPLY SYSTEMS.

New Lots Pumping Station.

Year.	Physical Examination		Chemical Analysis (Parts per Million).									Bacteriological Examination	Microscopical Examination. Number of Standard Units per c.c.	
	Turbidity (Parts per Million of Silica)	Color (Parts per Million of Platinum.	Nitrogen as Albuminoid Ammonia Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c. 48 hours at 20°C	Total Microscopic Organisms.	Amorphous Matter.
1898	..	0	.008	.000	.002	6.40	305.0	20.0	124.1	....	.00	35	..	..
1809	..	2	.010	.000	.001	10.40	284.3	22.3	140.8	102.1	.01	137	..	..
1900	..	4	.026	.004	.001	10.40	313.0	20.0	191.4	101.0	.00	110	..	..
1901	..	0	.009	.002	.007	9.36	296.8	21.4	181.7	103.3	.12	....	..	..
1902	..	1	.012	.002	.008	14.18	283.5	22.1	191.9	104.0	.06	263	..	24
Average	..	1	.012	.002	.004	10.15	296.5	21.2	167.8	*102.6	.04	*136	..	*24

German-American Water Co.

Year.	Turbidity	Color	Albuminoid Ammonia Total	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria	Total Microscopic Organisms.	Amorphous Matter.
1897	..	..	....	....	....	....	....	....	....	....	....	....	..	..
1898	..	0	.002	.000	.001	6.80	336.0	27.0	165.9	....	.05	45	..	200
1899	..	3	.008	.002	.000	7.70	312.8	29.3	172.3	....	.00	76	..	40
1900	..	3	.013	.005	.001	8.80	296.6	28.2	156.1	101.0	.03	....	..	18
1901	..	0	.009	.007	.003	8.80	286.0	24.9	189.5	107.8	.03	....	..	15
1902	..	1	.016	.023	.012	10.20	307.3	26.3	186.3	100.3	.05	....	..	18
Average	..	1	.010	.007	.003	8.46	307.7	27.1	174.0	‡103.0	.03	60	..	58

Flatbush Water Works.

Year.	Turbidity	Color	Albuminoid Ammonia Total	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria	Total Microscopic Organisms.	Amorphous Matter.
1897†	..	2	.006	.002	.001	4.16	160.0	12.2	95.7	....	.20	....	..	..
1898	..	2	.011	.002	.001	3.41	179.5	12.5	95.7	....	.05	1	..	93
1899	..	0	.008	.002	.000	4.80	175.6	12.9	99.6	....	.01	129	..	16
1900	..	2	.011	.004	.002	6.65	183.0	13.0	109.9	58.0	.03	60	..	18
1901	..	1	.007	.002	.002	5.80	177.5	13.0	109.9	61.5	.03	12	..	20
1902	..	2	.013	.002	.002	6.72	190.6	14.1	112.0	60.4	.02	....	..	15
Average	..	1	.010	.002	.001	5.48	181.3	13.1	105.4	‡60.0	.02	50	..	32

* Average for 4 years. † 1 month only. ‡ Average for 3 years.

TABLE 7—*Continued.*

Year.	Physical Examination: Turbidity (Parts per Million of Silica)	Physical Examination: Color (Parts per Million of Platinum)	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia Total.	Nitrogen as Free Ammonia	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Total Solids	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination: Number of Bacteria per c.c. 48 hours at 20°C	Microscopical Examination. Number of Standard Units per c.c.: Total Microscopic Organisms.	Amorphous Matter.
Gravesend Pumping Station.														
1897†........	..	1	.004	.001	.000	3.00	155.6	12.9	87.1	....	.10	....	..	..
1898........	..	1	.007	.003	.001	3.44	151.2	12.8	91.1	....	.08	256	..	86
1899........	..	1	.006	.001	.001	3.68	150.0	12.7	91.6	....	.02	12	..	68
1900........	0	0	.012	.002	.001	3.98	157.5	13.3	100.8	54.1	.05	49	..	13
1901........	0	0	.008	.001	.001	4.63	151.8	13.5	88.3	56.0	.06	40	..	18
1902........	0	0	.007	.001	.002	4.50	156.1	13.4	94.2	62.2	.01	7	..	18
Average...	..	..	.008	.002	.001	4.05	153.3	13.1	93.2	‡57.4	.04	81	..	43
New Utrecht Pumping Station.														
1897†........	..	1	.008	.001	.000	2.88	169.0	23.6	91.8	....	.05	....	..	..
1898........	..	1	.006	.024	.000	2.48	155.5	21.1	90.1	....	.05	131	..	81
1899........	..	..	.007	.000	.001	3.24	143.7	21.2	87.5	....	.00	73	..	54
1900........	0	0	.010	.006	.001	2.84	254.0	67.4	135.9	54.0	.10	27	..	32
1901........	0	1	.005	.000	.002	2.88	308.0	123.0	185.6	56.7	.10	49	..	28
1902........	0	0	.011	.000	.002	4.13	324.2	88.0	144.2	74.7	.03	132	..	22
Average..	..	..	.008	.004	.001	3.11	255.1	64.1	128.7	‡61.8	.06	82	..	43
Blythebourne Water Co.														
1898........	..	0	.004	.000	.000	5.60	164.5	8.0	75.7	....	.00	....	..	..
1899........	..	1	.006	.001	.000	5.00	166.3	8.9	80.1	....	.10	4	..	50
1900........	..	0	.029	.002	.007	5.87	168.5	8.6	91.2	58.3	.02	98	..	26
1901........	..	0	.007	.001	.001	5.10	153.2	7.6	92.1	65.5	.05	....	4	30
1902........	..	0	.010	....	.003	5.25	161.6	7.4	126.3	67.0	.01	....	2	30
Average..	..	..	.011	.001	.002	5.36	162.8	8.1	93.1	‡63.6	.04	*51	3	*34
Pfalzgraf Water Co.														
1898†........	..	2	.022	.010	.004	7.00	310.5	16.8	72.9	....	.75	....	..	..
1899........	..	1	.013	.004	.001	7.65	230.4	17.9	167.8	....	.13	130	..	29
1900........	..	0	.022	.001	.003	9.75	246.9	12.8	183.0	102.0	.08	....	..	..
1901........	..	2	.010	.000	.007	7.80	250.5	14.8	196.4	102.0	.13	102	..	22
1902........	..	1	.028	.001	.604	9.60	270.6	14.3	192.0	100.5	.16	104	..	23
Average..	..	1	.019	.003	.004	8.36	261.8	15.3	162.4	‡101.5	.25	‡112	..	‡25

* Average for 4 years. 1 month only. ‡ Average for 3 years.

TABLE 8.

SUMMARY OF ANALYSES BY YEARS—BOROUGH OF QUEENS.

Year.	Physical Examination.		Chemical Analysis (Parts Per Million).									Bacteriological Examination.	Microscopical Examination. Number of Standard Units per c. c.	
	Turbidity. (Parts per Million of Silica.)	Color. (Parts per Million of Platinum.)	Nitrogen As				Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c. c. 48 Hours at 20° C.	Total Microscopic Organisms.	Amorphous Matter.
			Albuminoid Ammonia. Total.	Free Ammonia.	Nitrites.	Nitrates.								
Long Island City Water Supply, Station No. 1.														
1898....	....	1	.010	.006	.000	1.90	386.0	105.0	203.3	....	.03	83	0	50
1899....	....	1	.008	.001	.000	4.40	304.4	73.0	150.5	....	.05	768	0	58
1900....	....	1	.015	.034	.002	3.20	335.8	62.0	166.0	85.0	.04	850	0	47
1901....	....	1	.018	.003	.002	3.70	366.8	71.0	196.8	104.2	.08	25	0	15
1902....	....	0	.023	.005	.005	4.00	344.2	56.0	184.0	85.4	.09	673	0	14
Average.	....	1	.015	.004	.002	3.44	359.4	73.4	181.9	†91.5	.06	480	0	37
Long Island City Water Supply, Station No. 2.														
1898....	....	3	.015	.006	.000	.50	1780.0	725.0	325.1	....	.08	613	0	110
1899....	....	2	.010	.001	.001	4.60	412.5	26.5	215.4	....	.05	1,485	0	38
1900....	....	1	.020	.005	.001	4.55	732.1	212.4	282.9	124.3	.05	4,600	0	30
1901....	....	1	.017	.010	.001	3.65	1862.5	726.0	676.5	153.5	.05	....	....	....
1902....	....	0	.017	.002	.001	3.48	1822.9	716.8	591.0	157.8	.01	....	....	....
Average.	....	1	.016	.005	.001	3.36	1322.1	481.3	418.2	†145.2	.05	†2,233	0	†59
Long Island City Water Supply, Station No. 3.														
1898....	....	3	.015	.001	.000	3.60	300.5	15.3	145.7	....	.03	4	0	75
1899....	....	3	.019	.001	.000	3.28	291.5	15.0	172.3	....	.06	75	1	55
1900....	....	2	.025	.001	.001	3.65	300.6	16.7	204.4	124.0	.05	250	0	30
1901....	....	4	.017	.000	.001	4.40	312.3	14.9	240.9	142.0	.26	0	0	20
1902....	....	1	.032	.003	.000	4.60	325.8	14.5	235.5	138.8	.00	1,800	0	38
Average.	....	2	.022	.001	.000	3.91	3c6.1	15.3	199.8	†134.9	.08	626	0	44
Citizens' Water Company, Station No. 1.														
1898....	....	1	.016	.006	.000	6.00	339.5	6.4	227.0	....	.10	400	0	100
1899....	....	0	.015	.003	.003	7.00	319.8	14.1	212.5	....	.00	28	0	38
1900....	....	0	.023	.005	.003	8.80	305.5	12.3	172 7	147.5	.03	23	0	20
1901....	....	1	.010	.002	.001	11.10	335.0	13.0	204.6	141.8	.00	....	10	25
1902....	....	0	.016	.000	.001	10.90	311.8	13:2	213.5	136.8	.00	....	....	....
Average.	....	0	.015	.003	.002	8.76	322.2	11.8	206.1	†142.0	.03	†180	‡3	‡46

† Average for 3 years. ‡ Average for 4 years.

TABLE 8—*Continued.*

Citizens' Water Company, Station No. 2.

Year.	Physical Examination. Turbidity (Parts per Million of Silica.)	Color. (Parts per Million of Platinum.)	Chemical Analysis (Parts Per Million). Nitrogen As Albuminoid Ammonia, Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c.c. 48 Hours at 20° C.	Microscopical Examination. Number of Standard Units per c. c. Total Microscopic Organisms.	Amorphous Matter.
1898.	....	0	.008	.010	.022	5.60	217.5	10.6	154.8	....	.10	405	0	40
1899.	....	1	.008	.003	.027	4.85	251.6	14.0	148.8	....	.00	37	1	58
1890.	....	0	.016	.006	.021	6.40	265.9	13.6	169.5	99.5	.04	830	0	34
1901.	....	0	.008	.003	.052	8.20	305.6	15.9	207.1	113.5	.00	....	0	25
1902.	....	1	.020	.006	.054	9.76	349.2	14.0	207.8	114.8	.01	....	....	....
Average.	....	0	.012	.006	.035	6.96	277.9	13.6	177.6	†109.3	.03	†424	0	‡39

Citizens' Water Company, Station No. 3.

Year.	Turbidity	Color.	Albuminoid Ammonia, Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteria	Total Microscopic Organisms.	Amorphous Matter.
1899.	....	.000	.006	.003	.011	.78	140.5	6.4	97.0	....	.12	....	....	....
1900.	....	.000	.010	.005	.006	.74	159.0	7.5	112.8	97.3	.13	190	0	30
1901.	....	.001	.005	.004	.008	.91	153.8	8.5	116.6	92.3	.04	....	0	28
1902.	....	.001	.010	.005	.007	1.19	148.1	7.9	103.6	88.8	.02	....	....	....
Average.	....	1	.008	.004	.008	.91	150.3	7.6	107.5	†92.8	.08	*190	**0	**29

Citizens' Water Company, Station No. 4.

Year.	Turbidity	Color.	Albuminoid Ammonia, Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteria	Total Microscopic Organisms.	Amorphous Matter.
1900.	0	....	.003	.000	.002	5.70	199.3	9.7	128.8	104.5	.08	0	0	20
1901.	0	....	.003	.000	.001	5.87	190.2	8.6	137.8	95.7	.07	0	0	47
1902.	0	....	.010	.002	.003	5.78	187.1	8.8	124.6	91.8	.01	....	....	....
Average.	0	....	.005	.001	.002	5.78	192.2	9.0	130.4	97.3	.05	**0	**0	**34

Citizens' Water Company, Station No. 5.

Year.	Turbidity	Color.	Albuminoid Ammonia, Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteria	Total Microscopic Organisms.	Amorphous Matter.
1901.	0	0	.009	.001	.001	5.20	103.8	6.9	134.5	96.5	.00	....	....	....
1902.	....	0	.006	.000	.003	6.50	197.0	8.2	114.0	95.0	.00	....	0	35
Average.	0	0	.008	.001	.002	5.85	195.4	7.6	124.3	95.8	.00	....	*0	*35

* 1 year only.
† Average for 3 years.
** Average for 2 years.
‡ Average for 4 years.

TABLE 8—*Continued.*

Flushing Water Works.

Year.	Physical Examination. Turbidity. (Parts per Million of Silica.)	Physical Examination. Color. (Parts per Million of Platinum.)	Chemical Analysis (Parts Per Million). Nitrogen As Albuminoid Ammonia. Total.	Nitrogen As Free Ammonia	Nitrogen As Nitrites.	Nitrogen As Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c.c. 48 Hours at 20° C.	Microscopical Examination. Number of Standard Units per c. c. Total Microscopic Organisms.	Amorphous Matter.
1898.	....	3	.018	.004	.006	2.20	87.5	6.6	58.6	....	.55	96	24	100
1899.	....	1	.021	.001	.011	2.65	90.3	6.2	46.6	....	.01	150	39	69
1900.	....	4	.034	.014	.007	2.90	98.9	7.3	50.8	35.0	.08	600	79	78
1901.	....	8	.048	.010	.005	3.90	100.3	6.9	51.8	29.8	.13	....	83	40
1902.	....	9	.044	.012	.020	3.23	103.2	7.0	51.9	29.8	.11	442	13	29
Average.	....	5	.033	.008	.010	2.98	96.0	6.8	51.9	†31.5	.18	‡322	48	63
Whitestone Water Works, Station No. 1.														
1898.	....	0	.000	.000	.001	2.40	191.5	9.4	140.6	....	.00	2	0	80
1899.	....	1	.008	.001	.001	3.85	200.6	10.9	127.0	....	.00	140	1	48
1900.	....	3	.008	.000	.001	4.52	210.0	11.8	138.1	105.0	.05	109	1	31
1901.	....	1	.009	.000	.001	4.30	212.3	11.2	140.6	111.3	.04	....	0	33
1902.	....	0	.012	.000	.000	5.60	214.0	11.2	147.5	105.7	.07	192	9	60
Average.	....	1	.007	.000	.001	4.23	205.7	10.9	140.0	†107.3	.03	‡111	2	50
Bayside Water Works.														
1898.	....	3	.008	.004	.000	2.40	87.0	6.8	52.9	....	.15	18	5	70
1899.	....	2	.021	.002	.002	2.40	91.1	6.0	42.6	...	.06	800	5	31
1900.	....	1	.012	.001	.001	2.48	90.5	7.3	51.3	32.7	.08	230	10	28
1901.	....	5	.020	.004	.005	2.70	95.5	5.6	51.6	37.8	.13	....	4	40
1902.	....	4	.030	.009	.007	2.95	99.5	6.0	47.4	35.0	.12	298	98	535
Average.	....	3	.018	.004	.003	2.59	92.8	6.3	49.2	†35.2	.11	‡364	24	141
Jamaica Water Supply Company.														
1898.	....	0	.008	.014	.014	4.80	146.0	12.8	67.1	....	.15	135	14	150
1899.	....	0	.007	.019	.007	4.65	156.3	12.4	79.0	....	.08	16	0	64
1900.	....	3	.012	.022	.006	6.80	158.6	12.7	81.4	39.3	.19	77	0	20
1901.	....	4	.013	.011	.003	6.40	168.6	13.9	93.4	35.0	.25	11	0	38
1902.	....	1	.017	.009	.003	7.40	176.1	15.7	88.0	41.8	.09	447	0	7
Average.	....	2	.011	.015	.007	6.01	161.1	13.5	81.8	†38.7	.15	137	3	56

† Average for 3 years. ‡ Average for 4 years.

TABLE 8—*Continued.*

Woodhaven Water Supply Company.

Year.	Physical Examination: Turbidity. (Parts per Million of Silica.)	Physical Examination: Color. (Parts per Million of Platinum.)	Chemical Analysis (Parts Per Million). Nitrogen As: Albuminoid Ammonia. Total.	Nitrogen As: Free Ammonia	Nitrogen As: Nitrites.	Nitrogen As: Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Bacteriological Examination. Number of Bacteria per c.c. 48 Hours at 20° C.	Microscopical Examination. Number of Standard Units per c. c. Total Microscopic Organisms.	Amorphous Matter.
1898.	....	0	.006	.000	.000	1.40	175.5	5.4	107.5	....	.10	6	1,020	125
1899.	....	0	.006	.002	.000	1.73	179.5	9.2	128.8	....	.00	37	0	28
1900.	....	0	.007	.001	.002	2.45	181.9	8.3	132.5	108.0	.03	18	3	37
1901.	....	0	.009	.010	.001	2.40	180.5	8.4	131.4	108.5	.03	....	0	20
1902.	....	1	.014	.001	.001	2.49	181.5	9.1	131.4	111.8	.10	329	2	17
Average.	....	0	.008	.001	.001	2.09	179.8	8.1	125.3	†109.4	.05	‡ 98	205	45

Montauk Water Supply Company.

Year.	Turbidity.	Color.	Albuminoid Ammonia. Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c.	Total Microscopic Organisms.	Amorphous Matter.
1898.	....	0	.012	.000	.000	3.20	155.5	13.6	81.4	....	.00	15	0	25
1899.	....	0	.007	.002	.000	3.55	171.0	15.6	96.5	....	.01	20	0	50
1900.	....	0	.008	.005	.001	5.40	182.5	15.8	111.6	71.0	.05	119	0	18
1901.	....	0	.012	.018	.016	5.20	186.6	17.7	131.1	80.5	.05	179	0	25
1902.	....	0	.012	.014	.004	5.60	204.9	19.9	119.0	76.0	.03	23	0	20
Average.	....	0	.010	.008	.004	4.59	180.1	16.5	107.9	† 75.8	.03	69	0	28

Queens County Water Supply, Far Rockaway—Unfiltered.

Year.	Turbidity.	Color.	Albuminoid Ammonia. Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c.	Total Microscopic Organisms.	Amorphous Matter.
1898.	....	6	.002	.024	.000	.02	46.0	3.20	....	....	4.50	....	....	....
1899.	....	10	.004	.014	.001	.02	37.5	3.70	16.5	....	1.05	....	....	....
1900.	....	4	.017	.026	.000	.01	44.4	3.20	13.1	10.0	1.85	....	....	....
1901.	....	4	.005	.013	.000	.01	50.1	3.15	15.9	7.2	2.73	....	....	....
1902.	....	7	.035	.013	.002	.00	48.1	3.04	15.5	9.0	1.83	....	....	....
Average.	....	6	.013	.018	.001	.01	45.2	3.24	‡15.2	†8.7	2.57	....	....	....

Queens County Water Supply, Far Rockaway—Filtered.

Year.	Turbidity.	Color.	Albuminoid Ammonia. Total.	Free Ammonia	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Number of Bacteria per c.c.	Total Microscopic Organisms.	Amorphous Matter.
1898.	....	2	.016	.006	.000	.00	41.5	3.40	....	....	.00	....	....	....
1899.	....	0	.004	.001	.000	.00	34.0	3.80	12.0	...	.00	....	....	....
1900.	....	2	.020	.026	.000	.00	38.1	3.40	15.8	11.0	.04	....	....	....
1901.	....	0	.009	.000	.000	.00	41.3	3.15	15.2	8.6	.00	....	....	....
1902.	....	0	.007	.001	.002	.00	44.1	3.04	13.0	8.3	.00	....	....	....
Average.	....	1	.011	.007	.000	.00	39.8	3.36	‡14.0	†9.3	.01	....	....	....

† Average for 3 years. ‡ Average for 4 years.

18
18
19
19
19

Av

189
189
190
190
190

Av

1891
1899
1900
1901
1902

Ave

1898
1899
1900
1901
1902

Ave

TABLE 10A.

Average Temperature of the Ground Waters of the Ridgewood System, Brooklyn.

Well Station.	1897.	1898.	1899.	1900.	1901.	1902.
Deep Wells—						
Springfield	61.4	62.4	60.0	60.2	59.5	59.1
Jameco	55.2	55.8	56.2	56.7	55.0	54.0
Oconee	54.7	54.8	54.7	55.6	55.3	54.2
Shetucket	54.5	54.5	54.7	55.5	53.9	54.0
Deep and Shallow Wells--						
Massapequa	....	....	....	52.0	51.3	53.5
Wantagh	52.3	....	53.6	53.5	52.4	52.5
Matowa	55.1	....	55.0	53.1	52.5	52.0
Merrick	54.0	....	52.0	51.8	52.0	51.6
Agawan	54.5	....	52.5	53.1	53.2	51.7
Jameco	54.8	....	55.0	56.2	52.7	54.1
Spring Creek, Old Plant No. 1	52.8	53.1	53.0	53.1	51.1	54.1
Spring Creek, Old Plant No. 3	54.1	54.7	53.9	54.4	53.6	53.5
Shallow Wells—						
Watt's Pond	52.0	56.1	54.9	54.5	53.5	53.7
Clear Stream	57.5	54.2	52.5	53.0	54.8	52.7
Forest Stream	57.0	55.0	54.1	55.0	55.0	54.2
Baiseley's	53.2	53.4	53.2	53.0	52.7	53.5
Spring Creek Temporary Plant	52.8	53.4	53.4	53.7	53.3	53.2
New Utrecht	59.8	56.3	55.8	56.3	54.8	57.0
Gravesend	58.7	56.8	55.9	55.8	55.2	56.6
Flatbush	....	....	....	57.5	56.6	56.7

6. QUALITY OF THE WATER SUPPLY OF THE BOROUGH OF MANHATTAN.

The Borough of Manhattan is supplied with water by the Croton System, which is collected from the Croton River and its tributaries and stored in eight artificial storage reservoirs, five large natural lakes and several smaller ponds. The drainage area of the Croton River above the old dam is approximately 338 square miles. The drainage areas of the various tributaries, together with other data, are given in Table 1. From the lower end of Croton Lake, two aqueducts about thirty-five miles long lead to the distribution reservoirs in the City. The old aqueduct is not in use at the present time. Both aqueducts terminate at the One Hundred and Thirty-fifth Street Gate-House, and from this point several lines of 48-inch pipe lead to the main distribution reservoirs in Central Park. These consist of the old reservoir divided into two basins, known as the North and the South Basins, and the New Receiving Reservoir, which has a dividing wall 33 feet high, but which is entirely under water when the reservoir is full. All of the water of the low service system passes through one or the other of these reservoirs. Water for the high service districts is repumped either at the Ninety-eighth Street Pumping Station or at High Bridge. The distribution system will be modified and considerably improved on the completion of the new reservoir at Jerome Park.

The Croton water as delivered to the consumers may be characterized as reasonably safe from the sanitary standpoint; noticeably colored and slightly turbid, with an odor persistently vegetable and occasionally aromatic, grassy or even fishy; reasonably soft; a good boiler water and generally satisfactory for industrial purposes. Whatever complaints have been made against the water have been due to its occasional unsightly appearance and bad odor. Its physical qualities, therefore, merit our first attention.

The water yielded by the watershed is represented by the samples which are collected daily from the aqueduct at the One Hundred and Thirty-fifth Street Gate-House. The results of physical examinations for the present year are shown chronologically on Plate II., together with the rainfall on the Croton Watershed and the results of microscopical examinations.

Turbidity.

The turbidity of the water varies more or less from day to day, sometimes being as low as 1 on the silica scale, and at other times running as high as 25. The average turbidity from January to September, 1903, was 5.

The high turbidities usually follow heavy rainfalls, and are evidently caused by them. The rain washes the dust and silt from the surface of the ground into the streams and reservoirs, and it eventually reaches the aqueduct and distribution pipes. The suspended matter contains but little clay, and the particles are comparatively large. They settle readily, therefore, so that the streams and reservoirs soon clear up, making the turbid periods of short duration. It has been found that most of the turbidity in the water which reaches the aqueduct is acquired more from Croton Lake itself than from the watershed at large. This lake is long, narrow and not very deep in its upper portion. It has a muddy bottom, and when drawn down, mud flats, which represent the accumulated sediment of many years, are exposed. When the water is low, a sudden rain disturbs the deposits and makes the water roily. A heavy wind also creates currents which disturb the mud deposits. During the month of May, daily samples collected at the upper end of Croton Lake had an average turbidity between 2 and 3, while the water in the aqueduct had an average of 8. There are reasons to believe that the aqueduct contains deposits which, under unusual conditions, may add to the turbidity of the water in the City.

The water delivered to the consumers is generally less turbid than the water at the One Hundred and Thirty-fifth Street Gate-House. This is because of the sedimentation which takes place in the reservoirs at Central Park and High Bridge and in the pipes of the City. Occasionally, however, growths of organisms in these reservoirs increase the turbidity. These facts are shown by the following figures:

Turbidity (Parts per Million).

Month (1903).	One Hundred and Thirty-fifth Street Gate House.	Central Park Reservoir Outlets.			Tap at City Hall Square.
		New.	Old.		
			North.	South.	
January	5	3	2	3	3
February	6	5	4	4	3
March	5	4	4	5	4
April	4	4	4	5	3
May	8	4	4	4	5
June	6	3	3	4	2
July	3	1	6	3	2
August	2	3	4	6	2
Average	5	3	4	4	3

Color.

The color of the water at the One Hundred and Thirty-fifth Street Gate-House also varies with the rainfall, but the fluctuations are not as great as those of turbidity. The extreme range is from about 16 to 30, and the average is about 24. It is nearly always high enough to be noticeable in a clear glass tumbler. The color is not acquired at any particular place on the watershed, although the swamplands in the upper portion of the watershed tend to materially increase it. For example, the average color of the water in the streams above Boyd's Corner Reservoir is about 50, or about double the average color for the entire supply. A certain amount of color is acquired in Croton Lake. By draining the swamp areas on the watershed, the average color might be reduced to about 20. Filtration would reduce the color to about 15 and possibly to 12, at which point it would scarcely attract attention.

Odor.

It has been stated that the Croton water has a persistent vegetable taste and odor. This is plainly shown by the shaded areas in Plate No. II. The odor is usually distinct, that is, it is readily noticed by one drinking the water. It is due to the presence of organic matter. The same substances that make the water colored also give it a vegetable taste and odor. Some of the suspended matter adds to this odor, as well as certain of the microscopic organisms. The vegetable odor, although undesirable, is one that is not wholly unpleasant, and unless unusually strong, one readily becomes accustomed to it.

The water, at times, has a moldy odor, due to decomposing organic matter. Sewage polluted water has this odor intensified sometimes until it is "musty" rather than moldy, but not all moldy odors are due to pollution. A moldy odor, however, always leads one to suspect the quality of the water, unless its cause can be definitely attributed to something other than pollution. A study of the seasonal distribution of the moldy odors in the Croton water, as given by Plate II., shows that they are seldom observed apart from the presence of microscopic organisms, hence, they may be fairly attributed to that cause. Moldy odors are sometimes observed in the water from the dead ends of the system.

Microscopic Organisms.

The most objectionable odors observed in the Croton water are those due to the presence of microscopic organisms. Some of these organisms are always present in the water, but there are many different genera and they come and go with the seasons, often appearing and disappearing with great suddenness. They are found in all of the storage basins on the watershed, but they appear to attain their greatest development in the reservoirs at Central Park.

The following figures show their relative abundance in the different storage reservoirs:

Microscopic Organisms.

Reservoir.	Average Number of Standard Units per c. c.									
	1903.									
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Ave.
Sodom Reservoir	....	145	177	481	1,005	809	804	2,019	973	824
Bog Brook	....	483	317	1,406	1,703	783	359	448	855	794
Middle Branch	....	443	414	3,748	1,360	292	948	584	550	1,043
Boyd's Corner	....	125	86	526	661	196	208	234	283	289
West Branch	....	667	714	1,418	1,045	484	893	330	304	732
Lake Gleneida	....	117	106	446	214	35	25	105	72	140
Lake Gilead	....	49	90	76	46	80	41	19	17	52
Lake Mahopac	....	695	446	1,235	313	88	40	95	148	383
Kirk Lake	....	658	464	2,315	341	242	149	450	612	654
Muscoot Reservoir	....	893	471	1,258	1,186	617	215	926	1,517	885
Titicus Reservoir	....	593	474	938	954	596	1,345	340	203	680
Croton Lake	....	290	279	1,207	753	434	1,498	448	488	675
One Hundred and Thirty-fifth Street Gate-house	205	205	202	1,205	1,300	844	1,855	945	1,701	829
Central Park New Reservoir	236	222	271	1,066	800	960	1,411	2,855	2,229	1,117
Central Park Old Reservoir, North Basin	242	327	1,110	1,552	3,496	1,870	4,675	2,795	5,290	2,373
Central Park Old Reservoir, South Basin	329	251	428	1,025	2,574	1,283	2,445	3,021	2,672	1,558
Tap at City Hall Square	155	285	219	739	815	682	1,445	1,186	933	737

To describe in full the nature and magnitude of the growth of microscopic organisms would too greatly extend this report, hence, a few generalizations must suffice.

Since the examinations of the Croton water were begun in June, 1902, the following genera have been observed. Those printed in heavy type represent the genera found at any time in quantities greater than 100 standard units per c. c. Those found in quantities less than that have but little practical effect on the quality of the water. The genera which are starred are those likely to cause bad tastes and odors.

List of Microscopic Organisms

Plant Organisms.

Diatomaceæ.	Chlorophyceæ.	Cyanophyceæ.	Schizomycetes and Fungi.
Amphora	Chaetophora	**Anabaena** *	Cladothrix
Asterionella *	Botryococcus	**Aphanizomenon** *	**Crenothrix**
Cyclotella	Coelastrium	**Chroococcus**	Leptothrix
Cymbella	**Closterium**	**Clathrocystis** *	Mold Hyphae
Diatoma	Confera	**Coelosphaerium** *	
Epithemia	**Cosmarium**	Cylindrospermum	
Fragilaria	Desmidium	Merismepedia	
Gomphonema	Dictyosphaerium	**Microcystis** *	
Melosira	Dimorphococcus	**Oscillaria**	
Meridion	Draparnaldia		
Navicula	**Eudorina**		
Nitzschia	**Gonium**		
Stephanodiscus	Pandorina		
Surirella	**Protococcus**		
Synedra *	Raphidium		
Tabellaria *	**Scenedesmus**		
	Spirogyra		
	Staurastrum		
	Volvox		
	Xanthidium		
	Zygneam		

Which Have Occurred in the Croton Water.

Animal Organisms.			
Protozoa	Rotifera.	Crustacea.	Miscellaneous.
Anthophysa	Anuraea	Branchipus	Acarina
Arcella	Asplanchna	Bosmina	Ova
Bursaria	Brachionus	Cyclops	
Ceratium	Conochilus	Daphnia	
Cercomonas	Notholca		
Codonella	Polyarthra		
Coleps	Rotifer		
Colpidium	Synchaeta		
Cryptomonas	Triarthra		
Diffulgia			
Dinobryon *			
Enchelys			
Epistylis			
Euglena			
Glenodinium *			
Halteria			
Mallomonas			
Monas			
Nassula			
Opalina			
Paramaecium			
Phacus			
Peridinium			
Stentor			
Synura *			
Tintinus			
Trachelomonas			
Uroglena *			
Vorticella			

The observations on the watershed have not yet covered a sufficiently long period to enable one to classify the storage reservoirs with respect to the prevalence of these organisms. All of the reservoirs appear to be more or less affected. The heaviest growths during the summer of 1903 occurred in Sodom Reservoir, Bog Brook Reservoir, Middle Branch Reservoir, West Branch Reservoir and Croton Lake. Lake Gleneida, Lake Gilead and Boyd's Corner Reservoir contained comparatively few. Speaking generally, the old reservoirs give less trouble than the newer ones. Croton Lake, however, receives water from all the reservoirs above, and its water is influenced by the particular reservoirs which are being used.

The organisms which ordinarily give rise to the worst odors in the Croton Aqueduct are the blue-green algæ. Several genera, such as Anabæna, Aphanizomenon, etc., unite to give the water a grassy, moldy odor.

The growths of organisms in the reservoirs on the Croton Watershed differ in no respect from those which occur in storage reservoirs elsewhere, except in their intensity. The Diatomaceæ occur in the spring and autumn, the Chlorophyceæ and Cyanophyceæ occur in the summer and early fall, while the Protozoa occur spasmodically at all seasons. These growths do not reflect the sanitary quality of the water, but rather the unclean condition of the reservoir bottoms. When these reservoirs were constructed, no precautions were taken to remove the peat, turf, stumps and organic matter from the reservoir sites, which modern engineering considers necessary when the water is to be used without filtration. The areas were simply flooded and the organic matter left to decompose. This decomposition was very active for the first few years after construction, and the water drawn from the lower gates was most offensive. Gradually the active decomposition has ceased, and the older reservoirs are acquiring the characteristics of old lakes with muddy bottoms.

Most of the reservoirs are quite deep, and they undergo the same process of stagnation during the winter and summer that were so completely studied in the reservoirs of the Boston Water Works a number of years ago. These phenomena may be described briefly as follows:

During the summer the water in the reservoir becomes thermally stratified, with the colder and denser water at the bottom and the warmer and lighter water near the surface. During this period, which has been described as the "period of stagnation," only the water in the upper strata is agitated by the wind and is "in circulation." The water near the bottom is stagnant. Under these conditions the lower quiescent water does not change in quality if the bottom of the reservoir is clean. If, however, there is a deposit or organic matter at the bottom, it will undergo putrefactive changes. The water in the stagnant layer will lost its oxygen, and after this is gone decomposition will take place under anærobic conditions, the water becoming charged with ferrous compounds or iron, carbonic acid, hydrogen sulphide, etc. In the autumn, as the temperature of the surface water cools to a point approaching that of the bottom, the circulation of the upper layers will extend to greater and greater depths, until finally it will be complete throughout the entire vertical. The bad water at the bottom will thus be mixed with the rest of the water in the reservoir, causing the entire body to deteriorate and furnishing food material for heavy growths of diatoms and other microscopic organisms. During the winter season when the reservoirs are covered with ice, there is a second period of stagnation. This time, however, the thermal conditions are reversed, the warmer water being at the bottom and tending to approach the temperature of maximum density—that is, 39.2 degrees Fahr. (4 degrees Cen.). The winter stagnation is of shorter duration than the period of summer stagnation, and the phenomena are less pronounced. To a slight extent, the effects of stagnation in the reservoirs may be obviated by drawing water from the lower gates, but the diameter of the circle of influence of the outward current from the lower gate is unknown. The effect of drawing off the stagnant water upon the reservoirs further down stream must also be considered. This water rapidly becomes oxidized, however, in the "fountains" and raceways below the dams. Diagram No. 4 shows the temperature of the water at different depths in several of the storage reservoirs during the summer stagnation of 1903.

If the reservoirs had been stripped of their vegetation and top soil before they were filled, it is probable that the growth of objectionable organisms would have been materially less, and the citizens would have been furnished with more palatable water. There is reason to believe, however, that most reservoirs tend to approach a condition of uniformity after long periods of time. The bottom of reservoirs like those on the Croton Watershed tend to improve with age, while the bottom of reservoirs which were originally cleaned of their organic matter become more or less covered with deposits from the water, so that the ultimate end in both cases is not greatly different. For reservoirs less than ten or twenty years old, however, the advantage is all with those from which the soil was stripped, and when the water is not to be filtered, the gain to be derived from stripping is well worth the added expense. All conditions must be considered, however. It might be ill-advised, for example, to strip the soil from a reservoir situated below a large swamp, or a reservoir fed by a stream from an unstripped reservoir above it. It is true, however, that satisfactory surface water can be obtained only from clear watersheds and clean reservoirs.

To what extent it may be considered wise to attempt to rectify the

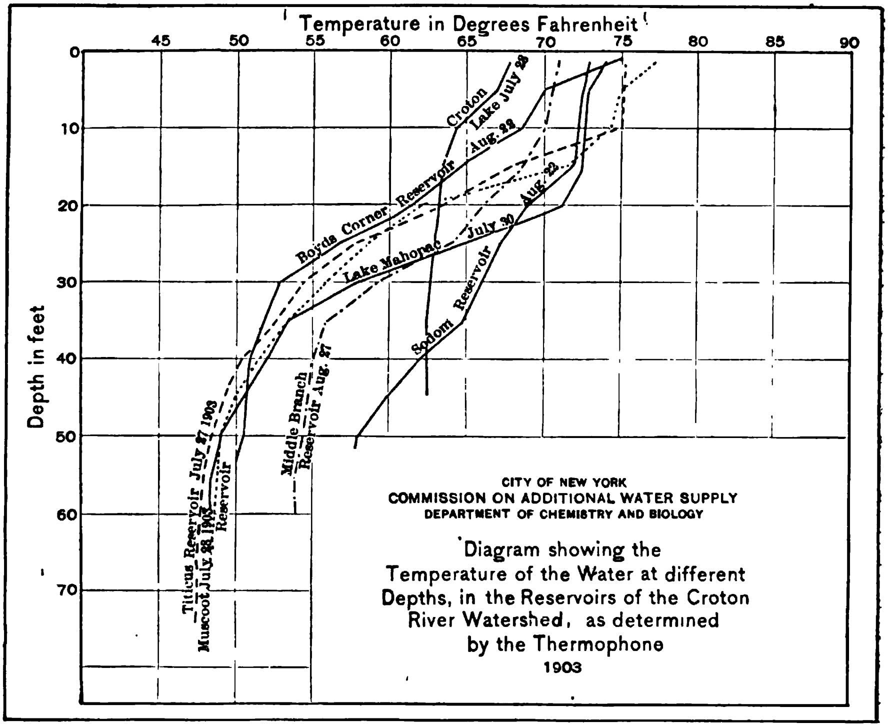


DIAGRAM 4. APP. VI.

existing conditions in the storage reservoirs at the present time is a matter which depends largely upon the plans for the additional supply. If a general filtration project is undertaken, comparatively little need be done to the reservoirs, as filtration would render the present supply satisfactory. There is no doubt, however, that the removal of the deposits of organic matter from Croton Lake would be of great benefit, even if filtration were adopted, as the lessened algæ growths would enable the filters to be more satisfactorily and economically operated. In the case of the New Croton dam, it would appear to be highly desirable to have at least the vegetation destroyed from the area to be flooded, and a careful study of the top soil should be made to determine the wisdom of its removal before the reservoir is filled. The effect upon the quality of the water in the City attendent upon the initial decomposition of the organic matter in this immense reservoir is one which cannot be contemplated without the greatest anxiety. The fact that all the water from the watersheds would have to pass through this reservoir before reaching the City adds to the gravity of the situation.

The bad odors which are noticed at times in the City water do not all originate on the watershed. It often happens that the water reaches the One Hundred and Thirty-fifth Street Gate-House in good condition, and becomes foul in the reservoir in Central Park. The table below shows that the microscopic organisms are much more abundant at the outlet gate-houses of the three basins than at the terminus of the aqueduct. This was even more noticeable in 1902 than 1903, as shown by the following figures:

	Number of Microscopic Organisms (Number of Standard Units Per C. C.).						
	1902.						
	July.	August.	Sept.	October.	Nov.	Dec.	Average.
One Hundred and Thirty-fifth Street Gate-house........	2,400	564	2,303	792	....	146	1,241
Central Park, New Reservoir..	2,388	4,482	2,512	1,178	...	237	2,159
Central Park, Old Reservoir, North Basin............	6,252	4.426	4,363	2,489	....	507	3.607
Central Park, Old Reservoir, South Basin....	4,304	4,166	3,525	2,083	....	292	2,874
Tap at City Hall Square	....	752	1,674	1,171	....	232	957

Table No. 9 gives in detail the results of the microscopical examination of the samples collected from the outlet gate-house of the North Basin of the Old Central Park Reservoir from July, 1902, to October, 1903.

They serve as an illustration of the relative numbers of the different organisms present. During the summers of both years the odor of the water at the outlet of this basin was stronger than at the inlet.

The Central Park reservoirs are from 20 to 36 feet deep, and their capacity is such that the water remains in them for 4 or 5 days. The basins have not been cleaned for many years, and there must be considerable deposits of mud at the bottom. Calculation shows that with an average of 200 million gallons of water a day passing through the reservoirs there would be a solid deposit of .12 inches in the reservoir every ten years for every part per million suspended matter deposited. This is on the assumption that the sediment has the same specific gravity as sand, *i. e.*, 2.65, and settles into a mass which has 40 per cent. void space. As a matter of fact, the sedimentation, though not exactly known, probably amounts to several parts per million and the sediment has a specific gravity considerably lower than that assumed. In all probability, the deposit amounts to an inch or more in depth every ten years, which is increased by dust blown into the reservoir. This is a striking contrast to the sedimentation basins of the St. Louis water supply, where the sediment forms a deposit of several feet annually. It is not the amount of sediment that interests us in this instance, however, so much as its character. It is largely organic and contains many cells of microscopic organisms in a resting state. These basins have become so thoroughly seeded with algæ, protozoa, etc., that the organisms appear annually in the reservoirs, regardless of the character of the influent water. There seems to be no practical way to prevent their growth, but to empty the basins and remove the spore-laden mud.

Unfortunately, the reservoirs are not provided with by-passes and the risks attendant upon putting any one of them out of service at the present time are, perhaps, too great to warrant the undertaking. As soon, however, as the Jerome Park Reservoir is ready for use the cleaning of the Central Park Reservoirs should be no longer delayed. Especially will it be important to have these reservoirs cleaned before the introduction of filtered water. To pass filtered water through them in their present condition would be only to invite trouble. If the reservoirs were provided with suitable by-passes it might be possible to isolate one or another of the basins should they become affected with anabæna, for instance, and allow the water to pass around them, just as is done in Brooklyn. The ultimate remedy, of course, and the one which must be eventually adopted, is the covering of the reservoirs.

When the water leaves the reservoirs and flows through the distribution pipes, many of the microscopic organisms become disintegrated. This accounts for the smaller numbers of organisms in the tap at City Hall Square, shown in a preceding table. The disintegration sometimes increases the odor of the water by liberating the oil globules and on occasions it may impart a faint opalescence to the water.

Although the blue-green algæ are most heavily responsible for the bad odors in the Croton water, the most serious trouble in recent years was caused by Synura, one of the protozoa. During November, 1900, the water in the City had a strong fishy taste and odor, and microscopical examinations made at that time showed the presence of those organisms in comparatively large numbers. Thus, on November 23, a sample of water collected at the Manhattan Terminal of the Brooklyn Bridge, contained 450 standard units per c. c. of Synura, while on November 27, a second sample from the same place, contained 300 standard units. At this time there was no other organism present which was capable of producing the peculiar fishy odor which was observed. When it is remembered that this organism disintegrates rapidly when subjected to pressure in the pipes of the distribution-system, it may be readily conjectured that the numbers of Synura in the water of Central Park were very large.

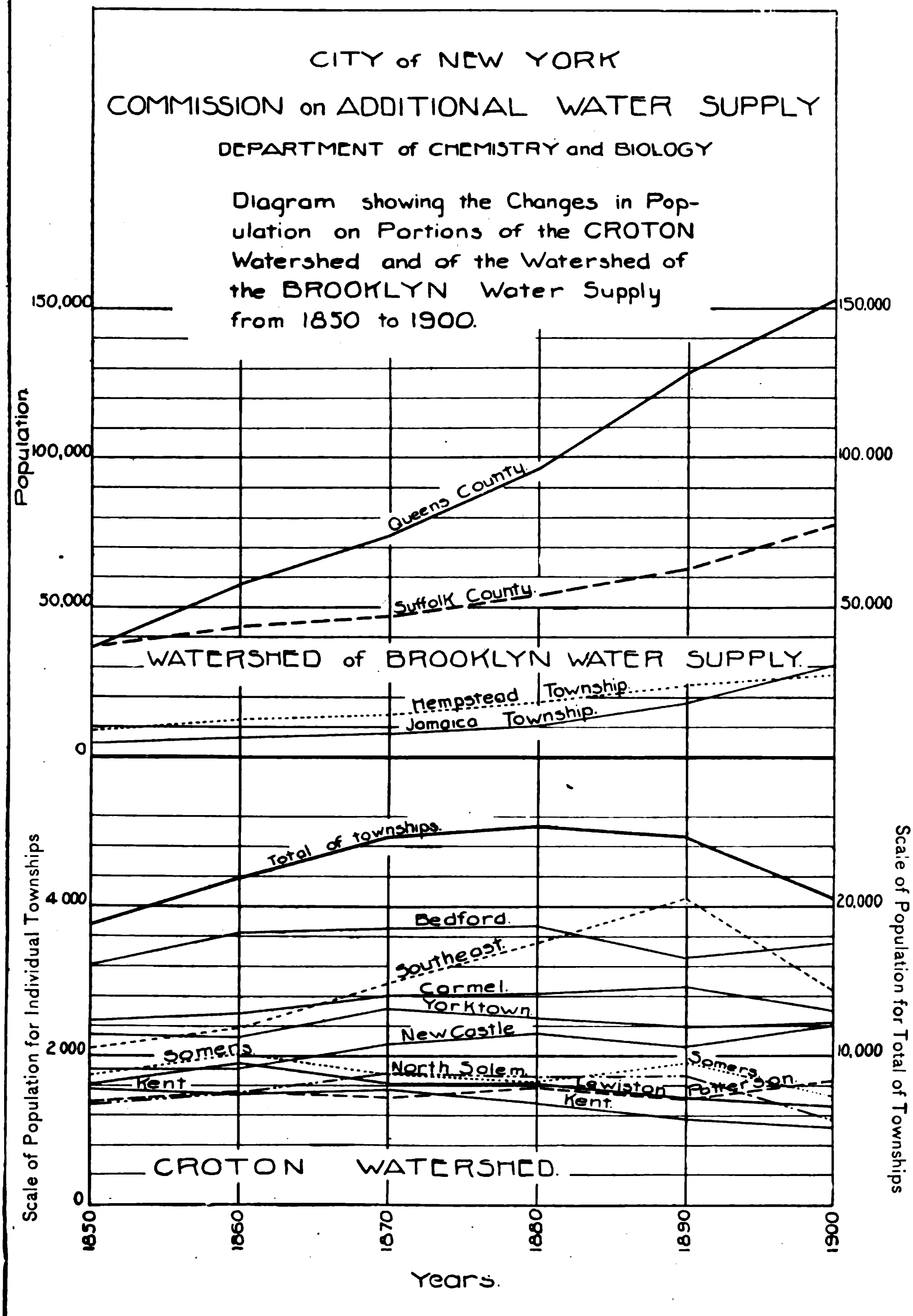
The microscopic organisms have another effect on the water supply system which ought not to be overlooked. They serve as food for the various animal organisms which dwell upon the insides of waterpipes and which are often described under the name of "pipe-moss." Examination has shown that the fresh water sponges, Spongilla and Meynia, and the bryozoa, Paludialla and Pectinatella, are by no means uncommon in the distribution pipes of New York. They are objectionable because they materially clog the pipes and decrease their carrying capacity; they facilitate tuberculation, and they act as a nidus for many little animals, such as snails, shrimp, crustacea, etc., which occasionally appear in the tap water, to the consternation of the consumers. Sometimes they become detached in large tufts, when they are liable to clog up house services. These various pipe-dwellers are absolutely dependent upon the microscopic organisms, and they are not found in ground water systems. To permit the growth of algæ in the Central Park Reservoir, therefore, is to foster these objectionable sponges and bryozoa in the pipes of the City.

Sanitary Quality—Pollution of the Watershed.

The Croton River Watershed above the old dam has an estimated population of about 10,000, or about 52 per square mile. This is nearly all rural in character. The people live in scattered farms or in small villages, and there are only a few large towns. The relative stability of the population is shown by Diagram No. 5. The watershed contains no cities. There is but one sewerage system, and this is a small one in the village of Brewster. The sewage, which in dry weather amounts to 4,000 gallons per day, is disinfected by means of an " Electrozone Plant " and then allowed to discharge into the ground through a system of tile pipes. Tests made by the Health Department several years ago showed that this plant was doing effective service, and a recent test made at Mt. Prospect Laboratory gave similar results. A sewage disposal system for the village of Mount Kisco is in contemplation, and its installation should be made at the earliest possible date. The close proximity of this growing village to Croton Lake makes it the most serious source of pollution now existing on the watershed. At the present time, the privies and cesspools at Mount Kisco are frequently and regularly cleaned under a local contract. At Lake Mahopac, there are several large hotels which are occupied during the summer by nearly one thousand people. There are a few large institutions, like the Montifiore Home at Bedford, which are provided with independent systems of sewage disposal. Naturally on a watershed of 338 square miles, nuisances may be found. Danger from them, however, may be eliminated to a considerable extent by proper attention. During the past year an assistant engineer has given his entire attention to existing nuisances, making maps showing their location and describing each one in detail. This work, which is receiving the hearty co-operation of the Department of Health of New York and also of the State Department of Health, is already bearing fruit, and many of the worst nuisances are being abated. Until the Croton water is filtered, this sanitary patrol of the watershed should be diligently pursued. In matters of this character it is emphatically true that " eternal vigilance is the price of safety."

It has been the policy of the City of New York in the past to remove pollution from the watershed by the wholesale purchase of property along the streams. While this has involved a large expense, it has been of unquestioned value to the health of the City. Studies of population statistics for those towns which are included in the Croton Watershed show, that since 1850 the population has increased scarcely any. This is evident from an inspection of Diagram No. 5, which gives the population of the most important towns.

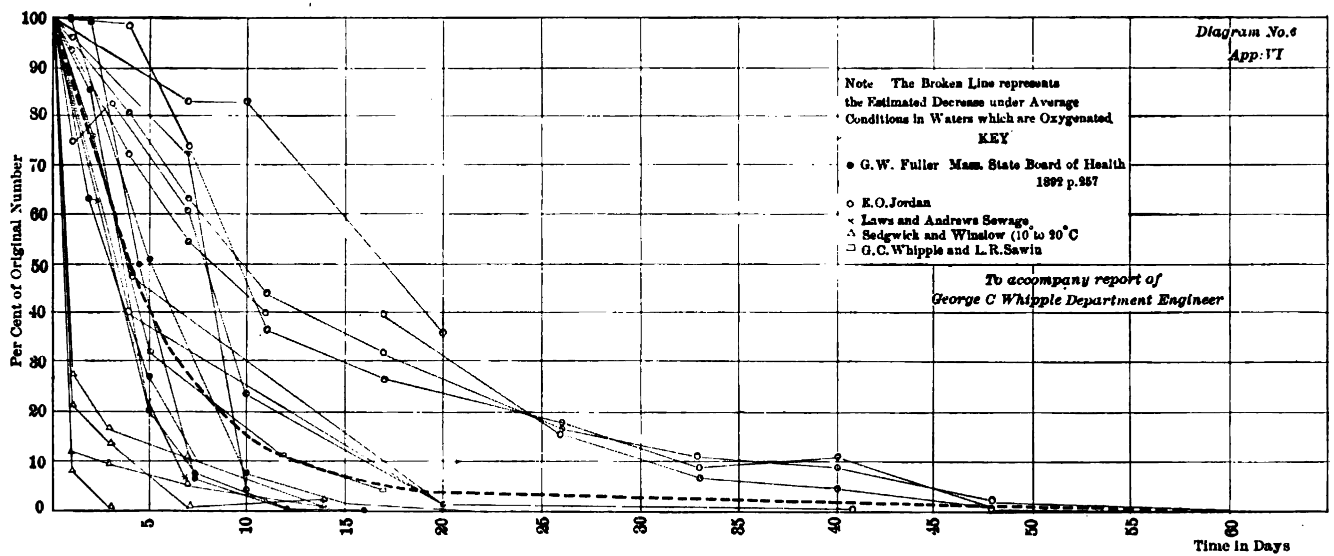
Diagram No. 5
App. VI



The distribution of the population on the watershed is shown in Table 1A, where column 11 gives the population per square mile on the watersheds tributary to the different storage reservoirs. In case of reservoirs on the lower streams, which include areas tributary to reservoirs higher up, these latter are not included in the column mentioned. In column 12, however, they are so included. It will be seen that except on the watershed of Lake Gleneida, and of Lake Mahopac during the summer, the population per square mile is comparatively low. The Village of Carmel is situated near Lake Gleneida, but in spite of the large density of population per square mile, the sanitary conditions are not serious. The density of population is lower in the upper watersheds—such as Boyd's Corner Reservoir, Middle Branch Reservoir, West Branch Reservoir and Sodom Reservoir—than on the lower watersheds—like Muscoot Reservoir, Titicus Reservoir, Cross River, Mount Kisco River and Croton Lake.

Typhoid fever is not common on the Croton Watershed. As nearly as can be learned from the published records of the State Department of Health, the average death rate from typhoid fever during the past six years has been about 34 per 100,000. This is equivalent to about 17 deaths per 1,000 square miles.

The Croton water has one great safeguard against danger from infection—namely, its large storage reservoirs. It is a fact generally admitted by bacteriologists that the germ of typhoid fever does not multiply in water under conditions of laboratory experiment, and presumably it does not multiply in water under natural conditions. It lives in water, to be sure, sometimes for many months, but in ever decreasing numbers. Laboratory experiments upon the longevity of Bacillus typhi have given somewhat discordant results, partly on account of differences in the vitality of the bacilli employed and partly because of different environmental conditions. Yet, in spite of this, the experiments present a general similarity. They show a rapid initial decline in the number of bacilli after innoculation, followed by the continued life of the more hardy individuals, terminating finally in the apparent death of all. In Diagram No. 6 the results of a number of the most carefully conducted experiments have been assembled, and a mean curve drawn to represent the general results. This line, of course, does not exactly express the decrease in the number of typhoid fever germs in nature in any particular case, but it tells in a general way what effect an unfavorable environment has upon them. It will be seen that *time* is a safeguard against an infected water. A water ten days after infection is perhaps one-sixth as likely to cause disease as that water one day after infection, while one month it is perhaps only one-fiftieth as great. The value of long storage is thus evident. Furthermore, sedimentation and other factors are at work in storage reservoirs to materially reduce the danger from an infected water.



CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing the Progressive Decrease in the Number of Typhoid Bacilli under Different Conditions as determined by Laboratory Experiments.

From Table No. 1 it will be seen that the storage reservoirs of the Croton system are from 1.75 to 4.50 [illegible] and hold from [illegible] to 11,000 million gallons, while they are from [illegible] miles distant from the lower end of Croton Lake and [illegible] miles distant from the [illegible] Hundred and Thirty-fifth street gate-house, at the lower end of the aqueduct. They are so situated also, that in several cases the water from the most distant reservoirs has to pass down through a lower reservoir, and then through Croton Lake before entering the aqueduct, so that the water remains in some of the reservoirs for weeks and months before being used. The reservoirs [illegible] so that [illegible] is an important [illegible] the water at any time becomes infected. It is [illegible] that the [illegible] of the watershed are those which [illegible] protected against infection.

While the Croton supply may be considered as fairly safe at the present time, yet it must be borne in mind that a surface water supply of this character is always open to infection, and no such supply can be considered as absolutely safe until supplemented by filtration. The statistics of [illegible] water supplies are becoming more and more numerous and the time will soon come, if it is not already here, when the citizens of New York will demand the filtration of all the surface water supplied to the city.

Bacteria [illegible]

In a water supply like that of the Croton, the number of bacteria is subject to great fluctuations. The soil is the great repository of bacteria, and every rainfall that washes the surface of the ground carries countless millions of bacteria into the streams. Hence, after every rain the number of bacteria in the water supply increases. This is very evident from Plate III. The heavier the rainfall the larger in general will be the number of bacteria found. A rain falling after a long drought, however, has a much greater effect than the same amount of precipitation at the end of a rainy period. For example, the rain which fell on June 1, 1893, caused a far greater increase in the number of bacteria than the rain which fell on June [illegible]. A high wind which stirs up the reservoirs also causes an increase in the number of bacteria. Speaking generally, however, the number of bacteria in the Croton water measures the amount of surface wash into the streams, and hence the chances of infection.

Diagram [illegible] the relative number of bacteria in the water of the Croton system at different seasons of the present year. The influence of the spring freshets is plainly seen, as well as the effect of the heavy rains in June.

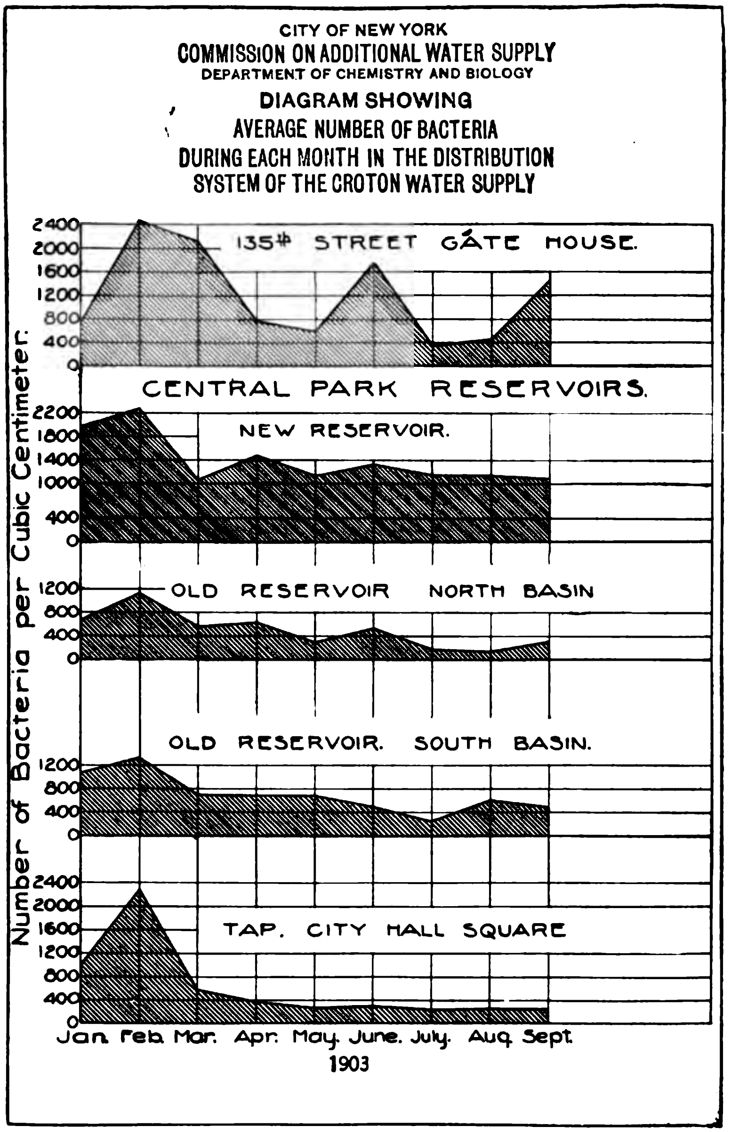


DIAGRAM 7. APP. VI.

The diagram shows how the numbers of bacteria are reduced by storage in the Central Park Reservoir and how they become further reduced in the distribution pipes. The average number of bacteria in the tap water at City Hall Square, Manhattan, from January 1 to September 30, 1903, was 370 per cubic centimeter, but the number varied at times from 80 to 7,000. The average reduction of bacteria by storage in Central Park was as follows:

	Percentage Reduction of Bacteria.
In Central Park, New Reservoir	29
In Central Park, Old Reservoir, North Basin	58
In Central Park, Old Reservoir, South Basin	47
Average	45

The tap at City Hall Square, where the samples are collected, is supplied by the mains from the New Reservoir, and the reduction of bacteria between Central Park and City Hall Square is found to be about 29 per cent. The tap water at City Hall Square, therefore, contains only about one-half as many bacteria as the water at the One Hundred and Thirty-fifth Street Gate-house.

The bacteriological examination of the various reservoirs and streams on the watershed are not sufficiently complete at present to warrant the publication of generalized results.

When the numbers of harmless water bacteria increase in the supply, the chance of there being pathogenic bacteria present is proportionally increased. This is illustrated by the increased abundance of the intestinal bacterium, Bacillus coli, after heavy rains, as shown by Plate IV. The relation between the abundance of Bacillus coli as indicated by the presumptive tests and rainfall is not, however, as close as that between rainfall and the total number of bacteria. Detailed results of the tests of Bacillus coli show that out of 201 samples from the One Hundred and Thirty-fifth Street Gate-house, collected between January 1 and September 30, 1903, 18 (or 9 per cent.) gave positive tests in 0.1 cubic centimeter; 36 (or 18 per cent.) gave positive tests in 1 cubic centimeter; and 55 (or 27.5 per cent.) gave positive tests in 10 cubic centimeters. The reduction in the number of Bacillus coli in the reservoirs and distribution pipes was even greater than that of the water bacteria. Thus, at the tap at City Hall Square, out of 206 samples, 2 (or 1 per cent.) gave positive tests in 0.1 cubic centimeter; 7 (or 3.5 per cent.) gave positive tests in 1 cubic centimeter; and 18 (or 9 per cent.) gave positive tests in 10 cubic centimeters.

The direct relation between the sanitary quality of the water as revealed by analysis and the typhoid fever morbidity is one that is difficult to establish. At times, however, indications of it are discernable. Thus, from Plate IV., it will be seen that during the middle of March there was a decided increase in the number of reported cases of typhoid fever, and that this was just about two weeks after there had been a great increase in the number of bacteria. This difference in time is just about sufficient to allow the disease to make itself evident. Again, during the first week in July there was another decided increase in the number of reported cases, which followed about two and one-half weeks after a period when Bacillus coli were unusually abundant in the water.

Chemical Qualities of Croton Water.

The determinations of the free ammonia, nitrates, nitrites, etc., offer but little evidence as to the sanitary quality of the water, on account of complications due to the presence of the microscopic organisms. This is shown by Plate IV., where the lines representing these quantities do not appear to follow either the bacteriological examination or the typhoid fever morbidity.

The amount of organic matter, as revealed by the albuminoid ammonia, is higher than is desirable, but is no higher than might be expected from the color of the water and the number of miscroscopic organisms present.

The amount of chlorine in the water affords a slight basis for ascertaining the general amount of pollution, provided the normal chlorine for the watershed be known. For the Croton Watershed this normal may be estimated as about 1.6 parts per million. The average amount of chlorine in the water delivered to the City is 1.9 (average of weekly analyses for One Hundred and Thirty-fifth Street Gate-house and City Hall Tap). Mr. F. P. Stearns, C. E., long ago calculated that for every twenty persons per square mile inhabiting a watershed there would be an excess of chlorine above the normal of 0.1 parts per million. The population on the Croton Watershed is 52 per square mile, which would give by calculation 0.25 parts per million excess of chlorine, a figure which agrees with the observed amount within the limit of error of the observations.

The only chemical characteristic of the Croton water which deserves extended consideration is the hardness. The amount of iron in the water is small, the average of the weekly analyses at the One Hundred and Thirty-fifth Street Gate-House showing only 0.28 parts per million, and the maximum being only 0.60. About one-half of it is precipitated in the Central Park Reservoir, so that it does not reach the consumers.

Hardness.

The water on the Croton River Watershed differs considerably in hardness in different sections. It is much greater in the extreme northeastern portion, where there are deposits of limestone, than in the northwestern part where there are no such deposits. In White Lake, for example, the average hardness from February 1 to September 1, 1903, was only 14.7 parts per million, while in the stream at De Forest's Corners above the Sodom Reservoir, the hardness was 66.4. The hardness determinations for the different reservoirs are given in Table No. 5A, but the following diagram will more simply illustrate this fact (Diagram No. 8).

It will be noticed that the average hardness of the water in the east branch of the Croton River at De Forest's Corners for the period mentioned was 66.4, while at the lower end of the east branch (Sodom) Reservoir, into which this stream flows, it was 47.6 at the surface and 44.3 at the bottom, or about two-thirds of that in the stream. This is due to the fact that the water in the reservoir represents to a great extent the spring flood flow when the hardness of the surface water is below the average. The seasonal changes in the hardness in this region is illustrated by the following table:

Hardness (Parts per Million).

Date.	East Branch Stream at Deforest Corners.	Sodom Reservoir.	
		Surface.	Bottom.
February 11, 1903	48.5	45.5	36.5
March 17	45.5	39.0	36.5
April 21	64.5	43.0	45.5
May 19	89.0	53.0	48.5
June 2	94.0	55.5	54.5
June 29	57.0	45.5	40.5
August 31	51.5	51.5	48.5

The hardness of the water in Lake Gleneida and in Branch Brook below Mt. Kisco appears to be higher than would be expected from the geological conditions, and it is probable that the excess is due to the effect of the population dwelling upon those watersheds. This idea is supported by the fact that the chlorines are somewhat above the normal.

The average hardness at the lower end of Croton Lake during the period mentioned was 39.4 at the surface and 39.8 at the bottom, these figures being based on monthly determinations from February 1 to September 1. The average hardness at the lower end of the aqueduct at One Hundred and

Diagram No.8
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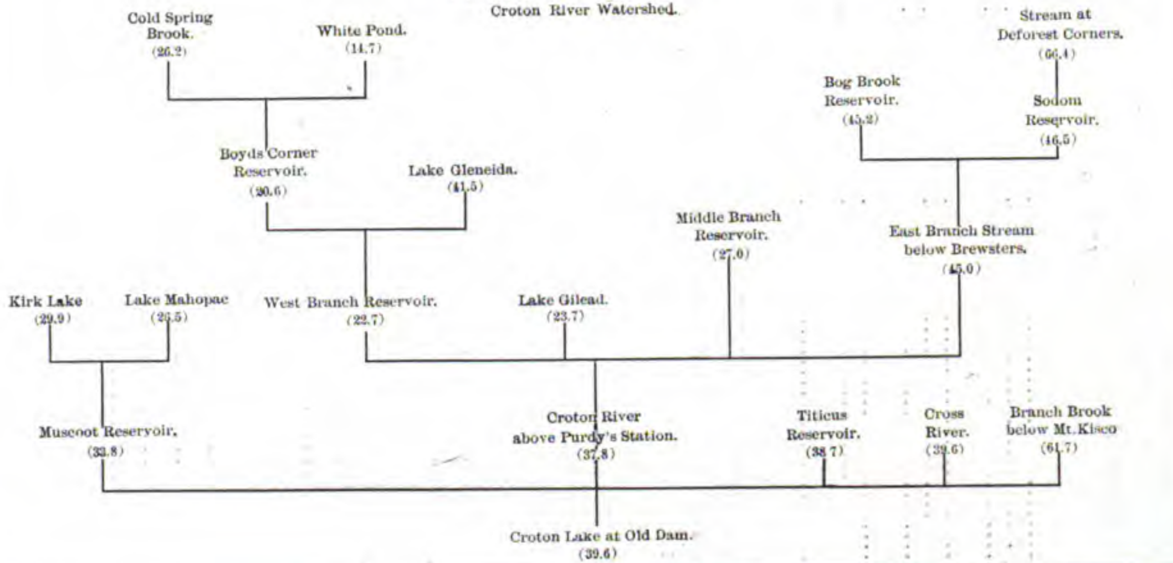
CITY OF NEW YORK

COMMISSION ON ADDITIONAL WATER SUPPLY

DEPARTMENT OF CHEMISTRY AND BIOLOGY

Diagram showing the Average Hardness (from Feb. 1 to Sept. 1, 1903) of the water in the Streams and Reservoirs of the Croton River Watershed.



Thirty-fifth Street Gate-House, from January 1 to September 1. 1903, was 37.4. The seasonal changes in hardness are shown by the following monthly averages:

Month (1903).	Average Hardness at 135th Street Gate-house—Parts per Million.		
	Alkalinity.	Permanent Hardness.	Total.
January	32.0	6.6	38.6
February	26.6	10.8	37.4
March	28.2	4.3	32.5
April	30.2	5.8	36.0
May	36.0	1.6	38.4
June	34.2	2.7	36.9
July	39.2	2.5	41.7
August	35.2	2.4	37.6
Average	32.7	4.7	37.4

These figures are slightly below the average for the past fifteen years, as shown by the following figures, kindly furnished by the Department of Health:

Year.	Average Hardness of Croton Water (Parts per Million).
1888	36.5
1889	40.0
1890	42.0
1891	43.0
1892	49.0
1893	41.3
1894	41.7
1895	42.5
1896	41.1
1897	44.9
1898	45.8
1899	39.7
1900	42.4
1901	39.8
1902	34.9
1903 (8 months)	37.4
Average (1888-1902)	38.9

Comparison of these figures with the rainfall and run-off data does not show any very definite relation. In 1892, when the hardness reached its highest annual average, the rainfall was comparatively low, yet in 1898, when the next highest average hardness was obtained, the rainfall was high. The years when the hardness fell below 40, however, were years of high rainfall. The records of the Department of Health show that the maximum hardness of the Croton water often exceeds fifty parts per million.

The following figures give the extreme limits of hardness during recent years:

Year.	Hardness.		
	Minimum.	Maximum.	Average.
1897	40.7	49.2	44.9
1898	41.4	55.5	45.8
1900	31.2	56.7	42.4
1901	19.6	55.2	39.8

These show that ordinarily the maximum hardness in any year is about 23 per cent. higher than the average hardness, although it may be nearly 37 per cent. higher. From this latter ratio it is estimated that the absolute maximum hardness of the Croton water is probably about 67 parts per million.

The hardness of the Croton water is due very largely to the carbonates of the alkaline earths, and not to any considerable extent to the sulphates, nitrates, etc. In other words, it is temporary hardness and not permanent hardness. It is the latter which is of especial importance in connection with use in boilers. This is shown by the fact that the average alkalinity, which represents the carbonates and bicarbonates, from January to September, 1903, was 32.7 out of a total hardness of 37.4, the difference of 4.7 being the hardness due to sulphates, etc. At this ratio, the average annual permanent hardness would be about 5 parts per million. The sulphates appear to be somewhat higher during the winter than during the summer, and occasionally are higher than 10 parts per million. For comparison of the hardness of the Croton water with that of the Brooklyn supply, see page 426.

High Service Supply.

The character of the water supplied to the high service districts of Manhattan resembles the water at the One Hundred and Thirty-fifth Street Gate-House more than that from the outlets of Central Park Reservoir. The water passes so rapidly through the reservoir and stand pipe at High Bridge that the influence of storage is comparatively slight.

7. QUALITY OF THE WATER SUPPLIES OF THE BOROUGH OF THE BRONX.

The main water supply of the Borough of The Bronx is derived from the Bronx and Byram Rivers. The combined drainage areas of these streams above the point from which the supply is taken is about 20 square miles. The water is impounded in Byram Lake, Rye Pond and the Kensico Reservoir. From the lower gate-house of Kensico Reservoir, a 40-inch pipe line conducts it to the distribution reservoir at Williamsbridge. The southern section of the borough is supplied with Croton water. The eastern section of The Bronx is supplied by the Westchester Water Company. This company operates two pumping stations, one at Glen Park, which takes water from the Kensico pipe line, and the other at Pelham, which takes water from driven wells. The extreme northwesterly corner of the borough is supplied by water furnished by the City of Yonkers. This is a mixed surface and ground water supply.

Bronx and Byram System.

The turbidity of the water entering the Williamsbridge Reservoir, as shown by samples collected between March 1 and September 1, 1903, has varied from 0 to 12, the average being between 3 and 4. The color has varied from 13 to 30, the average being 20. The odor has been persistently vegetable. At the outlet of the reservoir the water has been practically the same in its physical characteristics as at the inlet.

No important growths of microscopic organisms occurred during the present year, either in the storage reservoirs or the distribution system. This is evident from the following figures:

Williamsbridge Reservoir.	Microscopic Organisms: Number of Standard Units per Cubic Centimeter. 1903.							
	March.	April.	May.	June.	July.	August.	Sept.	Av.
Inlet Gate-house............	317	525	461	129	379	457	407	382
Outlet Gate-house..........	419	634	397	273	344	80	168	331

The average number of bacteria for the period was 167 per cubic centimeter; the extremes being 20 and 380. Out of 26 samples tested for bacillus coli, 3 per cent. gave positive results when tested with 0.1 cubic centimeter; 12 per cent. when tested with 1 cubic centimeter; and 23 per cent. when tested with 10 cubic centimeters.

The average amount of chlorine during the period mentioned was 2.2 parts per million, which is scarcely any, if at all, higher than the normal for the watershed, this normal being slightly higher than that for the Croton Watershed, because near the seacoast. The average amount of albuminoid ammonia was 0.114 parts per million; the free ammonia, .040; the nitrites, .003; and the nitrates, 0.10. These figures do not differ materially from those for the Croton supply.

As in the case of the Croton water, the hardness is the only chemical characteristic which deserves consideration. The average amount of iron in the water is very small.

The watersheds of the Bronx and Byram system are adjacent to the Croton Watershed, but the region is off the line of the railroads and no large villages are included within them. The population is only 34 per square mile, and except for a few nuisances the watershed is in excellent condition from the sanitary standpoint. This condition is reflected in the low typhoid fever death-rate in the borough.

The water from Kensico Reservoir is comparatively soft. The average hardness from February 1 to September 1, 1903, was 26.4, of which 21.8 was temporary (as shown by the alkalinity), and 4.6 permanent; these figures being based on monthly determinations. The more frequent analyses made at the lower end of the aqueduct at Williamsbridge gave the following figures:

Month (1903).	Parts per Million.		
	Alkalinity.	Permanent Hardness.	Total Hardness.
February	19.0	0.5	19.5
March	18.4	8.2	26.6
April	17.5	6.5	24.0
May	18.5	7.5	26.0
June	22.4	3.4	26.0
July	22.0	6.2	28.2
August	24.8	3.7	30.5
Average	20.4	5.4	25.8

Westchester Water Company.

The water pumped at the Glen Park Pumping Station is taken from the Kensico pipe line and agrees in quality with the water at the Williamsbridge Reservoir. The water from the driven well station of the Westchester Water Company is hard. The average hardness from February 1 to September 1 was 123 parts per million, of which 43 was due to sulphates. This water also had an average chlorine content of 53 parts per million, indicating contamination by sea water. Aside from these objectionable mineral constituents, however, the water is of good quality.

Supply from Yonkers.

The water furnished by the Yonkers Water Works is a mixture of surface and ground water. The surface water is taken from the Grassy Sprain Reservoir, and the ground water from a system of driven wells. The safety of the supply is well attested by the typhoid fever death rate of the City of Yonkers, which, during the years 1898 to 1901, averaged 11.2 per 100,000 inhabitants.

The samples which have been collected from this supply have shown an average turbidity of 2, an average color of 10, and in general have given a satisfactory analysis. The surface water from the Grassy Sprain Reservoir had in 1903 an average hardness of 34.5 parts per million, only 2.2 of which was "permanent." The ground water, however, is hard. On May 17, 1903, the hardness was 155 parts per million, of which 40 was due to sulphates, etc.

8. QUALITY OF THE WATER SUPPLIES OF THE BOROUGH OF BROOKLYN.

The chief water supply of the Borough of Brooklyn, namely, that from the Ridgewood system, may be considered as reasonably safe under ordinary conditions; occasionally turbid, but seldom high-colored; with a persistent vegetable odor which at times becomes aromatic and fishy; reasonably soft, but with relatively high sulphates, nitrates and chlorides, which make the water somewhat unsatisfactory for boiler uses; high enough in iron to cause precipitates in the distribution pipe, but not high enough to cause trouble otherwise than by the occasional disturbances of these precipitates. Although the analyses indicate that ordinarily the water is safe and wholesome, yet the large and increasing population on the watershed, the "flashy" nature of the streams, the small size of the supply ponds, the lack of large storage reservoirs and the short time required for the water of the streams to reach the city, are facts which cannot be viewed other than with feelings of insecurity.

Ridgewood System.

The main water supply of the Borough of Brooklyn is derived from Long Island. The watershed occupies a position on the southern slope of the Island east of the city, and includes portions of the counties of Queens, Nassau and Suffolk (a small portion of the drainage area of Massapequa Stream extends into Suffolk County). It has a drainage area of approximately 162 square miles. It includes about a dozen comparatively small streams flowing in a general southerly direction toward the Atlantic Ocean. A series of ponds or small storage reservoirs has been formed by constructing dams across these streams. A conduit which extends in an easterly and westerly direction from Ridgewood to Massapequa, collects the waters thus retained. This surface supply is supplemented by 15 driven well stations also located along the lines of the conduit. That portion of the watershed east of Rockville Center is known as the New Watershed, and that portion west of Rockville Center is the Old Watershed. The water from the new watershed is repumped at Millburn. East of Millburn Pumping Station there is a single conduit, but between Millburn Pumping Station and Ridgewood there are, in addition to the conduit, two pipe lines. At the main pumping station at Ridgewood there are two sets of pumps, one on the north side and the other on the south side of the Long Island Railroad. The distribution reservoir at Ridgewood comprises three basins, Nos. 1, 2 and 3. The north side pumps take water from the conduit and deliver it into Basin 1 and 2, while the south side pumps take water from the conduit and pipe lines and deliver it into Basin 3. The water pumped at the south side, therefore, contains a slightly larger proportion of water from the new watershed than the water pumped at the north side. With the exception of Hempstead Storage Reservoir, the supply ponds are very small and shallow, but the watershed is of such a sandy character that the amount of underground storage is very great. In fact, except during periods of flood, a very large proportion of the water flowing in the streams is in reality ground water.

The wells at the different driven well stations penetrate the sand layers to different depths. Those wells which terminate above the clay strata are generally referred to as " shallow wells." Those which penetrate the clay strata are known as "deep wells." Various data concerning the different streams and wells may be found in Table No. 1b. The low service system of the Borough is supplied directly from Ridgewood Reservoir. The high service sections, which are located not far from Prospect Park, are supplied from Mt. Prospect Reservoir and stand-pipe, the water being taken from one of the mains and re-pumped at the Mt. Prospect Pumping Station.

In addition to the Ridgewood supply, there are eight independent supplies in the borough, three of which are owned and operated by the Department of Water Supply, Gas and Electricity. They are all ground water supplies. The New Lots Station supplies the Twenty-sixth Ward of Brooklyn, which is known as East New York. The Gravesend and New Utrecht stations supply a large area in the southern portion of the borough. The Flatbush Water Company supplies the Twenty-ninth Ward of Brooklyn, known as Flatbush. The German-American Water Supply Company, the Pfalzgraf and the Blythbourne Water Supply Companies furnish water to relatively small sections of the borough. The old "West Brooklyn Water Works" were burned a few years ago. In addition to those mentioned, there is a water supply in Prospect Park which is used by many people during the summer.

Turbidity—The turbidity of the water yielded by the entire system, as represented by samples collected at the Ridgewood Pumping stations, is ordinarily low, except after heavy rains. It was not until the year 1900 that the turbidity of the water was expressed in figures, but since then observations have been regularly made. The average turbidity of the water at the North Side Pumping Station for the years 1900, 1901 and 1902 was 4, and at the South Side it was 3. The North Side Station receives a larger percentage of water from the western portion of the watershed, which is usually more turbid than that on the eastern portion, as shown by the following figures:

Table Showing the Minimum, Maximum and Average Turbidity and Color of the Water in the Supply Ponds for the Years 1900 *to* 1902.

	Turbidity.			Color.		
	Minimum.	Maximum.	Average.	Minimum.	Maximum.	Average
Massapequa Pond	0	4	1	5	172	40
Wantagh "	0	6	2	2	55	18
Newbridge "	0	4	1	6	75	26
East Meadow "	0	20	2	6	56	25
Millburn "	0	28	2	4	74	17
Hempstead Storage Reservoir	1	20	3	0	27	8
Schodack Brook	0	22	2	3	30	11
Hempstead Pond	1	360	3	0	26	11
Pine "	1	110	3	2	37	15
Smith's "	0	115	3	5	40	18
Valley Stream "	1	110	3	6	45	21
Watts "	0	80	4	4	110	19
Clear Stream "	1	150	4	2	55	12
Simonson's "	1	520	7	2	40	10
Springfield "	1	70	6	5	130	24
Baiseley's "	4	130	15	9	110	32

The turbidity of the water in the streams rises at times to figures much greater than those given in the table. The reason for the greater turbidity in the western ponds is due to the greater population dwelling upon the watershed, to the larger percentage of cultivated land and to the closer proximity of the roads to the streams. All of the well water is without turbidity as it issues from the ground. In certain cases, when it is charged with iron, however, this precipitates on standing so that the water is turbid by the time it reaches the laboratory.

A certain amount of the suspended matter is deposited in the distribution reservoir at Ridgewood and Mt. Prospect, but the turbidity there lost is often more than made up by growths of microscopic organisms, so that the turbidity of the tap water is no less than that of the water at the Ridgewood Pumping Station. This is shown by the following table:

Table Showing the Maximum, Minimum and Average Turbidity and Color of the Water in the Distribution System from 1898 to 1903.

	Turbidity.			Color.		
	Minimum.	Maximum.	Average.	Minimum.	Maximum.	Average.
Ridgewood Reservoir—						
Basin No. 2 Influx	1	65	4	2	32	13
" No. 3 "	1	60	3	3	34	13
" No. 1 Efflux	1	45	3	3	36	12
" No. 2 "	1	45	3	4	35	13
" No. 3 "	1	45	4	3	36	14
Mt. Prospect Reservoir	1	25	5	2	45	12
Tap in Mt. Prospect Laboratory	1	43	3	3	36	13
Tap corner Flushing and Clermont avenues	1	48	3	3	36	13
Tap corner Seventh and Flatbush avenues	1	32	3	3	33	13

The effect of rainfall in increasing the turbidity of the water in the city is clearly shown by Plate III. During the last few years, frequent complaints of muddy water have been made in Brooklyn, and investigations have shown that in almost every case this was due to the disturbance of local deposits of iron and organic matter in the distribution mains.

Color—The color of the Ridgewood water is low, but several of the sources of supply have quite a high color, especially those in the eastern portions of the watershed. The color of the water in Massapequa pond, for example, has averaged 40, while at times it has risen to 170. The high color is due to the water which stands in the large swamp just above the pond, and might be eliminated to a great extent by a well-devised system of drainage. The supplies near the centre of the watershed are low in color. A few of the western ponds are somewhat colored, but the waters of Baiseley's and Springfield ponds are not used without filtration, so that what little color the Brooklyn water has may be said to be acquired chiefly from the eastern ponds. All of the well water as drawn from the ground is colorless. The [illegible] the average [illegible] [illegible] [illegible]

[illegible] of the water [illegible] [illegible] vegetable and occasionally [illegible] [illegible] [illegible] [illegible] grassy or fishy. The vegetable [illegible] [illegible] [illegible] organic matter [illegible] [illegible] [illegible] have been present [illegible] [illegible] the decomposition of this organic matter. The number [illegible] [illegible] has been uniformly [illegible] [illegible] the absence of animalcul[illegible] grassy and fishy odors.

The supply ponds when used seldom become infested with growths [illegible] [illegible] organisms [illegible] such an extent as to give the water an objectionable [illegible] although in several instances this has happened. Heavy growths [illegible] [illegible] have at times led to shutting off [illegible] [illegible]

[illegible]

[illegible] Organisms [illegible] the Supply Ponds.

[illegible]	Average Number of Microscopic Organisms, Standard Units per c.c.					
	[illegible] *	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* [illegible] † [illegible]

For several years prior to 1901 no water was drawn from Baiseley's pond on account of pollution, and during this time the blue-green algae (chiefly Clathrocystis) developed in enormous numbers. In 1901 the pond was drawn down and the mud removed from a large part of the bottom. The beneficial effect of this cleaning may be seen from the above table.

The following is a list of the microscopic organisms which have been observed in the Brooklyn water at various times. The genera printed in heavy type are those which have at times occurred in numbers greater than 100 per c. c. The genera which are starred are those which have been the cause of objectionable odors.

List of Microscopic Organisms Which

Plant Organisms.

Diatomaceae.	Chlorophyceae.	Cyanophyceae.	Schizomycetes and Fungi.
Amphora	Botryococcus	**Anabaena***	Cladothrix
Arthrodesmus	Chaetophora	**Aphanizomenon***	**Crenothrix**
Asterionella*	Coelastrum	Chroococcus	Lepotothrix
Cyclotella	**Closterium**	**Clathrocystis***	Mold Hyphae
Cocconeis	Conferva	Coelosphaerium*	
Cymbella	Cosmarium	Cylindrospermum	
Diatoma	Desmidium	Merismopedia	
Epithemia	Dictyosphaerium	**Micricytis***	
Fragilaria	Dimorphococcus	Oscillaria	
Gomphonema	Docidium		
Hymantidium	Draparnaldia		
Melosira	**Eudorina**		
Meridion	Gonium		
Navicula	Gloeocapsa		
Nitzschia	Hyalotheca		
Pleurosigma	**Pandorina**		
Saturoneis	Pediastrum		
Stephanodiscus	**Protoccus**		
Surirella	Raphidium		
Synedra*	Scenedesmus		
Tabellaria*	Sphaerozosma		
	Spirogyra		
	Staurastrum		
	Volvox		
	Xanthidium		
	Zoospores		
	Zygnema		

Have Occurred in the Brooklyn Water.

Animal Organisms.			
Protozoa.	Rotifera.	Crustacea.	Miscellaneous.
Actinophrys	Anuraea	Branchipus	
Anthophysa	Asplanchna	Bosmina	
Arcella	Brachionus	Cyclops	
Bursaria	Conochilus	Daphnia	
Ceratium	Mastigocerca		
Cercomonas	Notholca		
Chlamydomonas	Ova		
Codonella	Polyarthra		
Coleps	Rotifer		
Colpidium	Synchaeta		
Cryptomonas	Triarthra		
Difflugia			
Dinybryon*			
Enchelys			
Epistylis			
Euglena			
Euglypha*			
Glenodinium			
Halteria			
Mallomonas			
Monas			
Nassula			
Opalina			
Paramaecium			
Peridininm			
Phacus			
Raphidomonas			
Stentor			
Synura*			
Tintinnus			
Trachelocerca			
Trachelomonas			
Trinema			
Uroglena			
Vorticella			

With the exception of the Hempstead Storage Reservoir, the supply ponds are very shallow, the water in the summer being often less than five feet deep. They are supplied largely with ground water. It is not surprising, therefore, that aquatic plants develop vigorously on the bottom and shores of the ponds. Late in the summer it is not at all an uncommon sight to see masses of Anacharis, Ceratophyllum, Potamogeton, Utricularia, etc., reaching to the surface of the water and covering great areas near the shores. In the winter these growths die and settle to the bottom. When growing they do not impart a noticeable odor to the water, but they form a nidus for microscopic organisms which are ultimately carried into the conduit to seed the distribution reservoirs. The aquatic plant masses in the ponds act as natural filters to remove turbidity from the water, but the matter which adheres to them eventually settles to the bottom and is added to the sediment there. It seems probable that without the presence of this plant life in these shallow ponds the organic matter would not accumulate there as rapidly as it does.

The ground water does not contain microscopic organisms except genera such as Crenothrix, Cladothrox, Lepothrix, etc., which are capable of living under anaerobic or semi-anaerobic conditions in the driven well tubes. Crenothrix is found at times in nearly all of the well waters, but it is especially abundant in those waters which contain much iron in solution. The well points at many of the stations become practically or wholly clogged after a certain period of service, and there is good reason to believe that Crenothrix plays an important part in the process by which iron oxide and sand unite to fill the meshes of the strainers. The common form of Crenothrix is that which deposits iron in its gelatinous sheath, but in some of the driven wells of the Ridgewood system a species has been discovered which appears to deposit aluminum instead of iron. (See paper by D. D. Jackson —A New Species of Crenothrix, Trans. Am. Micro. Soc., Vol. XXIII., p. 31, May, 1903.)

It was stated that the water which enters Ridgewood Reservoir contains but few microscopic organisms, and therefore has no odor properly described by the terms aromatic, grassy, wood, fishy, etc. If this water were delivered to the consumers in the condition at which it arrives at Ridgewood Pumping Station, its physical qualities would be considered as generally satisfactory, except after heavy rains. Unfortunately, however, growths of microscopic organisms occur in the distribution reservoirs at Ridgewood and Mt. Prospect, imparting to the water most unpleasant odors and render it turbid and unsightly. Before the year 1896, these organisms, although known to be present in the supply, did not develop in numbers sufficient to cause trouble. In the summer of that year the tap water became very offensive, and this led to an extensive investigation on the part of the Water Department, conducted by the late Dr. Albert R. Leeds, of Stevens Institute. His investigation plainly showed that the cause of the trouble was the diatom Asterionella, which was found in enormous numbers in Ridgewood Reservoir. His microscopical examinations were not begun until the fall of 1896, and from studies since made there is good reason to belive that the odors observed in the early summer of that year were due not to Asterionella but to Anabæna. Both organisms, however, developed in the distribution reservoirs and not on the watershed. The practical result of the investigation was the construction of a by-pass to lead the water around the reservoir when necessary, and the establishment of Mt. Prospect Laboratory.

Since 1896 growths of microscopic organisms have continually recurred in the reservoirs mentioned, different organisms appearing and disappearing with the seasons, but by a judicious use of the by-pass, the number of microscopic organisms in the tap water has been kept at a comparatively low figure, as shown by the following figures:

Number of Microscopic Organisms.

	Standard Units Per C. C.							
	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.
Ridgewood—								
Basin No. 2 Influx.	50	225	105	97	414	55	51	124
" 3 "	4	163	102	76	251	55	74	123
" 1 Efflux.	273	7,793	3,432	4,782	1,426	608	238	280
" 2 "	62	403	8,669	1,115	1,307	740	1,261	503
" 3 "	3,650	2,181	1,823	1,872	3,372	790	1,915	747
Mt. Prospect Reservoir	9,824	11,738	8,188	8,891	6,536	3,891	2,935	3,585
Tap in Mt. Prospect Laboratory*	200	1,320	1,170	859	1,330	461	426	397
Tap, Flushing and Clermont avenues†	3,840	1,710	1,266	863	1,337	328	449	327
Tap, Flatbush and Seventh avenues‡	5,730	4,414	3,571	1,786	3,614	1,713	1,125	1,103

The seasons of occurrence of these organisms are shown graphically on Plate No. VI.

It will be observed that there has been a gradual reduction in the intensity of the organism growths during the past five years.

The genera which have caused the most trouble are Asterionella, Anabæna, Synedra, Melosira, Diatoma, Chlamydomonas, Cyclotella and Scenedesmus.

* Water from Basins Nos. 1 and 2, Ridgewood Reservoir.
† Water from Basin No. 3, Ridgewood Reservoir.
‡ Water from Mt. Prospect Reservoir.

An examination of the figures given in the above table shows that the numbers of organisms in the city tap have been much less than those in the reservoirs. The taps at Mt. Prospect Laboratory and at Flushing and Clermont avenues are supplied from Ridgewood Reservoir, while the tap at the corner of Flatbush and Seventh avenues is supplied from Mt. Prospect Reservoir. The latter reservoir cannot be entirely shut off from the supply, hence more of the microscopic organisms from that reservoir find their way to the City.

The figures just referred to do not fairly show the difference between the tap water and the water in the reservoir, because they do not distinguish between the organisms which are objectionable and those which are not. The by-pass is used only when the odoriferous organisms are present, as it is advisable for sanitary reasons to take as complete advantage as possible of the limited storage. A better comparison of the water can be made by considering the odor caused by the organisms, and the following figures illustrate this:

	Per Cent. of Samples Which Had Odors Attributable to Microscopic Organisms.				
	1898.	1899.	1900.	1901.	1902.
Ridgewood—					
Basin No. 1 Influx....	0	0	13	0	0
" 3 "	0	0	9	0	2
" 1 Efflux....	33	45	29	11	2
" 2 "	14	9	32	8	16
" 3 "	17	31	49	10	36
Mt. Prospect Reservoir....	81	80	70	27	36
Tap in Mt. Prospect Laboratory..............	10	32	26	0	0
Tap at Flushing and Clermont avenues........	8	14	26	2	0
Tap at Flatbush and Seventh avenues.........	27	38	34	4	11

Even these figures do not fully show what has been accomplished by the use of the by-pass, as they do not take into account the intensity of the odor. The by-pass is not opened until the number of organisms is found to be sufficient to produce what is termed a " distinct odor."

The regimen of the growths of organisms which occur in the distribution reservoirs in Brooklyn is entirely in harmony with what has been observed elsewhere and emphasizes the fact that ground water cannot be stored satisfactorily in open reservoirs. Ground waters usually contain an abundance of plant food, such as nitrates, free carbonic acid, etc., and if stored in reservoirs exposed to sunlight, the waters often become affected with growths of microscopic organisms, if once they become seeded. Since this is true, there is all the more danger for growths to occur in mixtures of surface and ground water, the one furnishing the mineral constituents required by the organisms, and the other furnishing organic matter. Such waters, furthermore, have greater chances of becoming seeded with microscopic organisms. It was not until the percentage of ground water in the Brooklyn supply attained a high figure that these organisms began to develop abundantly in the distribution reservoirs, and the indications are that as time goes on the proportion of ground water will continue to increase until it reaches 100 per cent. In spite of this, however, there is good reason to believe that comparatively little trouble would be experienced in these reservoirs if they could be kept perfectly clean, that is, if deposits of organic matter could be prevented from accumulating on the bottom. For example, the dense growth of Anabæna, which occurred in Basin No. 2 of Ridgewood Reservoir during the summer of 1898, led to the basin being emptied and cleaned of its accumulated deposit. The cleaning did not entirely prevent all growths of organisms in the following years, but the Anabæna, which caused the trouble in 1898, has not since returned.

The use of the by-pass in ameliorating the objectionable conditions occasioned by the growth of organisms cannot be looked upon, however, in the present case as being entirely satisfactory, inasmuch as it materially shortens the time required for water to pass from the supply pond to the consumers, and thus increases the danger of an epidemic, should the water at any point become infected. The reservoir at Ridgewood must be ultimately covered, but this would be so hazardous an undertaking, with the existing limited facilities for storage, that it probably is not warranted at the present time. To make sure that these reservoirs are kept clean and that organisms are not allowed to form deposits on the bottom, therefore, is imperative. Mt. Prospect Reservoir, which supports much heavier growths of organisms than does Ridgewood Reservoir, should be covered at an early date if its use is to be continued. It is situated in the heart of the city, and the water is constantly becoming contaminated by the clouds of dust blown from the street. For sanitary reasons, therefore, this reservoir ought to be covered. Then the reservoir is so situated, with respect to the Park System, that some sort of architectural treatment is demanded on æsthetic grounds. The present sharp outlines of the reservoir banks do not harmonize well with the surrounding landscape. If this reservoir could be covered in such a way that its roof could be utilized by the public as a park this commanding spot would become one of the greatest points of attraction in the City. Such a plan would naturally involve modifications in the present embankments, the removal of the superstructure of the present gate-house, the planting of shrubs, trees, etc., the laying out of new pathways and perhaps the construction of a fountain supplied with water from the tower. It would appear that this plan is one in which the Department of Water Supply and the Department of Parks should be mutually interested.

The heavy growths of microscopic organisms which have occurred in the distribution reservoirs during the past few years have been the cause of no little fouling of the distribution pipes by growths of fresh water sponge, Byrozoa, etc. The relation between microscopic organisms and the so-called pipe-moss has been explained in connection with the Croton supply. The growths of Paludicella, however, appear to have been very much greater in the Brooklyn water pipes than in New York. On one occasion, when the flow through some of the large mains was suddenly reversed, these organisms became detached from the sides of the pipes in such masses that hundreds of water-taps in the City were plugged up, and in one or two instances, two-inch mains were entirely stopped by the fibrous masses. This is a further argument, therefore, for doing all that can be done to keep the microscopic organisms out of the distribution reservoirs.

Sanitary Quality—Pollution of the Watershed.

The population of the watershed of the Ridgewood system averages about 208 per square mile, but it varies in different sections from 78 to 1,250. The population densities on the different portions of the watershed are shown in Table No. 1a. The drainage areas there given are based in part upon data furnished by Mr. Walter E. Spear, Department Engineer of the Long Island Division, and in part upon planimeter measurements of watershed outlines drawn from the contours of the United States Geological Survey atlas sheets. They differ slightly from figures previously published. The populations are based partly upon the census returns and partly upon a count of the number of houses on the watersheds. There is a general decrease in population density from the western to the eastern portions of the watershed, the regions nearest the city being naturally the most thickly settled. There is also in some cases a decrease in population density northward, and this accounts for the lower population densities on some of the larger streams which extend northward to the backbone of the Island. The soil on Long Island is so sandy that many of the streams are non-existent in the upper portions of their watersheds except during the spring flows. An attempt was made to calculate the populations per square mile for the lower portions of the streams, but the results obtained did not appear to possess any advantage over those given in the table, although in some instances, as, for example, Valley Stream, the population densities were increased.

The population on the watershed is rapidly growing, and this growth is destined to increase at a still greater rate in the near future on account of the extension of rapid transit facilities to the suburbs of Brooklyn. Already speculators are purchasing property on the watershed and laying out the sites of future communities. The construction of an immense race track just above Elmont, on Simonson's Stream, will serve to greatly increase the population in that region, and will be the means of drawing thousands of people there during the summer season. The rapid increase in the population of the watershed of the Ridgewood system, which is in striking contrast with the stability of population on the Croton watershed, is shown by Diagram No. 5.

Except for the village of Jamaica, located upon the watershed of Baiseley's Stream, the population is rural in character. Jamaica has a sewerage system which carries the sewage to a point below the conduit, where it is to be treated by a special process before it is discharged into the bay. The system is a comparatively new one, however, and many houses near the feeders of Baiseley's Pond do not have sewer connections. For a number of years no water has been used from this pond except what has been purified by a system of mechanical filtration.

The next largest centre of population is the village of Hempstead, which is situated only about two miles above the Hempstead Storage Reservoir. This village has no system of sewers, although it should have, even for its own sake. Hempstead stream, otherwise known as "Horse Brook" or "Parsonage Brook," flows through the heart of the village, and there are many serious nuisances immediately adjacent to the stream. All privies are panned, however, and cleaned by the Department of Water Supply, Gas and Electricity. The water of the stream under dry weather conditions is not allowed to enter the reservoir, but is carried around and below it through a by-pass and wasted. When the flow of the stream exceeds the carrying capacity of the by-pass, as it sometimes does, the surplus accumulates in a sedimentation basin, and when this is full the water spills into the reservoir. During the summer, when it is necessary to husband all the water resources possible, this basin is allowed to fill and stand for about three weeks, and when time and subsidence have seemed to considerably purify the water the contents are turned into the reservoir. A sand filtration plant is being constructed below the dam to filter the water which is now being wasted through the by-pass and allow it to enter Hempstead Pond.

Although there are no other large centres of pollution, there are many nuisances existing along the various streams, especially on Springfield Stream and Simonson's Stream. The water from Springfield Pond had not been used for several years, however, until a mechanical filter was constructed to purify it. A sand filter, to purify the water of Simonson's Stream, is also being constructed.

No general attempt was made by the old City of Brooklyn to preserve the sanitary quality of the water by the purchase of property along the stream, although in some instances this was done. On most of the streams the privies which are located near the water are panned, and the pans are emptied weekly by the Department of Water Supply, Gas and Electricity. This serves to mitigate many serious nuisances, although the method itself is something of a nuisance, it being almost impossible to always empty the pans into the collecting cart without spilling some of the offal on the ground.

It will be seen from the data given in Table No. 1 that some of the conditions which tend to reduce the danger from infection of the Croton water are lacking in the Ridgewood system. The watershed is nearer the city, the ponds are small, shallow and adjacent to the conduit, so that the "time-factor" in the destruction of pathogenic bacteria is much less pronounced, and there is less opportunity for efficient sedimentation. Another factor which tends to prevent danger from infection, however, is much more potent than on the Croton watershed, namely, the sandy character of the soil. This is such as to cause almost the entire surface of the ground to act as a sand filter and thus purify the surface water. Indeed there are many reasons to believe that a large part of the water normally flowing in the stream is rain-water which has first passed through the soil. The entire supply of the Ridgeway system partakes of the character of a ground water supply to a very great extent. And it is in this direction that the safety of the water supplies from the Long Island watersheds must be sought. All of the water must be eventually drawn from beneath the surface of the ground. Filtration of some of the surface supplies may prove more economical for some time to come, but the time may eventually arrive when a single filtration will not prove adequate to the task of removing the danger from infection.

During recent years typhoid fever has not been prevalent in Nassau County, as shown by the following figures, compiled from the published records of the State Board of Health:

Typhoid Fever Death-rate per 100,000.

Year.	Nassau County.	Suffolk County.
1894	25.2	32.9
1895	10.5	33.0
1896	16.2	13.5
1897	21.7	17.4
1898	1.9	33.6
1899	9.3	21.4
1900	9.9	20.7
1901	8.8	11.1
1902	15.3	16.6
Average	13.2	21.1

In seeking to ascertain the sanitary character of the Brooklyn water from the analytical results, chief attention must be given to the odors of decomposition, the number of bacteria, the presence of Bacillus coli, the excess of chlorine above the normal and the amount and character of the nitrogen compounds. These are summarized for the supply ponds in the following table, which is based on weekly (in some instances monthly) analyses, covering a period of five years.

Summary of Weekly Analyses.

	Per Cent. of Samples which Had Odors of Decomposition.	Number of Bacteria Per C.C.	Per Cent. of Samples Which Gave Positive Tests for B. Coli With 1 C.C.	Excess of Chlorine Above Normal.	Nitrogen as			
					Albuminoid Ammonia.	Free Ammonia.	Nitrites.	Nitrates.
Massapequa	2	434	4.3	0.3	.083	.010	.001	0.32
Wantagh Pond	2	385	5.5	0.5	.072	.010	.001	0.40
Newbridge	7	172	5.0	0.9	.063	.007	.001	0.41
East Meadow	2	469	7.6	0.4	.065	.016	.001	0.51
Millburn Pond	8	417	11.3	1.7	.054	.009	.002	0.19
Hempstead Stream	99	3,010	30.0	14.6	.099	.826	.022	3.19
" Storage Reservoir	16	658	8.0	1.9	.092	.026	.006	1.09
Schodack Brook	7	664	13.9	1.0	.045	.020	.003	1.16
Hempstead Pond	8	448	6.2	1.0	.072	.037	.003	0.26
Pines Pond	7	522	6.9	1.2	.070	.019	.004	0.97
Smith's Pond	8	492	7.2	1.2	.070	.024	.003	0.55
Valley Stream Pond	9	571	4.2	1.5	.080	.014	.005	1.58
Watt's Pond	10	847	10.5	1.6	.068	.026	.004	1.43
Clear Stream Pond	21	903	9.4	3.0	.058	.018	.009	4.80
Simonson's Pond	49	2,171	9.8	3.3	.061	.025	.012	4.16
Springfield Pond	72	1,337	17.0	7.4	.114	.044	.012	2.82
Baiseley's Pond	55	1,168	10.6	4.9	.287	.072	.010	1.78
Ridgewood Reservoir—								
Basin No. 2, Influx	5	375	5.7	*	.044	.029	.003	1.14
Basin No. 3, "	3	320	5.3	*	.045	.019	.002	1.00
" No. 1, Efflux	8	379	5.5	*	.066	.018	.004	1.08
" No. 2, "	3	399	9.0	*	.061	.019	.003	1.07
" No. 3, "	4	329	4.5	*	.065	.012	.003	0.96
Mt. Prospect Reservoir	3	208	1.5	*	.128	.013	.009	0.82
Tap in Mt. Prospect Laboratory	3	291	4.2	*	.050	.005	.002	1.08
Tap at Flushing and Clermont avenues	2	317	4.1	*	.054	.005	.002	1.04
Tap at Flatbush and Seventh avenues	1	314	1.0	*	.065	.006	.003	1.00

The difference in the sanitary quality between the eastern and the western ponds, as shown by these analyses, is very marked. If the ponds are grouped according to the excess of chlorine above the normal, the following average figures are obtained.

*The excess of chlorine cannot be determined, because of the influence of the sea-water on some of the driven wells.

Summary of Analyses, with Sources Grouped According to "Excess of Chlorine."

Number of Groups.	Limits of Excess of Chlorine Above the Normal.	Average Excess of Chlorine.	Nitrogen as: Albuminoid Ammonia.	Nitrogen as: Free Ammonia.	Nitrogen as: Nitrites.	Nitrogen as: Nitrates.	Per Cent. of Samples Which Had Odors of Decomposition.	Number of Bacteria Per C.C.	Per Cent. of Samples Which Gave Positive Tests for B. Coli in 1 C.C.	Ponds Included in the Group.
I...........	.0– .5	0.4	.073	.012	.001	0.41	2	429	5.8	Massapequa, Wantagh, East Meadow.
II..........	.5– 1.0	0.9	.052	.022	.003	0.63	8	444	8.1	Newbridge, Schodack, Hempstead Pond, Smith's.
III.........	1.0– 2.0	1.6	.073	.019	.004	1.19	10	603	8.2	Millburn, Hempstead Stge., Pines, Valley Stream, Watts.
IV..........	2.0– 4.0	3.1	.059	.021	.010	4.48	35	1,537	9.6	Clear Stream, Simonson's.
V...........	4.0– 10.0	6.1	.200	.058	.011	2.30	63	1,202	13.8	Springfield, Baiseley's.
VI..........	10.0– ..	14.6	.099	.826	.022	3.19	99	3,010	30.0	Hempstead Stream, below Hempstead.

These show a progressive series, representing the chlorine excess, nitrites, odors of decomposition, bacteria and tests for Bacillus coli. The figures for albuminoid ammonia and free ammonia do not fall as regularly into the series, as they are too much affected by organic matter from sources other than those of pollution.

No analyses like these should be interpreted except in connection with the known conditions on the watershed, but when all the facts are considered, the following seems to be a fair classification of the surface supplies of the Ridgewood system:

Reasonably Safe Supplies.

Massapequa Pond.
Wantagh Pond.
Newbridge Pond.
East Meadow Pond.
Hempstead Pond.
Smith's Pond.

Insecure Supplies.

Millburn Pond.
Schodack Brook.
Hempstead Storage Reservoir.
Pines Pond.
Valley Stream Pond.
Watts Pond.

Unsafe Supplies.

Clear Stream Pond.
Simonson's Pond. (Safe when filtered. Filter being constructed).

Dangerous Supplies.

Springfield Pond. (Safe when filtered).
Baiseley's Pond. (Safe when filtered.)
Hempstead Stream below Hempstead (now diverted by by-pass. Filter being constructed).

The above table is liable to make the character of the present supply appear worse than it really is. About 40 per cent. of the supply is taken from driven wells, and may be considered as absolutely safe. Taking this into consideration and giving weight to the various surface sources in proportion to their drainage areas, we arrive at the following approximate percentage composition of the water furnished to the consumers:

	Per Cent. by Volume.
From absolutely safe sources	40
From reasonable safe sources	40
From insecure sources	16
From unsafe sources	4*
From dangerous sources	0
Total	100

By comparing the analyses of the water at Ridgewood Reservoir with those of the supply ponds, the weight of the "absolutely safe" and the "reasonably safe" water upon the general supply will be evident. This is especially noticeable in the odors of decomposition, the number of bacteria, the tests for Bacillus coli and the nitrites, tests which relate especially to the sanitary quality.

The beneficial effect of even the small storage in the distribution reservoir is shown by the tests for Bacillus coli. The average number of positive tests in the water as it enters Ridgewood was 4; in the taps supplied by Ridgewood Reservoir it was 2.5, and in the tap supplied by Mt. Prospect Reservoir it was 1.0.

*These supplies are shut off when analyses indicate that this is advisable. Filters are being constructed at Simonson's Pond, and Clear Stream Pond furnishes so little water that it may be abandoned. This "unsafe" water, therefore, will be soon entirely eliminated from the supply.

The variations in the sanitary quality of the water during the year 1903 is shown on Plate No. V. Just as in the case of the Croton supply, little appears to be learned from the regular chemical analyses, while the number of bacteria and the tests for Bacillus coli fluctuate with the rainfall.

Chemical Character of the Water.

Because of the large and increasing proportion of ground water in the Ridgewood system, the chemical character of the water deserves extensive consideration. This may be discussed under the heads of Chlorine, Hardness and Iron.

Chlorine.

The Ridgewood Watershed is located so close to the sea that the normal chlorine is relatively high. Whereas the normal for the Croton Watershed is only about 1.6 parts per million, it is somewhere between 5 and 6 parts per million for the Ridgewood system. This was ascertained by collecting samples of unpolluted water at widely scattered localities over Long Island, and from these data obtained in 1898, a map of normal chlorine was drawn. (See A Normal Chlorine Map of Long Island, by G. C. Whipple and D. D. Jackson, Tech. Quar., Vol. 13, Mo. 2, June, 1900.) During the past year this map has been revised by Mr. Jackson, who has also extended the isochlors over the entire State. (See Plate XI.)

At the eastern end of the Island, and except near the coast, the normal chlorine was below 6 parts per million. On the south shore, the isochlor of 6 parts per million was only 2 or 3 miles inland, while on the north shore it was 3 or 4 miles inland. The isochlor of 5 parts per million is about 2 miles further from the shore and is parallel with the former. The isochlor of 4 parts per million nearly surrounds an area in the centre of the island from 3 to 5 miles wide. In the centre of this region the normal chlorine is somewhat lower than 4 parts per million. Several samples in the interior contained as little as 3 parts per million. The normal chlorine at the line of the Aqueduct of the Brooklyn Water Supply is about 6 parts per million, but most of the streams cross the isochlor of 4 parts per million and a few take their rise in a region where the normal chlorine is below 4 parts per million. It seems probable that the normal chlorine for the supply ponds of the Brooklyn Watershed is somewhere between 5 and 6 parts per million. At the eastern end of the Island, the normal chlorine is very high and varies greatly in different localities. In this respect, it resembles the normal chlorine found on Cape Cod, Mass.

The following figures show the average amount of chlorine in parts per million in the different sources of supply for a period of five years:

Average Amount of Chlorine in Parts per Million in the Different Sources of Supply.

Surface Waters.	Chlorine.	Ground Waters.	Chlorine.
Massapequa Pond	5.3	Massapequa (deep and shallow)	5.5
Wantagh Pond	5.6	Wantagh (deep and shallow)	3.7
Newbridge Pond	5.9	Matawa	4.2
East Meadow Pond	5.4	Merrick	5.3
Millburn Pond	6.7	Agawam	5.0
Hempstead Storage Reservoir	6.4	Watts Pond (shallow)	7.5
Schodack Brook	6.0	Clear Stream (shallow)	6.3
Hempstead Pond	6.0	Forest Stream (shallow)	6.0
Pines Pond	6.2	Springfield (deep)	3.9
Smith's Pond	5.8	Jameco (deep)	4.8
Valley Stream Pond	6.5	Jameco (deep and shallow)	25.7
Watts Pond	6.6	Baiseley's (shallow)	114.9
Clear Stream Pond	9.0	Oconee (deep)	4.8
Simonson's Pond	8.8	Shetucket (deep)	264.2
Springfield Pond	12.4	Spring Creek Old Plant (deep)	7.1
Baiseley's Pond	9.9	Spring Creek Old Plant (shallow)	139.1
		Spring Creek, New Plant (shallow)	55.2

If the water supplied to Brooklyn contained no more chlorine than the normal for the watershed, it could not be objected to on this account. The pollution of the western streams tends to increase the amount slightly, but it is because certain driven wells are affected by sea-water that the chlorine in the city is undesirably high.

The following figures give the amount of chlorine in the water supplied to Brooklyn from January, 1895, to November, 1903. The

Table Showing the Amount of Chlorine in Parts per Million in the Water Supplied to Brooklyn.

Month.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.
January	11.80	23.00	13.60	10.25	15.30	19.20	17.80	24.10	13.9
February	10.75	13.00	14.50	7.30	17.80	17.30	21.35	23.00	9.4
March	9.88	12.00	14.30	11.75	16.45	16.45	17.75	19.80	8.5
April	10.50	9.80	14.10	17.60	14.45	15.00	16.35	18.65	10.3
May	10.55	7.50	15.50	13.80	18.40	16.55	16.25	15.30	10.3
June	10.63	8.20	16.20	11.50	18.35	17.15	20.25	20.15	9.7
July	16.90	10.10	17.00	10.15	15.85	18.60	21.25	19.90	7.9
August	20.63	12.00	18.60	12.00	19.00	15.40	19.40	19.95	12.5
September	17.25	12.50	20.60	16.55	19.10	17.55	21.55	20.35	12.2
October	17.20	14.00	17.70	18.90	17.40	16.85	22.45	22.10	10.5
November	20.00	16.60	13.20	17.20	15.30	22.90	23.50	23.25	9.1
December	22.40	15.00	7.20	11.45	17.75	18.00	24.25	15.90	....

NOTE.—The figures for 1895, 1896 and 1897 were taken from the published records of the Health Department; those from 1898 to 1902 were taken from the records of Mount Prospect Laboratory and represent the average water entering Ridgewood Reservoir.

figures for 1895, 1896 and 1897 were taken from the published records of the Department of Health. Those from 1898 to 1903 were taken from the records of Mt. Prospect Laboratory, and represent the monthly means of weekly analyses of the water entering the Ridgewood Reservoir. These results are shown graphically in Diagram No. 9. The high chlorine during the latter part of 1895 was due to the effect of water from the wells first sunk at Agawam, and which were afterwards taken up and redriven on account of the influence of the salt water. In 1897 the increasing chlorine was caused by excessive draught from the wells at Baisley's and Spring Creek. During the latter part of 1897 and 1898 a vigorous attempt was made to reduce the chlorine in the tap water by temporarily shutting down the well stations at Baisley's and Spring Creek and by disconnecting some of the wells at Jameco. At this time the well water at Shetucket had not become affected by the sea water. The influence of the infiltering sea water at Spring Creek, Baisley's and Jameco was shown by the following calculation. (See Table on page 409.) On September 28, 1897, the records showed that water was being taken from various sources according to the figures given in Column 2. The amount of chlorine for each source is indicated in Column 3. Column 4 represents the products of Columns 2 and 3. The total product of Column 4, divided by the total number of gallons pumped, as shown in Column 1, gives 21.39 as the calculated chlorine for the entire watershed on that date. Observations on the same date showed that the water entering Basins 1 and 2 of Ridgewood Reservoir contained 25.7 parts and that the water entering Basin 3 contained 17.2 parts per million. The average of these two figures is 21.45, which agrees very well with the calculated results given above. On the same day the water at the Efflux Basin contained 24.6 parts, Basin 2, 21.9 and Basin 3, 19. The average of these is 21.8, which also agrees well with the calculated value. By deducting the figures for Baiseley's and Spring Creek station, it is found that if these stations had been eliminated the chlorine in the tap would have been 6.76 parts per million instead of 21.39, and later observations showed that when these stations were shut down this figure was actually reached.

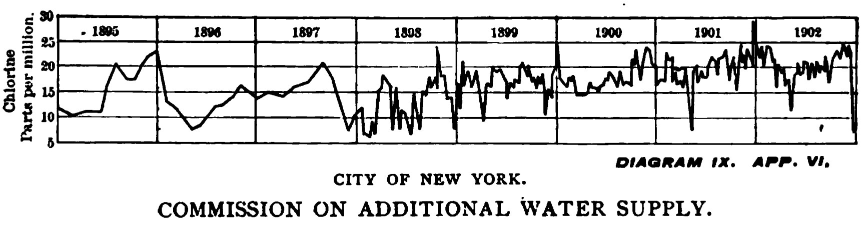


DIAGRAM IX. APP. VI.

CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing the Amount of Chlorine in the Water supplied to Brooklyn, from 1895 to 1902.

NOTE.—Data for 1895, 1896 and 1897, taken from published records of the Department of Health. Data for 1898, 1899, 1900, 1901 and 1802, taken from records of Mt. Prospect Laboratory.

From 1898 to 1902, there was a gradually increasing amount of chlorine in the water supplied to the city. During 1903 efforts have been made to reduce the amount of chlorine by drawing less water from the brackish wells, and the results have been quite successful. The unusually heavy rainfall has also acted to reduce the chlorine and has made possible the disuse of some of the well water. The fluctuations during this time, however, have been quite marked, and the low points on the profile of Diagram No. 9 represent occasions when the salt wells were temporarily shut down. It will be observed that the profile shows a general tendency to higher chlorines in the fall of the year than at other seasons. Table No. 5 shows that the wells which are most affected by sea water are those at Jameco, Baiseley's, Shetucket and Spring Creek. These stations will be considered individually.

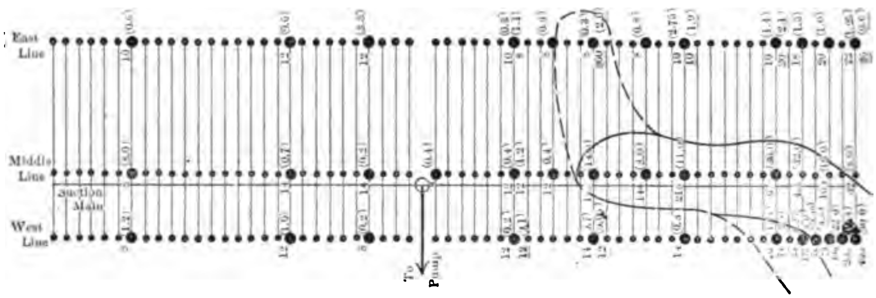
Calculation to Show the Effect of the Sea-Water from the Driven Wells at Baisley's and Spring Creek Pumping Stations on the Water Supplied to Brooklyn on September 28, 1897.

1. Source of Supply.	2. Number of Gallons Furnished.	3. Chlorine Parts per Million.	4. Product of Column 2 and Column 3.
Surface waters on the "New Watershed".	30,549,900	6.0	183,299,000
Surface gravity supply on "Old Watershed"	9,116.880	6.5	59,259,000
Smith's Pond	6,166,200	5.8	35.763,000
Wantagh Pumping Station	4,073,600	4.1	16,701,000
Matowa Pumping Station	4,074,700	4.4	17,930,000
Merrick Pumping Station	3,870,900	7.2	27,871,000
Watts Pond Pumping Station	2,268,300	6.7	15,198,000
Clear Stream Pumping Station	2,962,000	6.7	19,845,000
Forest Stream Pumping Station	3,640,700	6.0	15,846,000
Jameco Pumping Station, deep wells	2,455,900	5.2	12,770,000
Jameco Pumping Station, deep and shallow wells	1,900,000	34.4	65,360,000
Baiseley's Pumping Station	2,263,160	144.0	325,872,000
Oconee Pumping Station	2,624,000	4.2	11,021,000
Shetucket Pumping Station	2,554,740	4 3	10,953,000
Spring Creek Pumping Station—			
Old plant—deep wells	2,500,000	6.2	15,500,000
Old plant—shallow wells	3.580,900	280.0	1,002,680,000
Temporary plant	3,470,000	14.0	48,580,000
Total	88,071,880	...	1,884,448,000
Column 4 divided by column 2	....	21.39	....
Total deducting Baiseley's and Spring Creek.	82,227,820	....	555,896,000
Column 4 divided by column 2	... .	6.76	....

Chlorine at Jameco Pumping Station.

The pumping station at Jameco is situated near the head of Cornell Creek, about two miles inland from Jamaica Bay, and just below Baiseley's Pond. At this station there are two separate systems of wells, one composed entirely of deep wells, the other composed of both deep and shallow wells. The deep wells are not affected by sea water. The shallow wells system consisted originally of 183 two-inch wells driven to depths varying from 27 to 73 feet and averaging about 43 feet. The wells are arranged in three rows, parallel to a main suction, two rows being to the east of the suction main and one row to the west. (See Diagram No. 10.) The tiers of wells are about 14 feet apart.

DIAGRAM X. APP. VI.



CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram showing the Amount of Chlorine in Various Wells of the Shallow Well System of the Jameco Pumping Station on April 1st and 8th, 1903.

NOTE.—Figures in parenthesis denote Iron; other figures denote Chlorine. Figures underlined are for April 8th; other figures are for April 1st. Area of high Iron and Chlorine for April 8th lies within broken line, and that for April 1st within full line.

The suction main above mentioned is also connected with four 4-inch wells, three 6-inch wells, four 8-inch wells and one 10-inch well, which vary in depth from 147 to 165 feet, and all of which pierce the clay bed. The water pumped from this system is, therefore, a mixed one.

At the time when analyses were begun, namely, during the year 1897, it was noticed that the amount of chlorine in the deep and shallow wells was about 20 parts per million, and it was suspected that the difference between this figure and the normal of the region was due to the influence of the sea water upon the shallow wells. Later, examinations of individual wells showed that this was the case, and showed further that it was the wells located at the southwest corner of the plant which were most affected by the sea water. The plant is located practically in the bed of the creek, and it appeared from the results that beneath the surface there existed a pocket, or perhaps the bed of an old creek, which passed diagonally across the suction main. This is shown by Diagram No. 10, which gives the area where the wells showed the highest chlorine and iron. The observations upon which this diagram was constructed are given in the following table:

Chlorine and Iron in Jameco Shallow Wells—March 31 *and April* 1, 1898.

Well No.	Parts per Million Chlorine.	Iron.	Well No.	Parts per Million Chlorine.	Iron.
1	8	.40	73	10	.30
13	12	.40	76	8	.60
14	12	.20	79	8	.30
19	12	.40	83	8	.80
25	178	14.00	86	10	2.75
26	14	.70	93	10	1.40
33	144	8.00	95	18	1.50
39	218	11.00	97	20	1.00
40	14	.30	99	22	1.25
53	670	36.00	107	14	.20
54	16	1.75	108	8	.20
57	456	32.00	119	18	.70
58	26	3.25	120	12	1.00
60	76	9.40	143	8	8.00
61	160	16.00	144	8	1.20
62	136	22.00	160	12	3.30
64	282	.40	166	12	.60
65	32	8.00	178	10	.60
66	400	50.00			

April 8, 1898.

Well No.	Parts per Million Chlorine.	Iron.	Well No.	Parts per Million Chlorine.	Iron.
13	12	1.20	60	84	4 00
14	12	.10	73	8	1.10
26	12	.05	79	360	2.00
54	74	2.50	86	10	1.90
56	152	5.00	95	20	2.10
58	172	8.00	99	38	.60

When it was found that the wells enclosed in this area were responsible for the greater part of the chlorine, and it may be added of iron as well, these wells were shut off with temporary benefit to the supply, but it was found that after a time the salt water began to affect the wells in the east row, and as it was feared that ultimately many more of the wells would become salt if this process of shutting down the affected wells was continued, the plan was not carried further, and ultimately, when the need for water in the city became pressing, all of the wells were put into use. At the present time the amount of chlorine in the water furnished by this combined system is about 22 parts per million, about the same as it was five years ago.

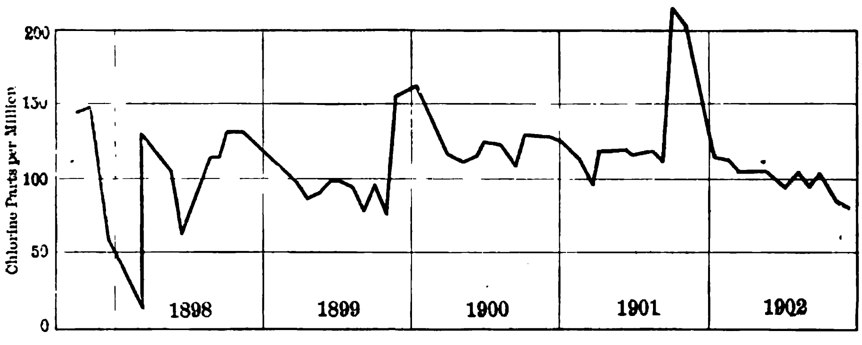
Chlorine at Baiseley's Driven Well Station.

This station is located at the head of Mud Creek, about one mile southwest of the Jameco station and about one and a half miles from Jamaica Bay. The plant consists of 100 2-inch wells, driven on the north side of the conduit and adjacent to it. Their depths vary from 28 to 65 feet and average about 44 feet. The wells are numbered from the east to the west end, the odd numbers being on the north side of the suction main and the even numbers being on the south side. Fifty-two of the wells are located east of the receiver and 48 wells west of it. The surface of the ground at this station has an elevation of about eight feet. The pumping plant has a capacity of three million gallons.

In the fall of 1897 the water at this station was found to contain about 150 parts of chlorine per million, which was obviously caused by the infiltration of sea water from Jamaica Bay. In order to determine whether or not all of the wells were equally affected, certain of the wells were disconnected and individually sampled. The results are shown in the following table:

No.	Chlorine. East End.	No.	Chlorine. West End.
93	12.0	100	12.0
81	12.0	88	13.0
69	13.0	74	13.0
	2.	64	22.0
41	12.0	48	220.0
23	425.0	34	550.0
9	1325.0	16	2950.0

These analyses indicated that it was the wells of the eastern half of the plant which were affected, and that the wells on the south side of the suction main contained a larger proportion of sea water than the wells on the north side. In order to get rid of the chlorine, the eastern half of the plant was shut off on November 8, 1897, when the chlorine dropped from 149 to 17 parts per million. After pumping for a few days, however, the chlorine began to increase until November 25, 1897, it reached 50 parts per million. The pumps were then stopped, and the plant remained inoperative until December 1. On that date the whole plant was put into commission. On December 8, the chlorine had reached 61 parts per million, and the pump was again stopped. It was started again on December 29, with the chlorine at 57 parts per million, but it was found on December 30 that the chlorine was 155 parts per million. Pumping was thereupon discontinued and the plant remained shut down until March 12. It was started on that date with a chlorine of 12 parts per million. This speedily increased until on March 28 it had reached 145 parts per million, when the plant was again shut down.



CITY OF NEW YORK.
COMMISSION ON ADDITIONAL WATER SUPPLY.
DEPARTMENT OF CHEMISTRY AND BIOLOGY.
Diagram Showing the Amount of Chlorine in the Shallow Wells at Baisley's Pumping Station.

The following table shows the results of chlorine determinations during these periods:

Chlorine at Baiseley's Driven Well Station (Entire Plant).

Date.	Chlorine.	Remarks.	Date.	Chlorine.	Remarks.
1897.			1897.		
Nov. 1	145.0		Dec. 29	57.0	Started.
" 3	149.0		" 30	155.0	Stopped.
" 8	17.0	Eastern half shut off.	Mar. 12	12.0	
" 9	18.0		" 13	50.0	
" 10	20.0		" 14	50.0	
" 11	20.0		" 15	80.0	
" 12	22.0		" 16	120.0	
" 13	23.0		" 17	125.0	
" 15	25.0		" 18	140.0	
" 17	26.0		" 19	140.0	
" 19	32.0		" 20	140.0	
" 21	37.0		" 21	150.0	
" 22	40.0		" 22	150.0	
" 25	50.0		" 23	150.0	
" 26	......	Stopped pumping.	" 25	145.0	
Dec. 1	38.0	Started entire plant.	" 27	145.0	
" 8	61.0	Stopped pumping.	" 28	145.0	Shut down.

It will be seen, therefore, that the attempt to get rid of the sea water by occasionally shutting down the plant was only partially successful, and in recent years the demand for water has been so great that this method has not been used. The fluctuations in the amount of chlorine present from 1897 to 1902 are shown in Diagram 11.

Brackish Water at Shetucket Pumping Station.

In the fall of 1897 the Shetucket Pumping Station was established at a point about one mile from Jamaica Bay, nearly south of the village of Jamaica, on the south side of and adjoining the conduit. The plant consisted of a 6-inch suction and twelve 8-inch driven wells. The wells passed through a deep layer of sand, thence through a layer of clay into a stratum of green sand. The wells were staggered along the main suction about 75 feet apart, and were numbered from 1 to 12, beginning at the easterly end. The even numbers were on the seaward side of the suction main. The depths of the individual wells are as follows:

Number.	Depth.
1	172 feet.
2	180.5 "
3	167 "
4	182 "
5	181 "
6	168 "
7	170 "
8	177.5 "
9	178 "
10	176.5 "
11	172 "
12	175 "

The average elevation of the surface of the ground was about 6.5 feet above the datum plane.

The first sample was taken from the wells on October 4, and showed that the water was of good quality. The chlorine was 4.3 parts per million, which was lower than the normal for that region, and which corresponds well with the normal chlorine in the middle of Long Island.

For a few months water was pumped at the rate of about 3,700,000 gallons per day, the quality of the water remaining about the same. In March, 1898, the rate of pumping was increased to nearly six million gallons, and following that, the amount of chlorine in the water began to increase and led to a reduction in the rate of pumping. From that time on the amount of chlorine in the water has steadily increased, until in 1902 the average chlorine was 433.7 parts per million. This increase of chlorine is shown in Diagram No. 12. The increasing brackishness of the water caused still further reduction in the rate of pumping, until on January 1, 1903, it was below one million gallons per day. The average daily amount of water pumped during each month is also shown on the diagram mentioned. It will be noticed that whenever pumping ceased, there was a decrease in the amount of chlorine in the water. Accompanying the increasing chlorine there was an increase in the free ammonia, iron, hardness and total solids. There was no increase, however, in the amount of organic matter, as shown by the albuminoid ammonia, neither was there any increase in the nitrates. The nitrites fluctuated between wide limits with no apparent regularity. The iron present in the water produced a noticeable milkiness, and caused the apparent color to increase from 6 to 32.

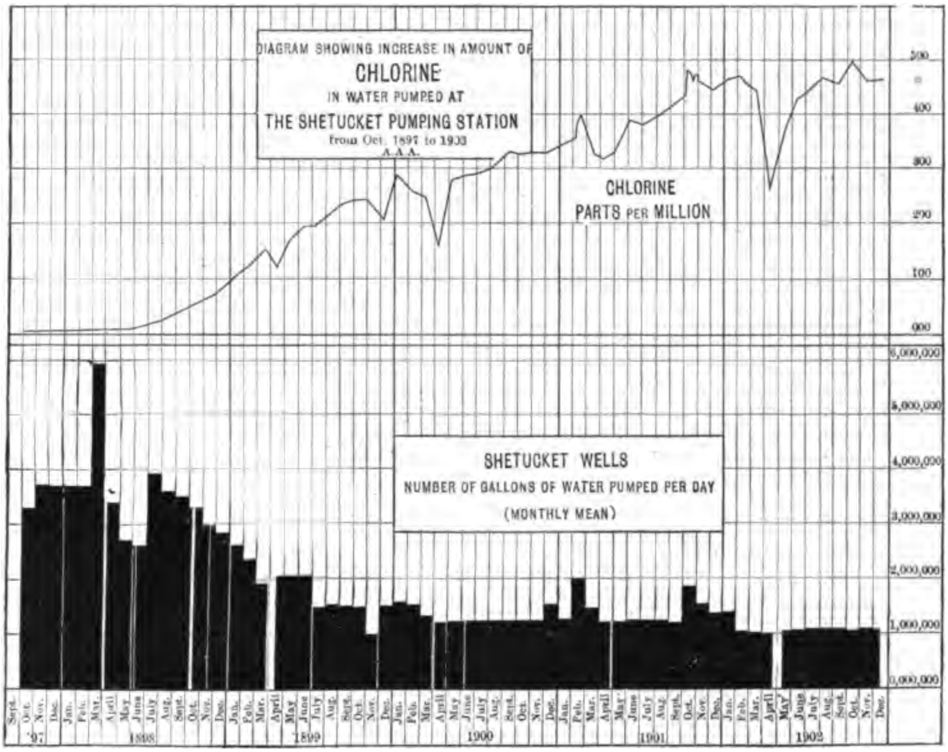


DIAGRAM XII. APP. VI.

Table Showing Parts per Million of Chlorine and Total Solids in Shetucket Well Water.

1897.			1898.			1899.			1900.			1901.			1902.			1903.		
Date.	Total Solids.	Cl.	Date.	Total Solids.	Cl.	Date.	Total Solids.	Cl.	Date	Total Solids.	Cl.	Date.	Total Solids.	Cl.	Date.	Total Solids.	Cl.	Date	Total Solids.	Cl.
Oct. 4	138.5	4.3	Jan. 4	174.0	4.8	Jan. 25	318.0	100.0	Jan. 17	750.5	290.0	Jan. 16	......	344.0	Jan. 15	1086.0	464.0	Feb. 3	1100.0	446.0
Nov. 3	143.0	3.9	" 27	143.0	4.4	Feb. 23	390.	126.0	Feb. 14	703.5	260.0	Feb. 7	......	360.0	Feb. 7	......	470.0	Apr. 16	788.0	321.0
" 30	138.0	4.3	Feb. 28	136.0	4.6	Mar. 24	460.	152.0	Mar. 16	694.0	248.0	" 14	979.0	390.0	" 20	......	458.0	June 23	510.0	152.0
			Mar. 24	138.0	4.6	Apr. 19	402.5	120.0	Apr. 11	502.0	160.0	" 26	......	400.0	Mar. 11	......	442.0	July 10	408.0	124.0
			Apr. 21	141.0	6.3	May 18	511.0	176.0	May 9	780.0	280.0	Mar. 19	......	328.0	Apr. 9	1075.0	270.0	Aug. 26	890.0	344.0
			May 19	150.0	9.6	June 14	557.5	196.0	June 12	810.0	290.0	Apr. 10	......	318.0	May 17	......	374.0			
			June 16	157.5	11.8	July 13	560.0	196.0	July 5	783.0	290.0	May 8	849.0	332.0	June 11	......	424.0			
			July 14	189.	18.0	Aug. 9	629.0	220.0	Aug. 8	828.5	306.0	June 5	......	388.0	July 9	1077.0	442.0			
			Aug. 11	208.5	27.1	Sept. 7	657.5	239.0	Sept. 14	873.0	334.0	July 3	......	380.0	Aug. 6	......	464.0			
			Sept. 8	217.5	38.0	Aug. 4	678.5	244.0	Oct. 10	709.0	328.0	Aug. 13	1036.0	398.0	Sept. 12	.....	452.0			
			Oct. 6	227.0	50.0	Oct. 31	677.0	246.0	Nov. 8	870.0	330.0	Sept. 11	......	416.0	Oct. 8	1144.0	496.0			
			Nov. 3	254.0	60.0	Dec. 6	569.0	204.0	Dec. 6	840.5	330.0	Oct. 9	......	434.0	Nov. 14	......	460.0			
			Dec. 5	285.0	74.0	" 8	604.5	222.0				" 15	......	480.0	Dec. 17	......	462.0			
												" 21	......	472.0						
												" 24	......	456.0						
												" 31	.....	470.0						
												Nov. 2	......	470.0						
												" 5	1083.5	460.0						
												Dec. 11	......	444.0						

In order to determine whether or not the chlorine came from certain particular wells, or from the wells on the water side of the suction main more than from the wells on the opposite side, series of observations were taken on September 20, 1898, March 9, 1899, and October 24, 1902. On these dates samples were taken from each of the different wells. The results showed no regularity at all. In general, the chlorine was higher on the water side than on the land side.

The source of the chlorine is evidently sea water, which reaches the wells not by passing vertically downward through the upper strata of sand, but rather by passing inward from the sea under the clay bed.

On October 24, 1902, a 2-inch test well was sunk at the station and carried down to a depth of 125 feet, samples being collected at various points as the well was driven down. The amount of chlorine found at different depths was as follows. They are in striking contrast to those obtained for the water pumped from below the clay.

Depth Feet.	Chlorine.	Depth Feet.	Chlorine.
12	20.0	65	11.0
22	4.0	76	5.4
33	11.8	96	5.8
44	13.4	106	5.4
54	7.2	125	5.4

In order to determine whether or not the amount of chlorine was increased by the tides, a series of samples was collected every two hours, from February 28, 1899, at 9 A. M. to March 1, 1899, at 11 P. M.

The results of these analyses were as follows:

Date.	Time.	Chlorine.	Date.	Time.	Chlorine.
Feb. 28	9 A. M.	126	Mar. 1	5 A. M.	128
" 28	11 "	126	" 1	7 "	128
" 28	1 P. M.	128	" 1	9 "	128
" 28	3 "	128	" 1	11 "	128
" 28	5 "	126	" 1	1 P. M.	126
" 28	7 "	128	" 1	3 "	126
" 28	9 "	126	" 1	5 "	128
" 28	11 "	126	" 1	7 "	128
Mar. 1	1 A. M.	128	" 1	9 "	126
" 1	3 "	128	" 1	11 "	126

A second series of hourly samples was collected on February 3 and 4, 1903, and the results were as follows:

Date.	Time.	Chlorine (Parts per Million).	Date.	Time.	Chlorine (Parts per Million).
Feb. 3......	8 A.M.	88	Feb. 3......	10 P.M.	90
" 3......	9 "	88	" 3......	11 "	90
" 3......	10 "	90	" 3......	12 "	92
" 3......	11 "	90	" 4......	1 A.M.	90
" 3......	12 "	92	" 4......	2 "	90
" 3......	1 P.M.	90	" 4......	3 "	92
" 3......	2 "	90	" 4......	4 "	92
" 3......	3 "	90	" 4......	5 "	92
" 3......	4 "	92	" 4......	6 "	92
" 3......	5 "	92	" 4......	7 "	94
" 3......	6 "	92	" 4......	8 "	92
" 3......	7 "	92	" 4......	9 "	90
" 3......	8 "	92	" 4......	10 "	90
" 3......	9 "	92	" 4......	11 "	90

On February 3 the tide in Jamaica Bay was high at 12 noon. Low water occurred at 7 P. M. On February 4 high water occurred at 1 A. M. and low water at 8 P. M. It will be observed that in both of these cases the fluctuations were extremely small, probably too small to be charged directly to the tidal changes.

On December 17, 1902, the amount of chlorine in the water of Shetucket was 462 parts per million. The plant was shut down on December 9, 1902. On January 9, 1903, at 8 A. M., the plant was started up, and the amount of chlorine was 80 parts per million. Samples were then taken twice a day for six days, with the following results of progressive increase in the amount of chlorine:

Date.	Time.	Chlorine (Parts per Million).	Date.	Time.	Chlorine (Parts per Million).
Jan. 9......	8 A.M.	80	Jan. 11......	12 P.M.	266
" 9......	12 M.	98	" 12......	12 M.	344
" 9......	12 P.M.	174	" 12......	12 P.M.	358
" 10......	12 M.	234	" 13......	12 M.	374
" 10......	12 P.M.	276	" 13......	12 P.M.	396
" 11......	12 M.	296	" 14	12 M.	396

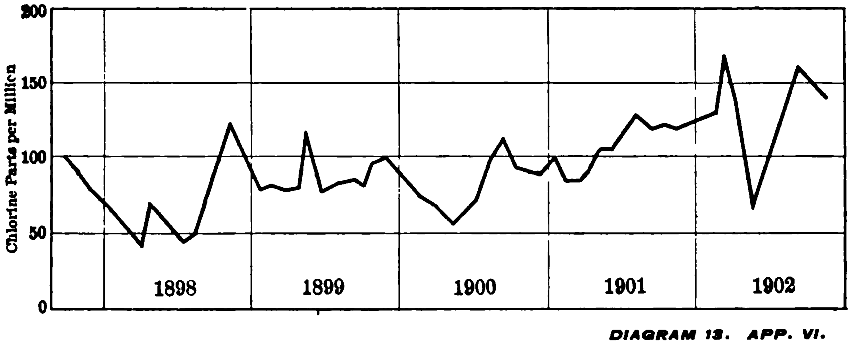
Chlorine at Spring Creek Driven Well Station.

The driven well station at Spring Creek is located at the head of Old Mill Creek, about one mile south of Woodhaven and about two miles from Jamaica Bay. There are at this station three systems of driven wells, namely, the deep wells of the old plant, the shallow wells of the old plant and the shallow wells of the new or temporary plant. The deep wells pierce the clay strata and are not salt, and therefore need not be considered. The old shallow well system consists of 100 two-inch wells driven to depths ranging from 30 to 42 feet, and averaging 36 feet. They were sunk in two rows along the main suction at intervals of 14 feet, the wells of each pair being about 14 feet apart. They are numbered from the central receiver towards either end, the most easterly well being called 50 east and the most westerly being called 50 west. The odd numbers are on the north side of the conduit and the even numbers on the south side. In September, 1897, the water pumped from this system was found to be affected by the sea water to such an extent that it contained nearly 300 parts per million of chlorine. On October 26 and 27 several of the wells were disconnected and individually sampled, with the results given in the following table:

Amount of Chlorine in the Water from Various Wells at Spring Creek Pumping Station (Old Plant) on October 26-27, 1897.

Number.	Chlorine.	Number.	Chlorine.
47 East	11.0	9 West	11.0
41 "	13.0	13 "	9.0
37 "	14.0	17 "	8.0
35 "	18.0	21 "	10.0
31 "	20.0	27 "	10.0
27 "	21.0	31 "	10 0
50 "	14.0	43 "	9.0
44 "	12.0	47 "	10.0
40 "	13.0	12 "	275.0
34 "	124.0	20 "	800.0
26 "	......	24 "	650.0
24 "	31.0	28 "	450.0
18 "	14.0	30 "	500.0
14 "	67.0	40 "	650.0
12 "	185.0	46 "	850.0
		50 "	1400.0

It will be seen from this table that it was the southwest quarter of the plant which was affected.



CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing the Amount of Chlorine in the Spring Creek Wells. Average of Old Plant, Deep and Shallow Wells, and Temporary Plant, Shallow Wells.

On October 21 the plant was shut down and the wells in this quarter were discontinued. On starting the pumps on October 30 it was found that the chlorine had dropped from 278 to 19 parts per million. In less than twenty-four hours after starting, however, the chlorine increased rapidly, showing that the water had passed over to the wells on the south side of the suction main. On November 5 the chlorine had reached 240 parts per million and the plant was shut down. It was started again on November 26, with the same result, and this continued until January 8. The plant remained shut down from January 8 to March 12, and when it was started up the chlorine increased much more slowly than before, probably because of the higher elevation of the ground water at that time. This is shown by the following table:

Chlorine in the Water from the Shallow Wells at Spring Creek, Old Plant.

Date.	Chlorine.		Date.	Chlorine.	
1897.			1898.		
Oct. 11	278.0		Mar. 17	35.0	
" 21	......	Shut down.	" 18	60.0	
" 29	......	Started up without S. W.	" 19	70.0	
		quarter.	" 20	80.0	
" 30	19.0		" 21	85.0	
" 31	168.0		" 22	95.0	
Nov. 1	196.0		" 23	110.0	
" 2	226.0		" 24	125.0	
" 3	230.0		" 25	130.0	
" 4	226.0		" 28	150.0	
" 5	240.0	Shut down.	" 30	165.0	
" 26	18.0	Started.	Apr. 1	170.0	
" 27	75.0		" 5	170.0	
Dec. 1	178.0	Shut down.	" 11	175.0	
1898.			" 15	170.0	
Jan. 2	10.0		" 21	170.0	
" 4	62.0		" 25	175.0	
" 5	82.0		" 27	165.0	Shut down.
" 8	136.0	Shut down.	Aug. 12	125.0	
Mar. 12	20.0	Started.	Sept. 8	482.0	Whole plant started.
" 13	20.0		" 9	240.0	
" 14	20.0		Oct. 6	210.0	
" 15	30.0		Nov. 3	166.0	

Chlorine in Individual Shallow Wells of the Spring Creek Pumping Station, Old Plant, September 9, 1898.

Number.	Chlorine.	Number.	Chlorine.
47	17.0	30 West	300.0
50 East	15.0	40 "	450.0
46 "	15.0	46 "	375.0
40 "	12.0	50 "	320.0
32 "	12.0		

On September 9, 1898, a second series of observations was made to determine the distribution of the chlorine. It was found as before that the salt came from the southwest quarter of the plant, but the figures were not as high as those obtained on October 26, 1897. The fluctuations in the chlorine from 1897 to 1902 are shown in Diagram No. 13.

The new or temporary plant at Spring Creek consists of 13 six-inch wells 30 feet long, staggered on each side of the main suction at about 35 feet from it, the wells being driven to depths ranging from 42 to 75 feet. The water from these wells is but slightly affected by the sea water. The chlorine seldom rises above 50 parts per million. Attempts were made to reduce this chlorine, however, in the fall of 1897, with results shown in the following table:

Chlorine in Water from Shallow Wells, Spring Creek Pumping Station, Temporary Plant.

Date.	Chlorine.		Date.	Chlorine.	
1897.			1898.		
Oct. 22	13.2		Mar. 25	25.0	
Nov. 30	42.0		" 30	40.0	
Dec. 6	56.0		Apr. 1	50.0	
" 7	58.0	Shut down.	" 11	45.0	
" 30	21.0	Started.	" 17	45.0	
1898.			" 19	60.0	
Jan. 4	62.0		" 21	50.0	
" 5	59.0		" 25	50.0	
" 8	37.0		" 28	50.0	Shut down.
" 25	....	Shut down.	May 2	....	Started.
Mar. 12	16.0		" 3	35.0	
" 13	30.0		" 5	50.0	
" 14	20.0		" 13	....	Shut down.
" 19	25.0		" 14	50.0	Started.

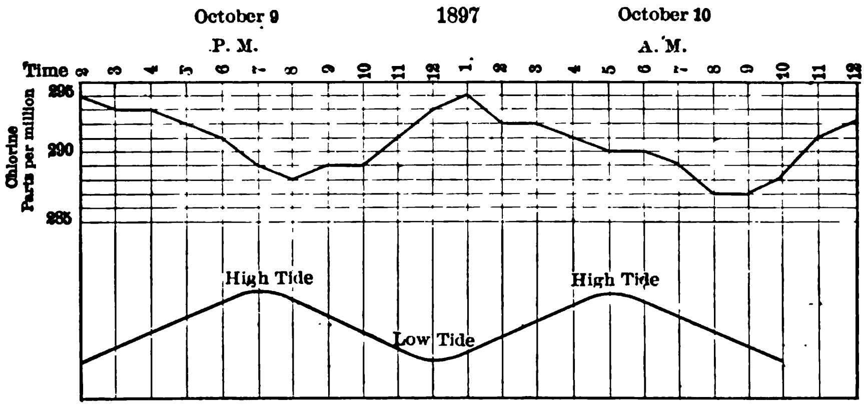


DIAGRAM 14. APP. VI.

CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing the Relation between the Tides and the Amount of Chlorine in the old Shallow Well Plant at the Spring Creek Pumping Station, Brooklyn Water Works, October 9 and 10, 1897.

The influence of sea water upon this station was well shown by observations made on October 9 and 10, 1897. Samples were collected from the pump every hour, with the results shown on Diagram No. 14. The times of high and low water in Jamaica Bay are also shown on the diagram. It will be seen from these calculations that the rise and fall of the tide caused fluctuations in the amount of chlorine in the water pumped. There was apparently a lag of several hours between the time of high tide and the time of highest chlorine in the water. The hourly increase in chlorine after the pumps had been shut down for some time is shown in Diagram 15.

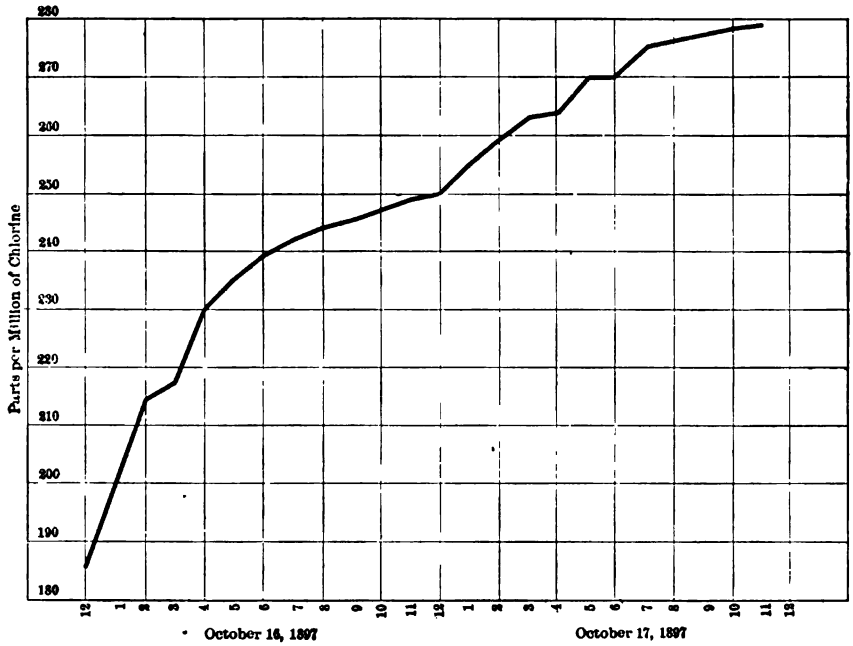


DIAGRAM XV. APP. VI.

CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing Hourly Increase in Chlorine in Water from Spring Creek Old Plant, Shallow Wells, October 16 and 17, 1897, after starting the pump.

Hardness—Ridgewood System.

The hardness of the various waters of the Ridgewood system is shown by the following table, giving the average hardness of these different sources for a period of five years:

Hardness of the Various Water Supplies Comprising the Ridgewood System.*

Surface Waters.	Alkalinity.	Permanent Hardness.	Total Hardness.	Ground Waters.	Alkalinity.	Permanent Hardness.	Total Hardness.
New Watershed.				*New Watershed.*			
Massapequa Pond	5.8	4.7	10.5	Massapequa (deep and shallow)	11.4	9.4	20.8
Wantagh Pond	4.6	8.5	13.1	Wantagh (deep and shallow)	1.7	5.0	6.7
Newbridge Pond	4.4	7.8	12.2	Matowa (deep and shallow)	2.1	7.2	9.3
East Meadow Pond	4.1	10.6	14.7	Merrick (deep and shallow)	5.0	11.4	16.4
Millburn Pond	5.3	12.4	17.7	Agawam (deep and shallow)	1.4	7.0	8.4
Millburn Pumping Station (mixed surface and ground waters)	5.4	9.1	14.5	*Old Watershed.*			
Old Watershed.				Watt's Pond (shallow)	8.3	19.9	28.2
Hempstead Storage Reservoir	8.0	12.4	20.4	Clear Stream (shallow)	7.1	21.0	28.1
Schodack Brook	5.6	12.4	18.0	Forest Stream (shallow)	9.5	14.9	24 4
Hempstead Pond	6.3	11.0	17.3	Springfield (deep)	4.0	11.7	15.7
Pines Pond	7.3	13.8	21.1	Jameco (deep)	84.8	3.6	88.2
Smith's Pond	6.2	11.0	17.2	Jameco (deep and shallow)	48.4	25.4	73.8
Valley Stream Pond	7.5	17.9	25.4	Baiseley's (shallow)	26 4	84.6	111.0
Watt's Pond	7.8	16.6	24.4	Oconee (deep)	101.1	4.9	105.0
Clear Stream Pond	8.7	20.6	29.3	Shetucket (deep)	80.6	159.4	240.0
Simonson's Pond	8.5	23.2	31.7	Spring Creek old plant (deep)	115.0	8.6	123.6
Springfield Pond	15.0	20.9	35.9	" " (shallow)	89.7	71.4	161.1
Baiseley's Pond	28.6	21.8	50.4	" new plant (shallow)	100.0	66.2	166.2
Ridgewood North Side Pumping Station (mixed surface and ground water)					17.8	20.3	38.1
Ridgewood South Side Pumping Station (mixed surface and ground water)					15.6	17.6	33.2
Average water entering Ridgewood Reservoir					16 7	19.0	35.7

*Based on monthly, and in some cases weekly, analyses from 1898 to 1902, inclusive.

There are no limestone deposits which outcrop on Long Island, and the surface waters are comparatively soft. They increase in hardness, however, from east to west, this fact being due apparently to the effect of increasing density of population. The permanent hardness due to the sulphates, nitrates, etc., is generally higher in these waters than in the surface waters of the Croton watershed, this being due in part, no doubt, to the proximity of these watersheds to the sea coast. Just as the chlorine is higher near the coast on account of the salt being blown in as a fine spray from the ocean, so also are some of the other mineral constituents increased.

The ground waters naturally show the greatest variations in hardness. The wells on the "new" watershed are extremely soft, and are especially low in alkalinity.

The hardness of the Ridgewood water since 1898 is shown by months in the following figures:

Mean Monthly Hardness of the Water Entering Ridgewood Reservoir.

	1898.	1899.	1900.	1901.	1902.	1903. (11 Months).
January	34.4	35.4	30.5	34.6	41.2	31.8
February	29.1	39.3	37.4	37.7	41.4	30.4
March	37.0	32.9	38.2	37.8	42.7	18.7
April	38.4	33.7	35.3	35.8	38.9	26.7
May	33.0	39.7	37.3	33.9	34.0	27.5
June	26.6	34.8	39.5	37.1	37.2	21.5
July	26.9	32.7	34.1	37.8	38.4	27.1
August	29.9	34.4	36.3	39.7	38.4	30.0
September	37.0	34.8	35.2	40.0	36.0	32.4
October	40.5	32.2	36.0	36.6	37.8	25.3
November	39.5	32.6	45.4	41.1	37.7	25.9
December	33.3	34.0	39.3	44.3	32.7	....
Maximum	56.5	43.6	49.0	52.3	43.5	41.5
Minimum	14.9	32.3	27.3	24.0	22.8	14.5
Average	33.8	34.7	37.0	38.0	38.0	27.0

It will be seen from this that there is no regular seasonal change in hardness of the city water, the fluctuations being caused rather by different combinations of the various sources of supply. During the past five years the average annual hardness has gradually increased until the present year, when the partially closing of some of the well stations has resulted in reducing it.

The shallow wells on the old watershed which are not affected by sea water, namely, Watts Pond Wells, Clear Stream Wells and Forest Stream Wells, are likewise comparatively soft, although harder than the eastern wells. The shallow wells which are affected by the sea water, as indicated by their high chlorine, namely, Jameco Deep and Shallow, Baiseley's and Spring Creek, have high hardnesses with especially high sulphates, nitrates, etc. The deep wells vary considerably. At Springfield the water is very soft, while at Jameco, Shetucket and Spring Creek there are high alkalinities, but low sulphates. At Shetucket, on the other hand, the hardness is very high, and is due chiefly to sulphates, nitrates, etc. These wells, however, are very much affected by sea water.

The waters from these various sources unite to give an average hardness at Ridgewood of 35.6 parts per million, of which 16.7 is due to carbonates and bicarbonates and 19.9 to sulphates, nitrates, etc. These figures often vary with great suddenness as one or another of the different sources of supply are turned on or shut oft. The bad effect upon the system of the use of such water as that from the Shetucket Wells, for example, is very obvious, and the good results attendant upon shutting down these wells is equally evidenced.

The high chlorine, relatively high sulphates and high nitrates unite to make the water from the Ridgewood system a poor water for use in steam boilers. A comparison between this water and that of the Croton supply, which is quite satisfactory for boilers, is instructive.

	Parts per Million.			
	Croton Water, 135th Street Gate-House. (Average 9 Months.)	Millburn Pumping Station. (Average for Five Years.)	Ridgewood Water, at Pumping Station.	
			Average for Five Years, 1898 to 1902.	1903.
Total solids	71.5	41.7	92.6	74.0
Chlorine	2.0	5.7	17.6	10.3
Alkalinity	32.7	5.4	16.7	12.2
Permanent hardness (sulphates, nitrates, etc.)	4.7	9.1	18.9	14.8
Total hardness	37.4*	14.5	35.6	27.0
Nitrates	0.14	0 91	1.07	1.14
Iron	0.28	0.25	0.52	0.34

It will be seen that the total hardness is not greatly different in the two waters, but the hardness of the Croton water is due chiefly to carbonates and tends to form a soft scale in boilers, which the hardness in the Ridgewood water is due largely to sulphates, etc., which tend to form a hard scale. The

*The average of 15 years was 38.9.

Ridgewood water is not a scale-forming water, however, so much as it is a corrosive water. This is due to the chlorides, especially to the chloride of magnesium, derived from the brackish wells. The amount of dissolved free carbonic acid, another corrosive constituent, is also greater in the Ridgewood water than in the Croton water, this also being derived from the driven wells. A practical example of the effects of the Brooklyn water upon boilers may be observed at the Ridgewood Pumping Station, where some of the boilers are very badly pitted. In contrast to these are the boilers at the Millburn Pumping Station, which are in excellent condition, and which are fed with the water derived from the eastern ponds. The average constituents of this water are also given in the above table.

A few years ago, before the use of those driven wells which are affected by sea-water, the Brooklyn supply was considered an excellent one for boiler purposes, equal, if not superior, to the Croton water. The following analysis made by the late Dr. Albert R. Leeds, Stevens Institute, in 1881, shows the hardness and chlorine to be much lower than they are at the present time, or than they are likely to be again (the population on the watershed having very greatly increased during the past 20 years):

Sample, from 321 Gates avenue, Brooklyn, N. Y. Date of collection, June 23, 1881—

Color	None.
Taste	None.
Smell	.0075 parts per million.
Free ammonia	.0826
Nitrites	.0000
Nitrates	1.2025
Oxygen consumed	4.13
Total solids	60.0
Organic and volatile	10.0
Mineral matter	50.0
Hardness	22.7
Chlorine	5.5

Nor has the water yet become serious enough to cause general complaint. Nevertheless, the presence of 25 parts per million of chlorine in the feed water of a boiler cannot be without its effect.

The elimination from the Ridgewood supply of the driven wells which are affected by the sea water is a measure which should be undertaken as soon as the amount of water thus lost can be made up from other sources. This is a practical proposition in which every boiler owner in the city should be interested.

Iron.

Some of the driven wells of the Ridgewood system contain large amounts of iron. This is shown by the following table of average figures:

Table Showing the Amount of Iron in the Different Sources of Supply (Average, 1898-1902).

Surface Water.	Iron Parts per Million.	Ground Water.	Iron Parts per Million.
Massapequa Pond	.08	Massapequa (deep and shallow)	.45
Wantagh Pond	.21	Wantagh (deep and shallow)	.51
Newbridge Pond	.18	Matawa (deep and shallow)	.45
East Meadow Pond	.51	Merrick (deep and shallow)	.67
Millburn Pond	.18	Agawam (deep and shallow)	.27
Hempstead Storage Reservoir	.27	Watt's Pond (shallow)	.64
Schodack Brook	.24	Clear Stream Pond (shallow)	.30
Hempstead Pond	.33	Forest Stream Pond (shallow)	1.18
Pine's Pond	.40	Springfield Pond (deep)	3.53
Smith's Pond	.55	Jameco (deep)	.63
Valley Stream Pond	.34	" (deep and shallow)	3.37
Watts Pond	.41	Baiseley's (shallow)	.20
Clear Stream Pond	.14	Oconee (deep)	.57
Simonson's Pond	.26	Shetucket (deep)	2.02
Springfield Pond	.81	Spring Creek, Old Plant (deep)	.70
Baiseley's Pond	1.26	" " (shallow)	.06
		" New Plant (shallow)	.13

	Parts per Million.
Ridgewood, Basin No. 2 Influx	.58
" " 3 "	.45
" " 1 Efflux	.38
" " 2 "	.37
" " 3 "	.33
Mt. Prospect Reservoir	.22
Tap in Mt. Prospect Laboratory	.41
" Flushing and Clermont avenues	.37
" Flatbush and Seventh avenues	.37

The iron is highest in the wells at Forest Stream, Springfield, Jameco and Shetucket. In general the deep well water, that is, water below the clay strata, contains the largest amount. The iron precipitates on standing and the figures show that a considerable reduction occurs in the distribution reservoirs and pipes. As delivered to the consumers the amount of iron in the water is comparatively small.

Independent Water Supplies—Borough of Brooklyn.

In every case, save one, the waters supplied by the independent driven well stations in the borough are entirely satisfactory from the physical and sanitary standpoint. They are cold, clear, practically colorless and odorless, contain little or no organic matter, very little iron, few bacteria, no offensive microscopic organisms, and invariably give negative tests for Bacillus coli.

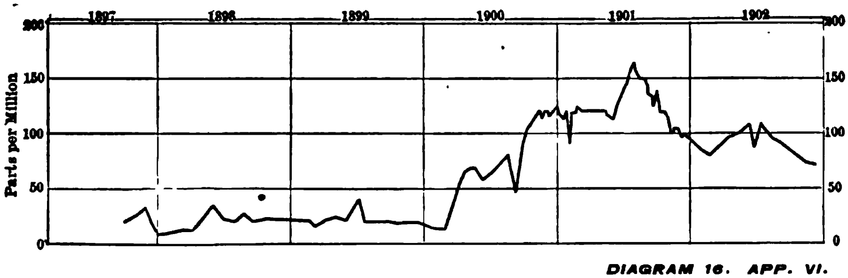
The exception referred to is that of the New Lots Supply (formerly the Long Island Water Supply Company) which supplies water to East New York. This supply has an open reservoir connected with its system, which frequently becomes foul from growths of microscopic organisms, such as Synedra and Chlamydomonas. These organisms are sometimes found in numbers as high as 25,000 per c. c. At such times, consumers who happen to receive the back flow from the reservoir, complain seriously of the quality of the water, and certainly with good reason. It is an exaggerated case of the evil effects of storing ground waters in an open reservoir. This reservoir is small, and if its use is to be continued, it should be roofed over.

The chlorine, however, is generally somewhat high in these independent supplies, as shown by the following table of average results for five years (1898-1902):

Supply.	Chlorine.	Supply.	Chlorine.
	Parts per Million.		Parts per Million.
New Lots	21.4	Flatbush	13.1
German-American	27.1	Pfalzgraf	15.3
Gravesend	13.1	Blythebourne	8.1
New Utrecht	64.1	Prospect Park	7.0

The most serious case is that of the New Utrecht supply.

This station is located about 1 mile east of Gravesend and about 1¼ miles north of Sheepshead Bay. It is near East Fourteenth street and between Avenues U and V. It is about 3,000 feet southwest from the Gravesend Pumping Stations. The system consists of eight-inch wells driven to an average depth of about 30 feet. Ordinarily, the chlorine in the water has not exceeded 25 parts per million, but during the spring of 1900, when the draught on the plant was increased, the effect of the infiltering sea water began to be noticed. The chlorine increased in a somewhat irregular manner until, in the summer of 1901, it reached 165 parts per million. After that it somewhat rapidly decreased. During the summer of 1902 there was a decrease of 70 parts per million. These fluctuations are shown on Diagram No. 16.



CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing parts per Million of Chlorine in the Water of the New Utrecht Wells, from 1898 to 1902.

The waters furnished by the independent companies, because of their hardness and high chlorine, are unsatisfactory as boiler-waters.

They are quite hard, as shown by the following table of average results, based on monthly or quarterly observations covering a period of four, and in some cases five years:

	Hardness in Parts per Million.		
	Alkalinity.	Permanent Hardness.	Total Hardness.
New Lots Driven Wells	102.6	65.2	167.8
German-American Water Supply Company	103.0	71.0	174.0
Gravesend Driven Wells	57.4	35.8	93.2
New Utrecht	61.8	66.9	128.7
Flatbush Water Supply Company	60.0	45.4	105.4
Pfalzgraf Water Company	101.5	61.9	162.4
Blythebourne Water Supply Company	63.6	29.5	93.1
Prospect Park	142.0	40.0	182.5

It will be seen that the water from New Lots (formerly the Long Island Water Supply Company), the German-American, the Pfalzgraf and Prospect Park driven well stations is excessively hard, and the hardness includes not only carbonates, but sulphates and nitrates in large quantities. The next hardest water is that from the New Utrecht driven wells, which are somewhat affected at times by sea water. The Flatbush water stands next in hardness, and last are the Gravesend and Blythebourne wells, which are only slightly softer than the Flatbush water, but which have lower permanent hardnesses.

The hardness of all these driven well waters has shown an increase during the past five years, as indicated by the following figures:

	Hardness, Parts per Million.					
	1898.	1899.	1900.	1901.	1902.	1903.
New Lots	124.1	149.8	191.4	181.7	191.9	182.8
German-American	165.9	172.3	156.1	189.5	186.3	195.0
Gravesend	91.1	91.6	109.8	88.3	94.2	98.7
New Utrecht	90.1	87.5	135.9*	185.6*	144.2	136.1
Flatbush	95.7	99.6	109.9	109.9	112.0	112.4
Pfalzgraf	72.9	167.8	183.0	196.4	192.0	165.4
Blythebourne	75.7	80.1	91.2	92.1	126.3	68.4

The water furnished by the independent plants has one desirable quality which that of the Ridgewood system does not have, namely, a more equable temperature. As the water is taken from the ground at a considerable depth and pumped directly into the distribution pipes, it retains with but slight difference its initial temperature, so that during the summer the citizens are furnished with water cool enough for drinking without adding ice (*i. e.*, about 55 degrees F.), while in the winter the temperature is about 15 degrees above the freezing point. The temperature of the Ridgewood water, on the other hand, is only a few degrees above the freezing point during the winter, and in summer often rises to above 70 degrees, making it unpalatable and emphasizing any objectionable odors that the water may happen to have. (See Diagram No. 17A.)

*Affected by sea water during these years.

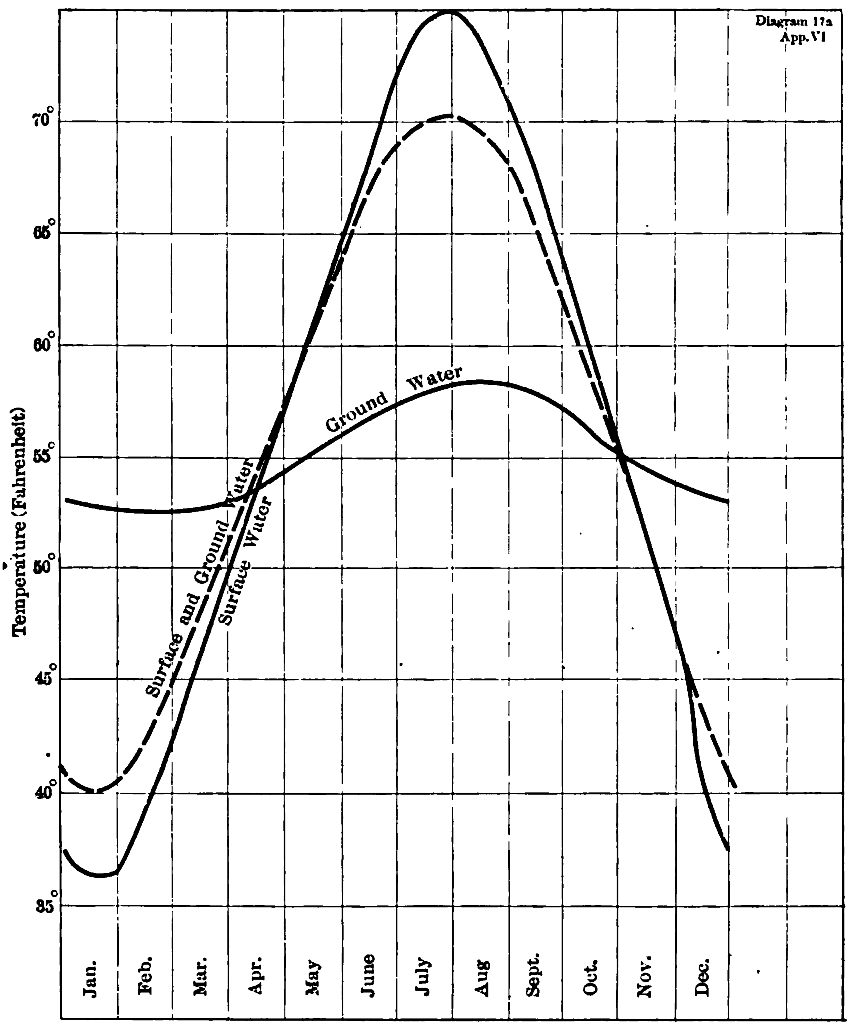


DIAGRAM 17A. APP. VI.

CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Typical Temperature Curves for Surface Water, Ground Water and Mixed Surface and Ground Water, showing seasonal variations.

9. QUALITY OF THE WATER SUPPLY OF THE BOROUGH OF QUEENS.

The Borough of Queens depends almost entirely upon ground water for its sources of supply. The only exception is the station at Bayside, where a small amount of water is occasionally drawn from Oakland Lake. Some of the supplies are owned and operated by the City, while others are owned by private companies, as indicated in Table No. 1c.

All of the waters supplied to the Borough of Queens are generally satisfactory as to their physical qualities.. They are generally clear, very low in color and without odor. They are also satisfactory from the sanitary standpoint. The water of Oakland Lake, part of the Bayside supply, is turbid at times and has a disagreeable odor, but this water is very seldom used. The water at the Flushing Station also has, at times, a slight turbidity.

There are only two water supplies in the borough where there is any practical danger of pollution. These are the Flushing Station (formerly called the College Point Station), and the Bayside Station (formerly called the Flushing Station). The former supply consists of an open basin which is fed almost entirely by ground water. A small stream passes along the side of this basin and is separated from it by an earthen embankment. This stream is more or less polluted. There are a dozen houses within a distance of about a mile from the basin, and the hills along the stream are steep and richly cultivated. Under ordinary conditions, the water in the brook is lower than that in the basin, but after heavy rains it becomes higher, and is in danger of entering the basin should there be any leak in the gate which connects it with the basin. The brook water should, under no condition, be used. On one occasion it was found that the gate had been left open by accident, and analyses indicated that the water pumped was temporarily in a bad condition.

Oakland Lake forms a part of the available supply at the Flushing Station. It is not ordinarily drawn upon, however. It has a small watershed upon which there is comparatively little pollution, although there are a few houses and some farm land upon it. The physical character of the lake water is unsatisfactory, however, and the supply is ordinarily unfit for use on account of the abundance of microscopic growths.

With one or two exceptions, the water supplies of the Borough of Queens are hard. This is shown by the following table of average results, based on quarterly analyses extending in most cases over five years:

Hardness—Borough of Queens.

	Alkalinity.	Permanent Hardness.	Total Hardness.
Long Island City, Station No. 1	91.5	90.4	181.9
" " No. 2†	145.2	273.0	418.2
" " No. 3	134.9	64.9	199.8
Citizens' Water Company, Station No. 1	142.0	64.1	206.1
" " No. 2	109.9	67.7	177.6
" " No. 3	92.7	14.8	107.5
" " No. 4	97.3	33.1	130.4
" " No. 5	95.8	28.5	124.3
Whitestone Pumping Station	107.3	32.7	140.0
Flushing Water Works	31.5	20.4	51.9
Bayside Water Works	35.3	13.9	49.2
Woodhaven Water Company	109.4	18.9	128.3
Montauk Water Company	75.8	32.1	107.9
Jamaica Water Supply Company	38.7	43.1	81.8
Queens County Water Supply Company (filtered)	9.3	4.9	14.2

The water at Station No. 2, used until last year, was excessively hard on account of infiltration of sea water and was totally unsuited for purposes of a public supply.

Station No. 2, Long Island City.

This station was located about ½ a mile southeast of Steinway and less than ½ a mile from the East River. It was separated only by a high embankment from a large swamp area, covered at times by the sea. In 1898, the water pumped from this station contained more than 800 parts of chloride per million. It was decidedly brackish. Samples have been collected from this station only once a quarter. During 1899 and a part of 1900, less water was pumped from this station and the pump was not operated during the night. This caused the chloride to drop to less than 10 parts per million. During 1901 and 1902, the chloride continued to increase until it reached 900 parts per million. During the first part of 1902 it decreased slightly, until, in November, 1902, the station came to an end through the explosion of one of the boilers which was indirectly due to corrosion caused by the muriatic character of the water. The above mentioned changes in chlorine are shown on Diagram No. 17.

†Destroyed in 1902 by boiler explosion.

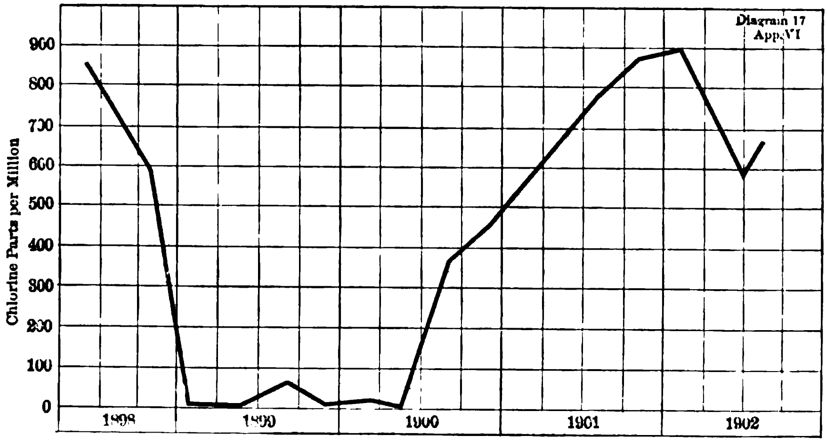


DIAGRAM 17. APP. VI.

CITY OF NEW YORK.
COMMISSION ON ADDITIONAL WATER SUPPLY.
DEPARTMENT OF CHEMISTRY AND BIOLOGY.
Diagram Showing Chlorine in the Wells at Long Island City, Station Number 2.

Of the existing plants, the chlorine is excessively high only in Station No. 1, Long Island City. In several of the stations, however, the chlorine is more than 10 parts per million.

The water of the Queens County Water Supply Company, which supplies the Far Rockaway section, contains a large amount of iron when it comes from the ground. It is passed through a sand filter, however, before it enters the distribution system and all of the iron is removed. The water is cool, clear, colorless, soft, and furnishes a well-nigh perfect supply. It contains quite a large amount of dissolved carbonic acid, however, and this is said to be the occasional cause of trouble in some of the iron service pipes.

10. QUALITY OF THE WATER SUPPLIES OF THE BOROUGH OF RICHMOND.

All of the water supplied to the borough is taken from the ground by means of driven wells. There are five stations, only one of which, namely, that at Tottenville, is operated by the City.

These waters are all safe from the sanitary standpoint.

The wells of New Springville, Clove Station and New Dorp, yield excellent water, save that it is very hard.

The water from the Tottenville plant is not only hard but contains a large amount of iron in such a condition that it precipitates easily. When the water leaves the ground it is clear, but by the time the samples reach the laboratory they have become turbid and colored because of the precipitation of the oxide of iron.

The water furnished by the West New Brighton Station of the Staten Island Water Supply Company is very unsatisfactory. Not only is it very hard, but it contains a large amount of chloride and iron. It is totally unfit for use in boilers, and is objectionable for domestic use. From the sanitary standpoint, however, there seems to be no reason to doubt its safety.

The relative hardnesses of the different water supplies in the Borough of Richmond are shown by the following figures, together with the chlorines and iron:

	Alkalinity.	Permanent Hardness.	Total Hardness.	Chlorine.	Iron.
Staten Island Water Supply Co.—					
West New Brighton Station..........	76.0	101.5	177.5	132.6	.78
New Springville Station............	77.6	67.0	144.6	11.9	.01
Crystal Water Supply Co.—					
Clove Station......................	97.4	41.1	138.5	6.9	.03
South Shore Water Supply Co.—					
New Dorp Station...................	143.4	35.6	179.0	9.4	.03
Tottenville Water Supply Co............	134.6	33.4	168.0	8.5	1.15

II.—Stream Investigations.

So many different sources had been suggested for the future water supply of New York City that at the outset it was deemed necessary to extend the sanitary investigations over a territory which included the entire watershed of the Hudson River and its tributaries, the upper portion of the Neversink River and the east branch of the Delaware River, the Ten Mile River, the Housatonic River and the streams on Long Island east of the present watershed of the Brooklyn supply. These regions covered over fifteen thousand square miles of territory and extended into five different States. As the work progressed its scope was contracted until finally all of the investigations were focussed upon the regions selected to furnish the future water supply of the city.

The investigations have shown that the streams of the Adirondack region would not furnish a water which would be in all respects satisfactory to the citizens of New York. The water there is collected from very sparsely settled watersheds, but on account of many swamp areas it has a color higher than that of the Croton water. This is especially true of the North Hudson and Sacandaga Rivers, where the color rose at times to more than 80 on the platinum scale, and had an average of 41, as against 21 for the Croton water and 15 for the Ridgewood water. The water is conspicuously clear, however, even during the spring freshets, and is quite soft.

The Battenkill, Hoosick and Mohawk Rivers, which enter the Hudson River above the Troy Dam, are all polluted streams, and their waters are quite turbid and hard.

The most important streams which enter the Hudson from the west below the Troy Dam are Catskill Creek, Esopus Creek, Rondout Creek and Wallkill Creek, the last two uniting before they reach the Hudson. These streams receive very little pollution, and from the sanitary standpoint would make excellent sources of supply. The water of the Wallkill, however, is open to the same objection as that of the North Hudson and Sacandaga Rivers, namely, its high color. At one time in July the color rose to 86, and it had an average of 58 for the entire month. At times, however, it is much lower. The color of the water is due to the effect of the "drowned lands," or extensive peat deposits, which cover many square miles on the watershed, and which in places are more than fifty feet deep. The water is open to the further objection of being quite hard.

The waters of the Rondout and Esopus are of most excellent quality, being very light colored and soft. After rains they become turbid from the effect of local clay deposits near the banks of the streams, but this is not a serious objection to their use. By proper protection of the banks at certain places most of this clay may be kept from entering the streams, and long storage and dilution would so reduce the remaining turbidity as to make it practically unnoticeable. Filtration would remove it completely. The water of the Esopus is slightly better in quality than that of the Rondout. In fact, the investigations have nowhere shown an available water likely to prove so satisfactory for general use as that which can be obtained from the Esopus Creek. It has less than one-half the hardness of the present Croton supply, is tasteless, odorless and practically colorless. It is clear, except for the turbidity observed after rains, which would be lost on storage. Filtration or long storage in clean reservoirs would render this water well-nigh perfect for purposes of public supply.

The water of the Catskill Creek is clearer than that of the Esopus Creek and its color is not much higher. It contains more calcareous matter, however, having a hardness which is but slightly less than that of the Croton water.

West of the Catskill region is the watershed of Schoharie Creek, which flows northward into the Mohawk, and southwest of this are the watersheds of the East Delaware and Neversink, which flow southward into the Delaware River. The waters of these streams are likewise clear, very soft and with little color.

On the east side of the Hudson, below Albany, the streams which have received attention are the Stockport Creek, the Roelif Jansen Kill, Wappinger Creek and Fishkill Creek. These may be all classed as practically unpolluted, clear, tasteless, odorless, and with low color, but with considerable amounts of lime salts in solution, rendering them about from one and one-half to three times as hard as Croton water. This region is overlaid in patches with limestone rocks, and much variation in hardness is found in streams very near together. The hardness of these waters is described at length on a later page.

The limestone deposits extend eastward over the watersheds of the Ten Mile and Housatonic Rivers, rendering the water in those streams very hard. They also extend over the northeastern portion of the Croton watershed.

The detailed results of the stream investigations are given below:

1. Territory Covered.

The territory covered by these investigations may be divided as follows, for purposes of description:

Upper Hudson.

(Region North of Glens Falls.)

North Hudson River.

Upper Hudson, West—
Sacandaga River.

Upper Hudson, East—
Schroon River.

Middle Hudson.

(Region Between Glens Falls and the Troy Dam.)

Intermediate Hudson, West—
Fish Creek.
Mohawk River.

Intermediate Hudson, East—
Battenkill Creek.
Hoosic River.

Lower Hudson.

(Region Between the Troy Dam and the Sea.)

Lower Hudson, West—
Catskill Creek.
Esopus Creek.
Schoharie Creek.
Rondout Creek.
Wallkill River.
Moodna Creek.

Lower Hudson, East—
Stockport Cree.
Roelif Jansen Kill.
Wappinger Creek.
Fishkill Creek.
Peekskill Creek.
Croton River.

Adjacent Watersheds.

Delaware River.
Neversink River.
Ramapo River.

Ten Mile River.
Housatonic River.

Long Island.

Several Streams in Suffolk County.

The locations of these various districts are shown on Plate VII. The map shows the general hydrographic systems, the locations of the sample stations, tide-gauge stations and the most important cities and towns. The lines of latitude and longitude correspond with those of the atlas sheets of the United States Geological Survey, and, for convenience, they have been numbered in the upper left-hand corner according to the decimal system of co-ordination. The names and numbers of the geological sheets are as follows: Vertical ranges are represented by thousands and horizontal ranges by hundreds. The subdivisions of each atlas sheet are represented by tens and units, the numbers beginning at the upper left hand corner. These figures are valuable as an index to certain data on file in the Department. The numbers given correspond to the atlas sheets, which are named by the United States Geological Survey as follows:

List of Geological Sheets.

Number of Sheet.	Name.	Number of Sheet.	Name.
1500	Staten Island.	9900	Greylock.
1600	Brooklyn.	10300	Canajoharie.
1700	Hempstead.	10400	Fonda.
1800	Babylon.	10500	Amsterdam.
2500	Paterson.	10600	Schnectady.
2600	Harlem.	10700	Cohoes.
2700	Oyster Bay.	10800	Hoosic.
2800	Northport.	10900	Bennington.
3300	Franklin.	11000	Oriskany.
3400	Greenwood Lake.	11100	Utica.
3500	Ramapo.	11200	Little Falls.
3600	Tarrytown.	11300	Johnstown.
3700	Stamford.	11400	Gloversville.
4500	Schunemunk.	11500	Broadalbin.
4600	West Point.	11600	Saratoga.
4700	Carmel.	11700	Schuylerville.
4800	Danbury.	11800	Cambridge.
5500	Newburg.	11900	Equinox.
5600	Poughkeepsie.	12000	Londonderry.
5700	Clove.	12100	Remsen.
5800	New Milford.	12200	Wilmurt.
6600	Rhinebeck.	12600	Luzerne.
6700	Mill Brook.	12700	Glens Falls.
6800	Cornwall.	13200	Old Forge.
7500	Kaaterskill.	13300	Canada Lake.
7600	Catskill.	13400	Indian Lake.
7700	Copake.	13500	Thirteenth Lake.
7800	Sheffield.	13600	North Creek.
7900	Sandisifield.	13700	Bolton.
8500	Durham.	13800	Whitehall.
8600	Coxsackie.	14400	Castleton.
8700	Kinderhook.	14500	Newcomb.
8800	Pittsfield.	14600	Schroon Lake.
8900	Becket.	14700	Paradox Lake.
9400	Schoharie.	15500	Santanoni.
9600	Albany.	15600	Mt. Marcy.
9700	Troy.	15700	Elizabethtown.
9800	Berlin.	15800	Port Henry.

2.—METHODS EMPLOYED.

The stream investigations were carried on in the following manner:

Stations were established on all the important streams, and local representatives were engaged to collect daily samples, observe the stage of the river by reading a staff-gauge and record the meteorological condition.

Thirty-four such stations were maintained, but not all of them were continued through the entire period of the investigation. At nine of these stations rain-gauges were located and the daily precipitation recorded. In all cases, the sampling points were selected with care to secure a representative sample of the water in the stream. In the case of the streams which empty into the lower Hudson, it was necessary to locate the stations some distance from the mouth in order to avoid tidal influence.

The regular daily samples were collected in 16-ounce Blake bottles and sent by express to the Poughkeepsie Laboratory in cases of twelve. There they were examined for turbidity, color, alkalinity and hardness, and in some cases for chlorine. The records of gauge-reading, rainfall, etc., were sent to Poughkeepsie weekly on mailing cards. From time to time samples for chemical analyses were collected at the most important stations and sent to Mt. Prospect Laboratory. Following is a list of the stations, with the location of each and the name of the collector:

Sample Stations.

Stream.	Location of Station.	Name of Collector.
Hudson River	Riverside	W. M. Clear.
"	Glens Falls	D. J. Ordway.
"	Schuylerville	George Efnor.
"	Waterford	J. S. Rhodes.
"	Wemple	Frank Welch.
"	Castleton	W. F. Willis.
"	Catskill	J. R. Johnson.
"	Saugerties	Theodore De Shong.
"	Rhinecliff	Charles Winchell.
"	Hyde Park	P. F. O'Rourke.
"	Poughkeepsie	Office.
"	Garrison	H. C. Robinson.
Schroon River	Warrensburg	J. H. Stewart.
Sacandaga River	Conklingville	C. C. Palmer.
Batten Kill	Clark's Mills	Edward Sherman.
Hoosic River	Schaghticoke	H. M. Sandford.
Mohawk River	Cohoes	James McKinley.
Stockport Creek	Columbiaville	David Harder.
Roelif Jansen Kill	Linlithgo	Clarence Temple.
"	Mt. Ross	J. E. Van Tassel.
Wappinger Creek	Wappinger Falls	D. I. Ashworth.
"	Manchester Bridge	Charles Bulmer.
"	Hibernia	Walter Sackrider.
" (Little Wappinger Creek)	Clinton Hollow	L. I. Tripp.
Fishkill Creek	Matteawan	Rawdon Taylor.
"	Brinckerhoff	William Barber.
"	Stormville	C. Simpson.
" (Sprout Creek)	Freedom Plains	John Steele.
Catskill Creek	South Cairo	C. J. Abrams.
Esopus Creek	Shokan	H. C. Smith and James Diamond.
Schoharie Creek	Prattsville	James Brennan.
Rondout Creek	Rosendale	Anne E. Huben.
"	Napanoch	H. F. Kuhfeldt.
Wallkill River	New Paltz	Charles McEntee.

Rain Gauges.

The rain gauges were located at Riverside, Conklingville, Schaghticoke, Saugerties, Rhinecliff, South Cairo, Shokan, Matteawan and Brinckerhoff. Each gauge consisted of a galvanized cylinder two feet in diameter and ten inches deep, with a conical bottom which had a central outlet two inches in diameter. This was set in a horizontal position over a bucket, which was placed in a hole dug in the ground, at such a depth that the sharp upper edge of the cylinder was one foot above the ground. The rain which collected in the bucket was measured in gills and the depth of the rainfall in inches obtained by calculation. Gauges of this type were adopted in place of the standard types, to save expense, as exact results were not required for purposes of the sanitary survey. In setting up the gauges a point was selected on level ground at least 100 feet from any building or tree.

In addition to the analyses of regular daily samples from the collecting stations, inspection tours were made over the regions named above to determine the general topographical and geological features of the watershed, the character of the vegetation, the extent of cultivated land, the appearance of the banks of the stream, and, most important of all, the sources of pollution. The completeness of these investigations varied according to the probability of the water being used. In some cases only a reconnoissance survey was made, while in other cases all of the important features of the streams were carefully studied. All of the watersheds given in the above summary were gone over at least once. The Upper Hudson region was covered twice, each watershed in the Lower Hudson region was covered twice, with the exception of the Rondout, Wallkill, Moodna, Stockport and Peekskill watersheds. The Esopus, Roelif Jansen, Wappinger and Fishkill watersheds were covered three times. On these trips many samples, representing both surface and ground water, were collected and sent to the laboratory for determination of color, turbidity, alkalinity and hardness. In some instances these observations were made in the field.

The detailed sanitary survey was confined to the watersheds of Fishkill Creek, Wappinger Creek, Roelif Jansen Kill, Esopus Creek, Catskill Creek and Schoharie Creek. It was made by four volunteer inspectors, undergraduates of the Massachusetts Institute of Technology, who devoted their vacations to the work. The object was to secure reliable data as to the permanent and visiting populations on the different streams, the size of the villages, their methods of sewage disposal, if any, the number of summer hotels, etc. Supplied with topographical maps the inspectors went over the territory either by carriage or bicycle, counting the occupied houses and locating them upon the maps. By using the ratio between population and houses given in the last United States census, the populations were determined for the various regions and these results were checked by comparing them with the census returns. The number of summer boarders was estimated by inquiry at the hotels and boarding-houses, and by talking with the postmasters in the different villages. Sources of pollution were, of course, noted, and located on the maps. The volunteer inspectors also collected many samples of water and made notes on the general character of the country.

3. UPPER HUDSON, OR ADIRONDACK REGION.

Three large Adirondack streams unite to form the Hudson River—the North Hudson, the Schroon and the Sacandaga. The first, which bears the name Hudson, and is sometimes referred to as the North Hudson, or the Upper Hudson, is the upward continuation of the main stream, while the Schroon and the Sacandaga are usually regarded as tributaries. The tributaries are, however, equal in importance to the main stream.

North Hudson.

The North Hudson River rises in Newcomb Township (north latitude 44 degrees 5 minutes and longitude 74 degrees 5 minutes west), and flows for about fifty-five miles in a general southerly direction until it is joined by the waters of the Schroon River just above Thurman. It has a drainage area of about 950 square miles. The whole watershed is well wooded, and the amount of cleared land is relatively small. But little farming is done. The country is mountainous and rocky. Gneiss and granite predominate, but there are scattered areas of anorthosite, schist and limestone. There are no clay deposits and no extensive swamp areas.

The permanent population on the watershed has been estimated as about 2,960, or 3 per square mile. To this must be added the transient summer population, sprinkled in camps over the watersheds, usually near the lakes. With the most liberal allowance, however, the total population per square mile cannot be considered as above 4. There are no large centres of population and no important sources of pollution. The worst cases are the drainages from occasional houses or from mills, and the number of such cases is insignificant.

The regular sample station, located at Riverside, about twelve miles above the mouth of the Schroon River, was maintained from March 27 to September 1. During this period samples were collected daily, and rainfall records were kept.

Schroon River.

The Schroon River rises in Elizabethtown, Essex County (latitude 44 degrees 5 minutes, longitude 73 degrees 40 minutes), flows in a southerly direction to Warrensburg, and then westerly, entering the Hudson at Thurman, thirty-five miles above Glens Falls. The drainage area, 580 square miles, includes several large lakes, Schroon Lake, Brant Lake and Paradox Lake. The watershed is generally mountainous and rocky, but in the lake region there is some swamp land. Granite, gneiss, anorthosite, with occasional small areas of limestone, constitute the surface rock formations. There are in places large areas of fine sand. As in the case of the North Hudson, the country is well wooded, the estimated cleared land forming only about 15 per cent. of the total area. The average run-off between 1895 and 1901 has been estimated by the State Engineer to be about 2.0 second feet per square mile (see Annual Report of State Engineer for 1901).

The permanent population on the watershed of the Schroon River is estimated as 17 per square mile. The increment of transient summer population would raise this figure to about 19 per square mile. The centres of population are somewhat more numerous than on the North Hudson River. The largest town is Warrensburg, about four miles above the mouth of the river. It has a population of about 2,360, and supports a large pulp mill, the untreated wastes from which enter the river. There are numerous other mills scattered along the stream. The sample station for the Schroon River was at Warrensburg, and was maintained from March 26 to September 1.

Sacandaga River.

The Sacandaga River rises in Johnsburg, Warren County (latitude 43 degrees 40 minutes, longitude 74 degrees 5 minutes), and flows south and east, entering the Hudson near Hadley, 15 miles below the mouth of the Schroon and about 20 miles above Glens Falls. It drains an area of 1,070 square miles. The watershed is quite different in character from those of the Schroon and North Hudson. It is less mountainous, and for long distances the stream runs through wide, sandy valleys. The bed of the river is sandy and gravelly, rather than rocky. The flats along the lower portion of the river are extensively cultivated, and on some of the tributaries there are extensive tamarack swamps. One of these swamps near the Town of Northampton is drained by Vly Creek, and covers an area of twelve square miles. The swamps and river flats are inundated at times of high water. The hills on the upper portion of the watershed are well wooded. Most of the rocks are granite, but in the southern part a tongue of limestone extends from Northville to Broadalbin, with a strip of sandstone on either side.

The permanent population on the Sacandaga Watershed is estimated at 7,000, or about 7 per square mile, which is increased by the summer population to about 8 per square mile. The only towns of importance are Conklingville (population 500) and Northville (population 1,000). There are no manufacturing centres. Lumbering is the chief industry.

The regular sample station was established at Conklingville on March 27 and maintained until September 1.

Upper Hudson River Above Glens Falls.

In addition to the watersheds of the North Hudson, Schroon and Sacandaga, the upper Hudson above Glens Falls has a drainage area of about 110 square miles, which gives a total drainage area above Glens Falls of 2,710 square miles.

The total population on the watershed of the Hudson River above Glens Falls is estimated at about 20,800, or 8 per square mile. This may be all classed as rural. The most important towns besides those already mentioned are Hadley and Palmer's Falls, these being located on the main stream, the one 25 and the other 20 miles above Glens Falls. At Palmer's Falls there are pulp mills which discharge their wastes into the river.

A regular sample station was maintained at Glens Falls from March 20 to September 1. The samples were collected at the falls.

Quality of the Water of the Upper Hudson.

The quality of the water in the Adirondack region is shown by the summaries of analyses given in Tables 11 to 14.

TABLE 11.

STREAM INVESTIGATIONS.

Representative Chemical and Miscroscopical Analyses of Samples Collected from the Most Important Streams During 1903.

Region.	Stream.	Station.	Turbidity.	Color.	Odor.	Nitrogen as Albuminoid Ammonia.	Nitrogen as Free Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Microscopic Organisms.	Amorphous Matter.	Remarks.
Upper Hudson	North Hudson	Riverside	3	42	2 v	.136	.026	.001	.18	38.0	0.6	19.9	8.0	.15	48	58	Average of three analyses, March 20, April 3 and June 15.
Upper Hudson	Schroon	Warrensburg	6	23	2 v	.122	.012	.001	.10	36.0	0.8	17.5	15.0	.10	..	..	Average of two analyses, March 20 and March 29.
Upper Hudson	Sacandaga	Conklingville	3	33	2 v	.128	050	.001	.18	33.5	0.5	17.5	11.0	.15	30	30	Average of two analyses, March 18 and April 3.
Upper Hudson	Hudson	Glens Falls	3	33	2 v + 1 d	.112	.020	.002	.12	42 0	0.5	18.0	12.0	.16	46	30	Average of seven analyses, February 9 to August 22.
Upper Hudson	Lake George	Ticonderoga	1	9	2 v	.092	.008	.001	.00	50 0	0 6	30 0	26.0	.20	110	75	August 21.
Middle Hudson	Moses Kill	Point Miller	12	30	2 v + 2 e	.356	.024	.018	.10	210.0	2.4	81.0	72.0	2.00	..	..	August 20.
Middle Hudson	Battenkill	Clark's Mills	10	17	2 v + 1 d	.102	.038	.006	.13	116.0	1 6	90.5	84.0	.25	90	90	Average of two samples, June 8 and August 20.
Middle Hudson	Hoosie	Schaghticoke	15	13	2 v + 2 d	.086	.018	.003	.38	96.0	1.6	49.0	39.0	.20	23	303	Average of three samples, February 10, March 14 and March 28.
Middle Hudson	Snook Kill	Gansevoort	2	28	2 v + 1 m	.130	.028	.000	.05	86.0	1.0	50.0	49.0	.20	200	45	August 22.
Middle Hudson	Anthony Kill	Mechanicsville	3	22	2 v	.112	.038	.000	.00	135.0	1.2	117.5	88.0	.20	120	130	August 12.
Middle Hudson	Mohawk	Cohoes	30	36	3 v + 1 d	.123	.047	.003	.32	137.5	1.2	63.5	51.5	.65	61	340	Average of five samples, February 10 to August 18.

TABLE II—*Continued.*

Region.	Stream.	Station.	Turbidity.	Color.	Odor.	Nitrogen as Albuminoid Ammonia.	Nitrogen as Free Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Microscopic Organisms.	Amorphous Matter.	Remarks.
Lower Hudson, East	Poesten Kill	Lake Ida	1	45	2 v	.136	.072	.000	.10	51.0	0.8	24.5	19.0	.10	300	65	August 18.
	Wynant Kill	Alba	3	10	2 v	.116	.068	.002	.10	69.0	1.5	34.0	30.0	.15	195	60	"
	Kinderhook Creek	Valatie Bay	2	20	2 v + 1 g	.128	.116	.032	.05	82.0	1.4	51.5	46.0	.10	1220	100	August 17.
	Stockport Creek	Columbiaville	15	11	3 v + 1 d	.232	.081	.032	.25	71.0	2.0	36.5	31.0	.20	..	..	March 28.
	Roelif Jansen Kill	Silvernails	3	16	3 v + 1 m	.116	.044	.004	.10	144.0	2.0	123.0	110.0	.10	..	..	June 5, 1903.
	Shekomeko Creek	"	3	10	2 v	.096	.164	.008	.45	192.0	1.8	150.0	145.0	.00	..	..	" "
	Wappinger Creek	Wappinger Falls	6	15	2 v	.180	.040	.001	.40	97.0	1.6	57.0	54.0	.15	..	..	April 1, 1903.
	"	Van Wagner	5	35	2 v	.208	.060	.005	.20	86.0	1.4	40.5	37.0	.20	180	165	June 13, 1903.
	"	Salt Point	5	35	2 v	.180	.052	.004	.15	73.0	1.0	35.0	29.0	.20	35	145	" "
	"	Hibernia	0	30	2 v	.188	.076	.002	.15	101.0	0.8	54.5	54.0	.20	195	95	" "
	Fishkill Creek	Brinckerhoff	5	30	2 v	.148	.068	.004	.10	112.0	1.0	75.0	69.0	.40	105	190	June 12, 1903.
	"	Hopewell Junc.	8	23	3 v	.124	.096	.006	.20	130.0	1.2	94.0	60.0	.20	..	.	January 30.
	Sprout Creek	Brinckerhoff	20	28	2 v	.252	.088	.003	.25	120.0	1.0	45.5	41.0	1.00	335	280	June 12.
Lower Hudson, West	Norman Kill	Kenwood	3	17	2 v	.096	.088	.002	.00	143.0	1.9	97.0	83.0	.10	140	120	August 17.
	Catskill Creek	East Durham	4	9	2 v	.096	.047	.003	.05	63.0	0.8	39.5	33.5	.05	55	40	Average of two analyses, March 17 and August 8.
	Schoharie Creek	Prattsville	18	18	3 v	.120	.040	.001	.15	42.0	0.6	8.0	6.0	.40	230	25	April 1, 1903.
	Batavia Kill	Above mouth	20	10	3 v	.064	.036	.002	.05	44.0	0.9	17.0	15.0	.10	140	120	August 12, 1903.
	Esopus Creek	Brodhead	5	8	2 v	.053	.029	.001	.05	32.0	0.5	15.0	10.0	.05	50	28	Average of two samples, March 18 and July 27.
	Rondout Creek	Napanoch	3	11	2 v	.081	.035	.001	.03	22.0	1.2	11.0	8.0	0.5	40	180	Average of two analyses, February 2 and March 12.
	Wallkill river	New Paltz	12	30	2 v	.160	.022	.002	.15	97.0	2.6	48.5	46.0	.20	95	335	March 16.
	Moodna Creek	Salisbury Mills	12	30	3 v	.196	.164	.003	.05	82.0	2.4	30.0	21.0	.20	110	390	January 31.
Adjacent Watersheds	Ten Mile river	Dover Plains	12	23	3 v + 1 m	.140	.054	.006	.40	172.0	1.6	106.0	51.0	.70	..	..	January 29.
	Housatonic	Canaan	3	17	2 v	.076	.020	.008	.20	130.0	1.2	123.0	82.0	.20	64	62	January 27.
	East Delaware	Margaretville	10	0	2 v	.068	.040	.002	.20	25.0	1.6	8.0	8.0	.10	..	..	March 29.
	Neversink	Cuddebackville	2	18	2 v	.112	.040	.002	.10	25.0	1.2	12.5	8.0	.10	55	140	March 30.
	Ramapo	Hillburn	16	28	2 v + 1 m	.078	.056	.004	.10	56.0	1.2	30.0	14.0	.10	68	106	January 30.

TABLE 12.

Summary of Daily Turbidity Observations at Sample Stations from March to October, 1903; Showing the Average Turbidity for Each Month, the Maximum and Minimum for the Entire Period, the Ordinary Turbidity and the Average during the Period Covered by the Observations, Expressed in Terms of the Silica Standard.

Stream.	Station.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Min.	Max.	Ord.	Ave.
North Hudson	Riverside	1	2	3	1	4	5	..	0	9	3	3
Schroon	Warrensburg	1	2	2	2	4	4	..	0	14	2	3
Sacandaga	Conklingville	3	3	3	4	5	5	..	1	13	4	4
Hudson	Glens Falls	4	3	2	3	3	3	..	1	10	3	3
Battenkill	Clark's Mills	..	..	..	4	4	5	..	1	25	4	4
Hoosic	Schaghticoke	68	7	2	40	3	2	..	1	300	4	20
Mohawk	Cohoes	102	20	5	28	16	6	..	1	500	5	29
Stockport Creek	Columbiaville	46	3	4	4	6	12	..	1	250	5	12
Roelif Jansen Kill	Mt. Ross	..	†5	†2	6	3	4	5	1	45	4	4
Wappinger Creek	Manchester Bridge	*5	*3	2	3	3	4	..	0	28	3	4
Fishkill Creek	Brinckerhoff	‡4	‡6	4	5	5	3	..	0	25	4	4
Schoharie Creek	Prattsville	5	3	3	4	3	5	..	1	30	3	4
Catskill Creek	South Cairo	..	6	2	4	2	3	..	0	22	3	3
Esopus Creek	Shokan	48	5	2	33	2	7	4	0	800	4	14
Rondout Creek	Napanoch	3	2	2	6	5	4	..	0	50	3	4
Wallkill Creek	New Paltz	27	15	3	60	32	16	..	1	150	6	25
East Delaware	Margaretville	10	5	2	2	3	..	..	1	80	3	4
Neversink	Cuddebackville	2	2	1	3	..	..	..	0	20	2	2

* Wappinger Falls. † Collected at Linlithgo. ‡ Matteawan.

TABLE 13.

Summary of Daily Color Observations at Sample Stations from March to October, 1903; Showing the Average Color for Each Month, the Maximum and Minimum for the Entire Period, the Ordinary Color and the Average During the Period Covered by the Observations, Expressed in Parts per Million of Platinum.

Stream.	Station.	Mar.	Apr.	May	June	July	Aug.	Sept.	Min.	Max.	Ord.	Ave.
North Hudson	Riverside	38	37	28	61	39	42	..	28	98	41	41
Schroon	Warrensburg	28	27	24	30	32	41	..	20	76	28	30
Sacandaga	Conklingville	33	32	26	52	55	46	..	22	80	41	40
Hudson	Glens Falls	36	32	26	48	47	40	..	23	92	28	38
Battenkill	Clark's Mills	..	..	..	28	31	26	..	20	48	28	28
Hoosic	Schaghticoke	20	15	15	19	13	21	..	7	38	16	17
Mohawk	Cohoes	27	20	18	32	34	35	..	12	50	28	27
Stockport Creek	Columbiaville	19	17	16	24	21	15	..	10	38	19	18
Roelif Jansen Kill	Mt. Ross	†17	†14	†11	19	22	17	15	8	29	16	16
Wappinger Creek	Manchester Bridge	*20	*12	12	26	24	21	..	7	38	19	10
Fishkill Creek	Brinckerhoff	‡18	‡21	17	17	24	23	..	10	40	20	21
Schoharie Creek	Prattsville	16	11	11	16	20	18	..	4	30	15	15
Catskill Creek	South Cairo	..	10	10	17	12	12	..	4	33	12	12
Esopus Creek	Shokan	9	6	8	12	12	11	9	3	30	9	9
Rondout Creek	Napanoch	28	23	16	20	29	24	..	10	45	24	24
Wallkill Creek	New Paltz	30	35	23	38	58	47	..	18	86	38	38
East Delaware	Margaretville	8	8	11	10	12	..	..	4	25	10	9
Neversink	Cuddebackville	22	19	13	26	..	..	..	7	60	20	20

* Wappinger Falls. † Collected at Linlithgo. ‡ Matteawan.

TABLE 14.

Summary of Alkalinity Determinations at Sample Stations from March to October, 1903; Showing the Average for Each Month, the Maximum and Minimum for the Entire Period, the Ordinary Alkalinity, and the Average for the Period Covered by the Investigations, Expressed in Parts per Million.

Stream.	Station.	Mar.	Apr.	May	June	July	Aug.	Sept.	Min.	Max	Ord.	Ave.
North Hudson	Riverside	10	10	15	12	17	19	..	8	22	..	13
Schroon	Warrensburg	16	18	19	17	19	25	..	12	28	..	19
Sacandaga	Conklingville	14	14	22	22	23	24	..	12	28	..	20
Hudson	Glens Falls	21	16	19	17	21	21	..	10	28	..	20
Bottenkill	Clark's Mills	..	..	..	59	78	84	..	43	98	..	73
Hoosic	Schaghticoke	55	63	88	62	69	77	..	40	95	..	69
Mohawk.	Cohoes	65	70	98	88	85	91	..	40	112	..	82
Stockport Creek	Columbiaville	38	45	61	47	57	60	..	32	71	..	51
Roelif Jansen Kill	Mt. Ross	†71	†88	†100	93	97	108	108	71	130	..	56
Wappinger Creek	Manchester Bridge	*66	*67	90	63	72	79	..	40	97	..	72
Fishkill Creek	Brinckerhoff	‡77	‡67	86	71	87	86	..	45	92	..	79
Schoharie Creek	Prattsville	13	13	20	17	24	21	..	10	29	..	18
Catskill Creek	South Cairo.	..	40	52	41	54	54	..	30	65	..	48
Esopus Creek	Shokan	18	13	17	15	20	19	17	9	28	..	17
Rondout Creek	Napanoch	13	16	25	18	27	30	..	12	29	..	27
Wallkill Creek	New Paltz.	50	54	90	62	67	70	..	33	104	..	65
East Delaware	Margaretville	17	18	19	22	..	..	..	11	34	..	19
Neversink	Cuddebackville	12	10	14	11	..	..	..	7	16	..	11

* Wappinger Falls. † Collected at Linlithgo. ‡ Matteawan.

The water is ordinarily quite clear. It does not become turbid even after heavy rains. The highest turbidity observed during the entire period of six months was 14 on the silica scale. The color was ordinarily higher than is considered desirable in a public water supply. This was especially true of the waters of the North Hudson and the Sacandaga, the former of which had a maximum of 98 and the latter a maximum of 80. At Glens Falls the maximum was 92, and the average for the entire period was 38, which is about double what is considered a desirable limit (see Diagram No. 18). The water had also the vegetable taste and odor which accompanies a dark colored water. The tamarack swamps on the tributaries of the Schroon River contribute largely to the color and taste of the Hudson River water. A few of the samples collected at Glens Falls had, in addition to the vegetable odor, an odor suggestive of decomposition.

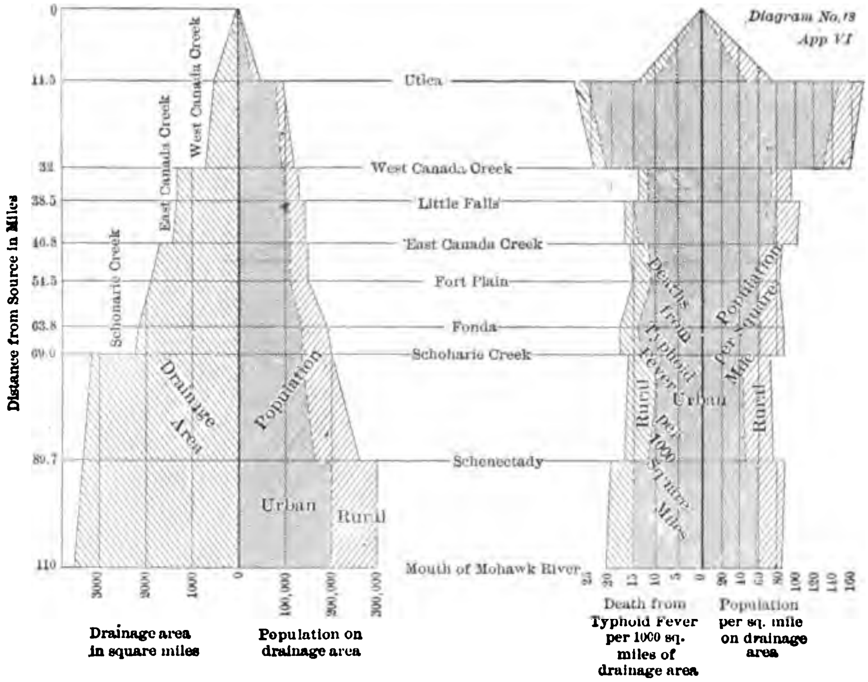


DIAGRAM 18. APP. VI.

Chemical analyses show the waters to be quite soft, and with chlorines which are practically normal. The samples from the Schroon contained chlorine slightly above the normal, which for this reason is about 0.4 parts per million, and were probably slightly influenced in this respect by the Town of Warrensburg, below which they were taken. The nitrogen as albuminoid ammonia was rather high, and evidently represented the coloring matter present. The nitrates were low. There were few microscopic organisms, and these were of no especial significance. Such as were found probably came from the lakes, where, however, it is not likely that they develop in large numbers. All of the samples when tested for Bacillus coli gave negative results.

Lake George.

Although Lake George can be hardly considered as an available source of water supply for New York City on account of its low elevation and limited watershed, yet, inasmuch as it is so frequently mentioned in this connection, it has not been left entirely out of consideration. Investigations showed that the permanent population on the watershed is equal to about 30 per square mile, and while no careful sanitary survey was made, it is a matter of common knowledge that the population is greatly increased during the summer season. Only one sample of water was taken for analysis and the result is given in Table 11.

4. THE MIDDLE HUDSON.

Between Glens Falls and the Troy dam the Hudson River has a total drainage area of 5,338 square miles. This region may be termed the " Middle Hudson." In it are included the Battenkill and Hoosic Rivers, and the great valley of the Mohawk River. There are other streams, also, of lesser importance. None of these streams is suitable for use as a public water supply for New York, although the Battenkill has been suggested as a possible source. Speaking generally, their waters are too much polluted, are hard, and at times, very turbid. Their effect upon the water of the Hudson River makes them worthy of consideration.

Battenkill.

The Battenkill rises in the State of Vermont, in the Town of Peru, Bennington County (latitude 43 degrees 15 minutes, longitude 72 degrees 55 minutes), and flows in a general westerly direction, entering the Hudson nearly opposite Schuylerville, 30 miles above the Troy dam. It is about 50 miles in length, and has a drainage area of 437 square miles.

The character of the watershed resembles somewhat that of the Sacandaga, especially in its lower reaches. It there flows through a valley about three-quarters of a mile wide, from which hills rise sharply on both sides. The river bed is sandy and muddy. Slates and mica-schists are the predominating rocks, but extensive limestone deposits are found in the upper portion and clay in the lower regions. These tend to make the water hard and turbid. The wooded areas are much less extensive than on the upper Hudson, and the lower valley is well cultivated.

The population on the watershed is estimated as about 1,500, or 34 per square mile, and most of this is included in about a dozen villages scattered along the river and its tributaries. There are a few large manufacturing centres, and although there are some paper mills, lime-kilns, etc., the amount of manufacturing wastes entering the stream is comparatively small. The chief source of contamination is the domestic sewage from the villages mentioned.

The sample station on this stream at Clark's Mills was not established until June 15, but after that date daily samples were collected until September 1.

The water of this stream is ordinarily fairly clear, but after rains the effect of the clay deposits is seen in the increased turbidity. The water has but a moderate color, the average for the three summer months being 28, and the maximum 48. The water is quite hard, the average alkalinity for the three months mentioned being 73. The normal chlorine for this region is about 0.4 part per million, and the excess of chlorine above this normal, as shown by the samples collected at Clark's Mills, was 1.2 parts per million.

Hoosic River.

The Hoosic River rises in Pittsfield, Massachusetts (latitude 42 degrees 30 minutes, longitude 73 degrees 15 minutes), and flows in a northwesterly direction, through the State of Vermont into New York State. Below Hoosic Falls it bends to the westward and flows into the Hudson a short distance above Mechanicsville. Below Hoosic Falls it receives an important tributary, the Walloomsae River, the drainage area of which lies entirely within the State of Vermont. The drainage area of the Hoosic River is about 738 square miles. The river flows through a wide valley bounded by precipitous slopes. The upper portion is quite mountainous. The rock formation consists of shale and sandstone, with scattered areas of slate. Limestone and dolomite are abundant in the upper portion, and clay deposits are numerous, especially in the lower reaches. The resident population is estimated as 59,000, or about 80 per square mile. There are a number of important centres of population—North Adams, Mass. (population 24,000); Williamstown, Mass. (population 5,000); Bennington, Vt. (population 5,600); Hoosic Falls, N. Y. (population 5,700); Eagle Bridge, Johnsonville, Valley Falls, Schaghticoke, etc. There are many manufacturing establishments such as cotton and woolen mills along the river, and the water receives a large amount of pollution.

The water of the Hoosic River as it enters the Hudson is ordinarily quite turbid. The average turbidity for the six months from March to August, 1903, was 20, while the maximum was 300. The average turbidity for the month of March was 68, and for the month of June, 40. During the periods of dry weather, however, the turbidity falls to about 4. The color is comparatively low, the average for six months being only 17, and the maximum only 38. The water has a hardness which is only slightly less than that of the Battenkill. The average alkalinity for six months was 69. The normal chlorine for this region is about .5 parts per million.

Mohawk River.

The Mohawk River rises in Leyden (latitude 43 degrees 30 minutes, longitude 75 degrees 30 minutes), about 15 miles northwest of the City of Rome, and flows for about 110 miles in a general easterly direction, entering

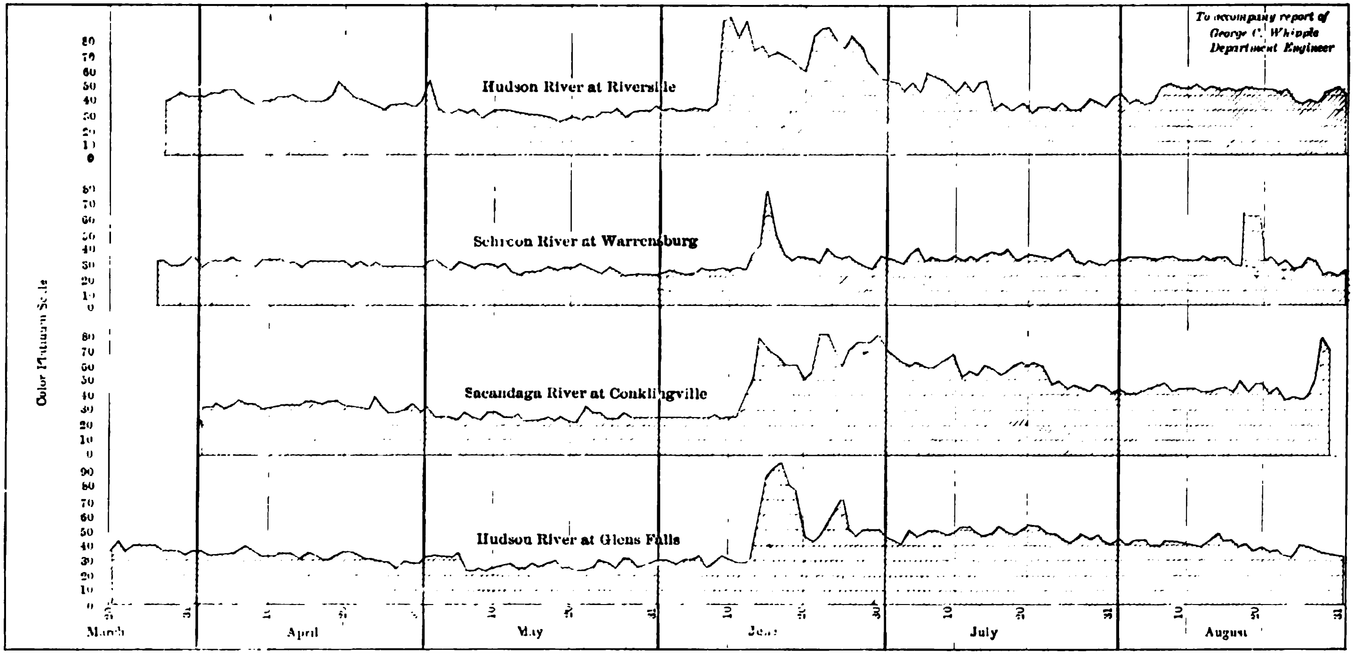


DIAGRAM 19. APP. VI.

CITY OF NEW YORK.

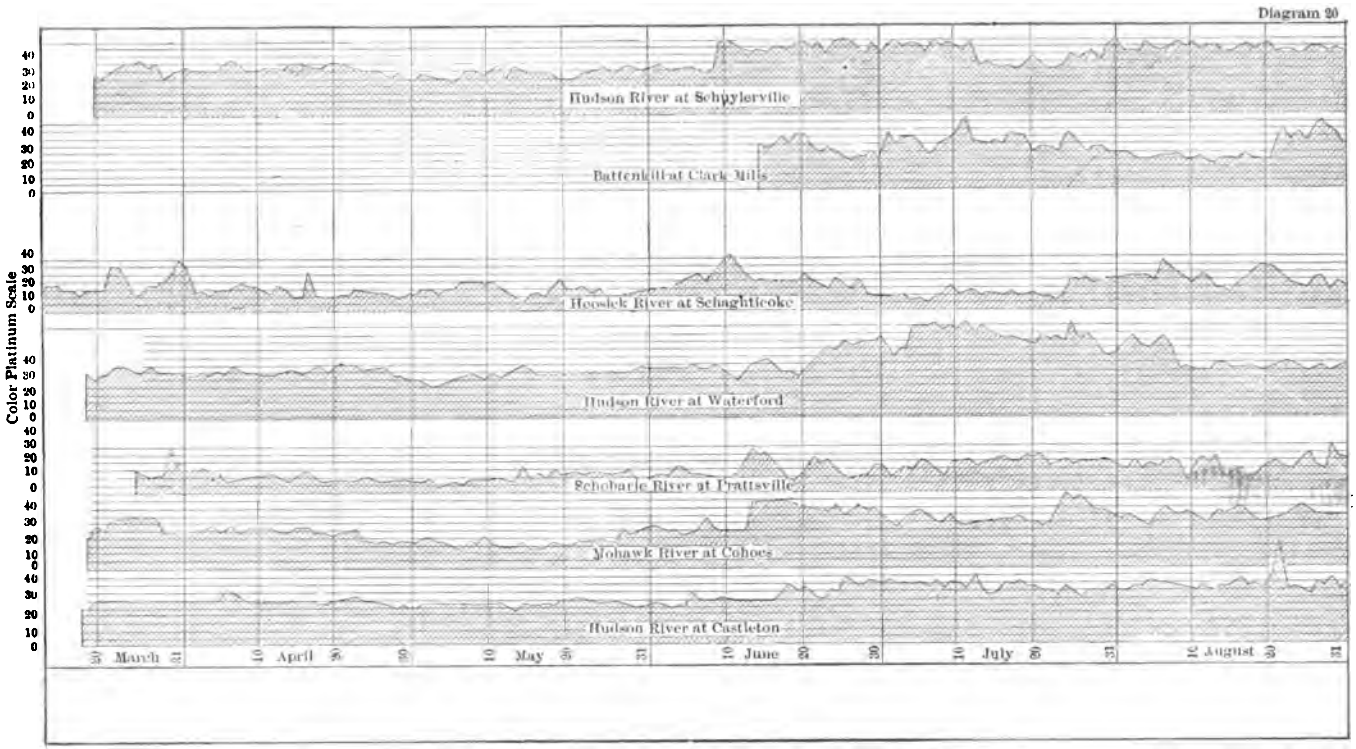
COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing Color of the Upper Hudson Streams.

the Hudson at the City of Cohoes, about 8 miles north of Albany. The stream has a total drainage area of about 3,500 miles. It receives two important tributaries from the north, namely, the West Canada Creek (drainage area 569 miles), and the East Canada Creek (drainage area 283 square miles). Both of these streams drain the southwesterly portions of the Adirondack region. From the south, it receives the Schoharie Creek (drainage area 947 square miles), which drains the northwestern section of the Catskill Mountains. The main valley of the Mohawk River is wide and fertile, and the bottom lands are uniformly used for agricultural purposes. The surrounding hills are well wooded. The river bed is generally shallow and wide, and there are many rapids along the course of the stream which give opportunity for aeration. From the mouth of the stream down to Palatine Bridge the river banks are generally muddy. Below that they become pebbly, and outcrops of shale and sandstone along the slope are numerous. This shale and sandstone runs as a narrow strip through the entire valley and covers about 50 per cent. of the watershed. North of this there are areas of gneiss and granite, with small areas of limestone, and south of it there are areas of limestone, shale and gypsum.

There are several large cities located upon the Mohawk River which drain directly into the stream, and in each of these cities there are many industrial enterprises which contribute to the pollution. The data bearing on these points have been collected and are on file. In Diagram No. 19, there is shown a graphical representation of the relative pollution of the stream at different points, based upon statistics of population. This diagram requires a few words of explanation. The mass profile at the left shows the increase in the size of the drainage area of the stream from the source to the mouth, the accessions from tributary streams being shown by steps, and also the total population on the watershed above certain important points. The right hand figure shows the urban and rural populations above the points mentioned, expressed in number per square mile of watershed, and also the number of deaths from typhoid fever per 1,000 square miles on the corresponding drainage areas. It is interesting to notice that the most polluted section of the stream is that immediately below the City of Utica. The effect of the relatively pure tributaries upon the water of the main stream is also shown. During the summer several series of samples were collected along the course of this stream. The results, which are on file in Mt. Prospect Laboratory, corroborate the findings of the statistical study as to general pollution, and so far agree with those which have been published by other writers, that they are not here introduced. Suffice it to say that the results of the daily samples collected at Cohoes, from March to September, 1903, showed that the water had an average turbidity of 29 on the silica scale. During ordinary



CITY OF NEW YORK

COMMISSION ON ADDITIONAL WATER SUPPLY

DEPARTMENT OF CHEMISTRY AND BIOLOGY

DIAGRAM SHOWING COLOR OF THE MIDDLE HUDSON STREAMS

To accompany report of
GEORGE C. WHIPPLE
Department Engineer

DIAGRAM 20. APP. VI.

dry weather, the turbidity of the water was about 5, but at times it rose as high as 500. The average turbidity for the month of March was 102. On account of the large volume of this stream it may be said that the Mohawk River, more than any other tributary, is responsible for the turbidity of the water in the lower Hudson. The water has but a moderate color, the average for the period mentioned being 27 and the maximum 50 (see Diagram No. 20). It is also a hard water, the average alkalinity for six months from March to September being 82, and the maximum 112. The water contains a larger proportion of sulphates than is found in most of the streams on the Hudson River Watershed. This is doubtless due to the above-mentioned deposits of gypsum.

Other Watersheds.

In addition to the watersheds of the Battenkill, Hoosic and Mohawk Rivers, there are about 616 square miles which drain into the Hudson River in the middle division. Aside from the streams mentioned, the most important tributaries are the Moses Kill, which enters from the east, and Fish Creek, Snook Kill and Anthony Kill, which enter from the west. Of these, perhaps, the most important is Fish Creek, because it drains the region around Saratoga Springs. The population upon the watershed of this stream is 82 per square mile. The chief sources of pollution are from Saratoga Springs and Ballston Spa. There are few important industries at Saratoga, and the domestic sewage which amounts to about 350 thousand gallons per day, is purified by filtration and discharged into Kazaderosseras Creek, a tributary of Fish Creek, at Ballston Spa. A number of tanneries and industrial establishments drain directly into this creek, and render the water noticeably polluted.

5. LOWER HUDSON, EAST SIDE.

Below the Troy Dam, the Hudson River has a tributary watershed of about 5,147 square miles, of which about 2,175 square miles are on the east side and 2,972 square miles on the west side. The most important streams on the east side, so far as an available water supply for the City of New York is concerned, are Stockport Creek, Roeliff Jansen Kill, Wappinger Creek, Fishkill Creek, Peekskill Greek and the Croton River. In addition to these may be mentioned the Housatonic and the Ten Mile Rivers, which, although they do not flow into the Hudson, have been considered as possible sources of supply for New York. On the west side of the river, the most important streams are Catskill Creek, Esopus Creek, Rondout Creek, Walkill River and the Moodna River. In addition to these may be mentioned Schoharie Creek, East Delaware River, which do not flow into the Hudson, but which have been considered as possible sources of water supply for New York. In addition to all these streams, there are a number of smaller tributaries, as for example, the Poesten Kill, Wynant Kill, Norman Kill, etc., which have an effect on the quality of the water of the Hudson River, but which are otherwise of no importance in the present study.

Stockport Creek.

The Stockport Creek enters the Hudson from the east side, about half way between Coxsackie and Hudson. The main stream is not more than two miles long. It is formed by the confluence of the Kinderhook Creek which comes down from the north, and Claverack Creek, which runs up from the south. The total drainage area of these streams is about 506 square miles, the greater part of which is tributary to the Kinderhook Creek. The watershed is almost entirely within the limits of the State of New York, but one or two of the small tributaries extend into Massachusetts. The rock formations consist almost entirely of slate and sandstone, but there is a narrow strip of limestone in the northeastern portion, and two small areas near the mouth of the stream.

Parts of the watershed are hilly—almost mountainous in character—but in spite of this, farming is carried on to a considerable extent. The total population on the watersheds is about 19,000, or 38 per square mile. There are few large centres of population. The most important towns are Chatham (population 2,000), New Lebanon (population 1,500), Hillsdale (population 1,400) and Caanan (population 1,300). There are no large industrial establishments which need to be taken into consideration. The sample station for this stream was located at Columbiaville, below the junction of the two streams. The station was maintained from March 17 to September 1.

Ordinarily the water of Stockport Creek is quite clear. The usual turbidity was about 5. At times, however, after heavy rains, the stream becomes quite turbid. The maximum turbidity observed was about 250. The average turbidity for the month of March was 46. Only on seven days, however, was the turbidity more than 20. The water has comparatively little color, the average for five months being only 18, and the maximum 38.

The chemical analysis shows that the water is fairly hard, the average alkalinity for the period mentioned being 51 parts per million. The total hardness exceeded this by only about 5 parts per million.

Roeliff Jansen Kill.

The Roeliff Jansen Kill rises in Austerlitz (latitude 42 degrees 15 seconds, longitude 17 degrees 30 minutes), and flows south and northwest into the Hudson at a point nearly opposite Catskill. It has a total drainage area of about 228 square miles, which lies almost entirely within the State of New York. Bashbish Creek, one of the main tributaries of the stream, however,

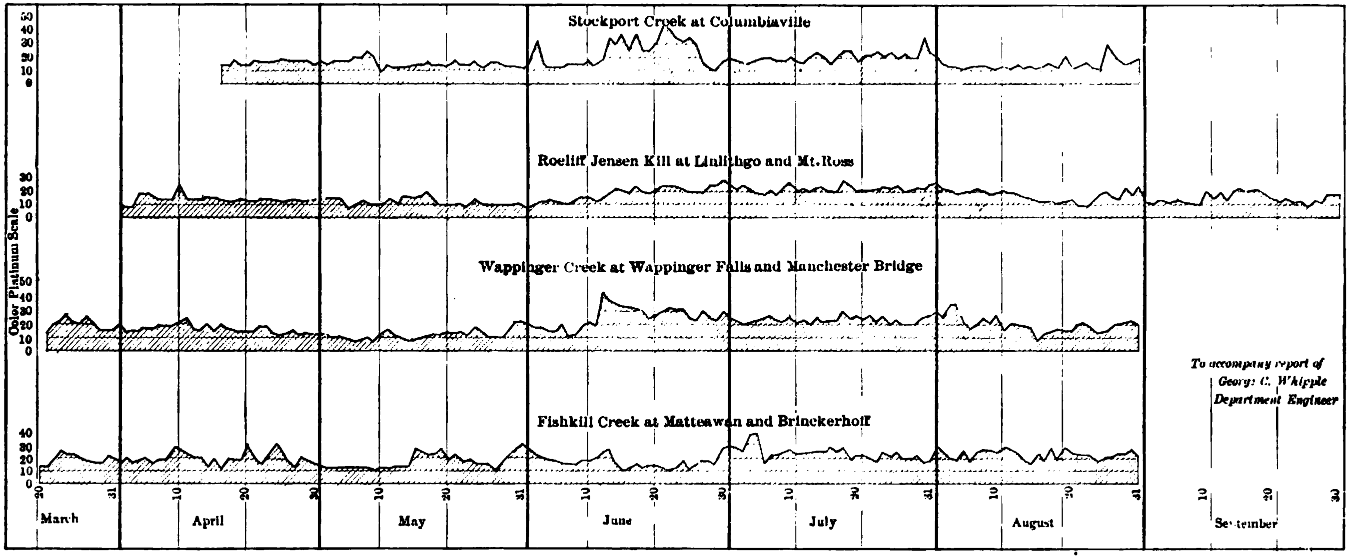


DIAGRAM 21. APP. VI.

CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing Color of the East Lower Hudson Streams.

has its source in Berkshire County, Massachusetts. The drainage area which is outside of the State of New York, however, is not more than six or seven square miles. Speaking generally the Roeliff Jansen Kill may be said to drain the northern part of Dutchess County and the southern part of Columbia County.

The watershed is rolling and hilly. The hills for the most part are covered with young timber and scrub brush. The valleys are devoted to agriculture. The top soil is for the most part a yellow loam, beneath which are glacial drift, coarse gravel, sand and occasionally clay. The underlying rocks are slate and limestone, and in some sections of the watershed the limestone outcrops at the surface.

The sample station was established first at Linlithgo, at the mouth of the stream, and was maintained from March 30 to June 6. Later, when this stream was considered as a possible source of supply for New York City, the sample station was changed to Mt. Ross, which is a short distance below Silvernails, the site of the proposed dam.

The results of the daily observations made at these sampling stations are given in Tables 12 to 15. In addition to these regular samples, special samples were collected from all the important feeders, and samples of ground water were also collected at various places on the watershed. The results of these special examinations are on file at the Mt. Prospect Laboratory.

Speaking generally, all of the water was found to be comparatively clear and light colored. The average color for six months was 16 and the maximum only 29. In only a few instances, where there were swamp areas, was dark colored water found. The maximum turbidity was 45 and the average 4. By far the most objectionable characteristic of the water of this stream is its hardness, and accordingly this was given careful attention. The normal chlorine for the region is about 0.7 part per million.

The important facts which relate to the hardness of the water are shown on Plate VIII. This shows the approximate locations of the limestone deposits as depicted on the State map of the State Geological Survey. The co-ordinates refer to the subdivisions of the geological sheets as described on page 439. The figures inside the rectangle show the prevailing hardness of the surface waters, such as the small brooks, lakes, ponds, etc., in the various districts expressed in parts per million. The figures inside the double circles give the hardness of the ground water in the same districts. The figures in the single circles give the hardness at various points on the main streams. These results are based on observations made chiefly on September 2 and 3, 1903, and October 8 and 9, 1903.

It will be seen from this diagram that the limestone deposits cover most of the watershed above the site of the proposed reservoir, and that nearly all of the water in the region is very hard. The ground water in almost all of the sanitary districts is much harder than the surface water. Calculations of the probable hardness of the water collected in the proposed reservoir are given on page 489.

The detailed results of the sanitary survey are on file among the records of Mt. Prospect Laboratory. From these results it has been calculated that the permanent population on the watershed above the proposed reservoir is 28 per square mile, which is increased during the summer months to 34 per square mile because of the influx of summer boarders.

The proposed dam is located across the main stream at Silvernails, just below the point where Shekomeko Creek enters it. The reservoir will consequently have two arms, one extending up the main stream toward the northeast through the Village of Gallatinville to Ancram, and the other extending up the Shekomeko Valley to Pine Plains. The latter arm will be almost entirely within the limestone region, and the water will be somewhat harder than that in the northeast arm.

The most important source of pollution on the Shekomeko arm of the Silvernails Reservoir is the village of Pine Plains, which has a resident population of about 500 and a transient summer population of about 200.

If the reservoir is constructed it will be necessary to give some attention to the sanitary conditions in this village, as it is located so near the flow line. The other sources of pollution on this stream are few and scattering. On the main stream the most important sources of pollution are at Ancram, Copake and Hillside. Ancram is a village of about 200 population, which during the summer is increased to nearly 300. There is a paper mill with 20 employees, now running night and day, and the waste products enter the stream. At the Copake Iron Works ten men are employed. Other iron and lead mines have existed on this watershed in the past, but they are now shut down, with little probability of ever being worked again. Cases of direct pollution of the stream by fecal matter are rare in this section, the practice of cooling milk in the streams by placing the cans in the running water being said to have created a local prejudice against it. All of the nuisances which exist on this watershed can be easily removed.

Wappinger Creek.

Wappinger Creek rises in Pine Plains, Dutchess County (latitude 42 degrees, longitude 73 degrees 40 seconds), and flows in a general southwesterly direction into the Hudson River at New Hamburg, about 10 miles below Poughkeepsie. The total drainage area is about 195 square miles. The upper portion of the stream has two forks, which come together just below Salt Point. The east fork, which is the real continuation of the main stream, takes its rise practically in a small chain of ponds near Stissing Mountain. At Hibernia it receives a large tributary from the south, which passes through Mill Brook and Washington Hollow. The west fork, sometimes known as "Little Wappinger Creek," rises in Milan and flows southward through Clinton Hollow till it meets the main stream at Salt Point. The proposed development of this watershed includes the construction of a storage reservoir on each of these forks, the first on the main stream with a dam at Hibernia, and the second on Little Wappinger Creek, with a dam near Clinton Hollow.

The sample station was first established at Wappinger Falls, near the mouth of the main stream, and maintained from March 21 to April 30. It was then changed to Manchester Bridge, and continued until September 1. During the month of September additional stations were maintained at Hibernia and at Clinton Hollow, the sites of the proposed dams.

Most of the country in the upper portions of the watershed of Wappinger Creek is rough and hilly. The hills as a rule are covered with forests of young trees, while the valleys are devoted to farming. Swamp areas are numerous, but not extensive.

The geology of the region is somewhat varied, and marked differences are noted between adjacent valleys. There is a narrow strip of limestone which follows the main creek from northeast to northwest, and there is another area of limestone which extends along the valley of Little Wappinger Creek above Clinton Hollow. Scattered areas of limestone were observed elsewhere. With the exception of the limestone, the rock formations consist chiefly of slate, schist and sandstone. In a few sections there are well defined beds of clay.

Speaking generally, the water of this stream and its tributaries is clear and light colored, save in a few unimportant instances where swamp areas exist. The hardness of the water is the particular quality which received most careful attention. The results obtained at various times are summarized in Plate IX., which is drawn in the manner described on page 458. It will be seen from this plate that the limestone areas are narrow, and are confined largely to the main river beds. Speaking generally, the hardness of the water is somewhat lower than that on the watershed of the Roeliff Jansen Kill. The difference between the surface and ground waters show somewhat greater variations. While in most districts the ground water is harder than the surface water, there are numerous contrary cases. The hardness determinations gave such results that there is good reason to believe that the locations of limestone shown on the map are not strictly correct, which may be accounted for in part by the fact that they were enlarged from a small scale map. It is worthy of note that in most cases the alkalinity closely approximated the total hardness, and in some cases exceeded it. The results taken as a whole indicate that the permanent hardness which is due to sulphates, nitrates, etc., is very low throughout this region, as it is throughout the Fishkill and Roeliff Jansen Kill watersheds.

The results of the sanitary survey are on file. For the watershed above Brinckerhoff, the total permanent population is estimated as 5,417, or 35 per square mile. The transient summer population is estimated as 350, which increases the population during the summer to 37 per square mile.

Observations indicate that the water impounded in the Clinton Hollow Reservoir will have a color which will probably not exceed 20 as a yearly average. During the month of September the average color of the stream was 25, although the color varied from 18 to 37. The water in the Hibernia Reservoir will probably be somewhat lower than this. The annual average color ought not to exceed 15 or 18. During September the average color of the stream at Hibernia was 19. (See Diagram 21.) The probable future hardness of the water in these reservoirs is given on page 489.

Above the Clinton Hollow Reservoir there are no large sources of pollution. The resident population has been estimated as 32 per square mile. On the watershed of the Hibernia Reservoir there are several villages which will need attention. The most important of these is Millbrook, a village which has a permanent population of somewhat more than a thousand people, which is increased during the summer by about two hundred. This village has no sewerage system, but a number of private drains empty into the stream. The brook as it flows past this village shows evidences of being considerably polluted. As this important source of pollution is located only two or three miles above the head of the reservoir, a sewage system for the village with satisfactory disposal works will become necessary.

The only other important centres of population are the villages of Staffordville and Bangall. These are rural communities, with a large proportion of summer residents. Many of the houses along the stream will be flooded out by the new reservoir, and those that remain can be individually cared for.

The resident population on the watershed above the Hibernia Reservoir is estimated as 57 per square mile. The normal chlorine for this region is about 0.9 parts per million.

Fishkill Creek.

Fishkill Creek rises in Unionvale, Dutchess County (latitude 41 degrees 45 minutes, longitude 73 degrees 40 minutes), and flows in a southwesterly direction into the Hudson River at Fishkill village. It has a total drainage area of about 196 square miles. A short distance above Brinckerhoff it receives as a tributary Sprout Creek, which flows down from Verbank between Billings and Freedom Plains. The method first proposed for developing this stream as a water supply for New York City involved the construction of a reservoir with the dam at Brinckerhoff. The second project—

and the one which was ultimately adopted—consisted of taking water from the upper portion of the main stream with the dam at Stormville, and from the upper portion of Sprout Creek, with the dam at Billings. Before any plans of development had been suggested, the sampling station was located at Matteawan near the mouth of the stream, and maintained from March 20 to April 30. It was then changed to Brinckerhoff and continued until September 30. During the month of September sampling stations were maintained at Stormville on the main stream, and Freedom Plains near the site of the Billings dam on Sprout Creek.

The upper portions of the watershed are hilly, and the tops of the hills are wooded. The wooded areas are less extensive, however, than on the watersheds of Wappinger Creek and the Roeliff Jansen Kill. About 75 per cent. of the area is devoted to agricultural purposes. The main stream flows for nearly its entire length through an area of limestone which is narrow at the upper end, but which spreads out to a width of five or six miles near Brinckerhoff. On Sprout Creek the limestone deposits are infrequent, although the hardness of the ground water in that region would indicate that they are not entirely absent. Aside from the limestone mentioned, the rock formations are chiefly slate, schist and sandstone, with some gneiss and granite in the lower portions. The water of the stream as it enters the Hudson is ordinarily clear and light colored. The maximum turbidity during the period covered by the observations was 25, and the maximum color 40.

The analyses indicate that the water impounded in the Billings Reservoir will have an average annual color of about 15 or 18. Some of the tributary streams had rather a high color at times, but on the whole the color of the water in Sprout Creek has been low. During September the average color at Billings was 13. The probable hardness of the water to be derived from the watershed is given on page 489. The normal chlorine for the region is about 1.1 parts per million.

There are no important sources of pollution on the watershed. The permanent population is estimated as 25 per square mile, which is increased during the summer months to 28 per square mile.

Swamp areas are somewhat more numerous above the Stormville Reservoir, and the probable average color of the water is estimated as between 20 and 25. The water will be harder also than that in the Billings Reservoir, as shown on page 489.

The population on the watershed above the Stormville Reservoir is estimated as 32 per square mile for permanent population and 35 for transient population. The villages are all small and the few nuisances which exist can be individually cared for with little trouble.

Housatonic River.

The upper portion of the Housatonic River Watershed lies almost entirely within the State of Massachusetts. Above New Milford the river has a drainage area of about 815 square miles, and upon this there dwells a population of about 59,000, which makes the population density about 72 per square mile. This includes a number of important cities and towns which drain directly into the stream.

No regular sampling place was maintained on this stream, but a number of samples were taken at various points on the watershed. These, together with the samples which had been collected by the United States Geological Survey in the course of its investigations, indicated that the water would be comparatively clear and have a color of about 25. The limestone deposits are abundant on this watershed, and the analyses indicate that the probable average hardness of this water would be about 86 parts per million. The normal chlorine of the region is about 0.8 parts per million.

Ten Mile River.

The watershed of the Ten Mile River lies just east of the Fishkill and Wappinger Creek watersheds and west of the Housatonic River. Above Pawling the river has a drainage area of about 200 square miles, upon which the population in 1900 was about 10,700, or 54 per square mile. The direct pollution is much less on this stream than in the case of the Housatonic River.

No regular sample station was maintained on this stream, but a number of samples were collected at various places on the watershed, and the results of their analyses, together with the observations which have been made by the United States Geological Survey, have shown that the water which could be collected from this watershed would be practically clear, and would have an average color of about 000. The limestone deposits extend across the watersheds of this river, and the probable average annual hardness of the water has been estimated as about 105 parts per million.

6. THE LOWER HUDSON, WEST SIDE.

Catskill Creek.

Catskill Creek rises in the town of Broome, Schoharie County, and flows in a general southeasterly direction, entering the Hudson at Catskill. It has a total drainage area of about 447 square miles. Some of the westerly tributaries of the stream rise in the Adirondack Mountains, but the greater portion of the watershed is north of the mountainous region. All of the country is hilly, however, and slopes are generally quite steep. During the

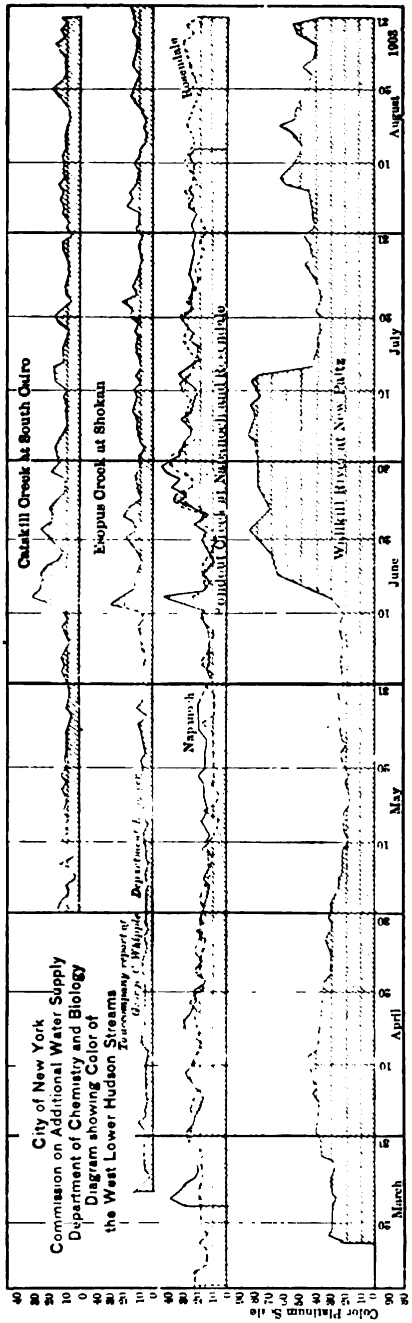


DIAGRAM 22. APP. VI.

summer months most of the small feeders become dry. The amount of land on the watershed is comparatively small, and there are some swamp areas noticeable above Franklinton.

The rock formations consist almost entirely of shale and sandstone, but there are narrow strips of limestone along the northerly area, and across the watershed from north to south. The limestone area, however, constitutes less than 10 per cent. of the total watershed.

Before any plans had been made for the development of this stream as a source of supply, the sample station was located at South Cairo, and was continued from April 19 to September 1. The upper portions of the stream were investigated only during the special trips of investigation.

The sanitary inspection was confined almost wholly to the upper portions of the watershed. It was found that the permanent population on the watershed above East Durham was about 4,500, or 25 per square mile, which is increased during the summer to about 33 per square mile. There are no other important sources of pollution on the watershed. The villages are small, and the few nuisances which exist can be individually cared for. The most important of these consist of small hotels and boarding houses which are located in one or two villages. The results of the daily observations made at South Cairo show that the water was ordinarily clear. The average turbidity was 4 and the maximum 22. The color was very low, averaging 12 for the entire period, and seldom rising above 25. The maximum observed color was 33. On account of the limestone deposits above mentioned, the hardness of the water is somewhat greater than in the case of the other streams in the Catskill Mountain region.

Esopus Creek.

Esopus Creek rises in Shandaken, Ulster County (latitude 42 degrees, longitude 74 degrees 25 minutes), and flows in a southeasterly direction to Marbletown, draining the southeastern slopes of the Catskill Mountains. It then turns at right angles and flows northeasterly, entering the Hudson River at Saugerties. Its total drainage area is about 426 square miles. The upper portions of the watershed are mountainous and the slopes to the creek precipitous. Most of the country is thickly wooded. Almost the entire population is found in the valleys, where farming is carried on to a limited extent. Below Shokan, the country becomes hilly and then comparatively level; while the extent of cultivated land increases proportionally.

In the lower courses of the river below Olive Bridge, limestone deposits are abundant, but above that the rocks are chiefly conglomerate and sandstone. In some localities there are beds of clay, but they do not overspread large areas, and have but little influence on the turbidity of the water in the stream, except after hard rains. There are certain deposits of clay, however, found on the caving banks of the stream which become much eroded at times of high rainfall. The stream bed in its upper portion is stony and gravelly.

The development of the Esopus Creek as a source of water supply for the City of New York, includes the construction of an immense storage reservoir, known as the Ashokan Reservoir, with a dam across the main stream at a point near Olive Bridge, and the construction of other reservoirs at points higher up. The sample station was located at Shokan before these plans had been fully developed, and the upper portions of the watershed were studied only on the special inspection trips.

The quality of the water, as indicated by the daily samples collected at Shokan, was generally excellent. The average color for 7 months was 9, and the maximum 30. Only on 4 days did the color exceed 20, and on all but 21 days it was below 15. The hardness of the water was uniformly low, as shown on page 491. The average alkalinity for the 7 months was only 17, and the maximum 28. The normal chlorine for the region was found to be about 0.6 parts per million.

The only thing to be said against the Esopus water is its occasional turbidity. Normally, the water is quite clear, the turbidity during dry weather seldom exceeding 3, and often being almost 0. After rains, however, the turbidity increases, sometimes with astonishing rapidity, and then disappears with equal suddenness. Thus on June 11, the turbidity of the water at Shokan was 1; on the following day it was 800; on the next day 28, and the next 6. During the 7 months, from March 2 to September 30, the average turbidity was 14, and the maximum 800, but during the heavy downpour on October 9, the turbidity rose to 1,000, and remained comparatively high for several days, as may be seen from the following figures:

Date.	Turbidity.	Date.	Turbidity.
October 9	1,000	October 14	84
" 10	200	" 15	78
" 11	110	" 16	71
" 12	90	" 18	39
" 13	84		

The water on October 9 had a brick-red color, due to the suspended matter. This became fainter on succeeding days until the turbidity showed itself as a sort of opalescence. During the 7 months mentioned, the turbidities ranged as follows:

Turbidity.	Number of Days.	Turbidity.	Number of Days.
0	6	10	2
1	33	11–15	6
2	58	16–20	4
3	32	21–30	1
4	13	31–40	0
5	10	41–50	0
6	5	51–100	5
7	5	275	1
8	2	800	1
9	1		

The turbidity is caused by the erosion of the clay banks on the shores of the stream. These deposits of clay are not numerous, and there is good reason to believe that, by protecting them from erosion, the turbidity of the river water can be largely eliminated. Sedimentation in the large reservoirs, moreover, will reduce the turbidity to what will be practically a negligible quantity. Filtration or long storage would remove it completely.

The clay seems to settle quite rapidly in the bed of the stream, and below the clay banks above mentioned the stones are found covered with deposits of clay. This rapid sedimentation is very likely due to the fact that the particles of clay continue to cohere for some time after erosion into masses of relatively large size which have a considerable hydraulic subsiding efficiency. The clay itself is composed of minute particles which settle in water very slowly. This was conclusively demonstrated by several sets of experiments.

The samples which were collected on October 9 and succeeding days were allowed to stand in gallon bottles for about two weeks. The clay gradually settled to the bottom, but the supernatant water remained turbid, as shows by the following figures:

Table Showing Rate of Subsidence of Suspended Matter in Esopus Water.

Date of Collection of Sample.	Turbidity (Parts per Million).							
	Day of Collection.	After 1 Day.	After 2 Days.	After 3 Days.	After 4 Days.	After 5 Days.	After 10 Days.	After 2 Weeks.
1903:								
October 9	1,000	260	270	220	170	120	110	87
" 10	200	130	120	55	52	49	49	42
" 11	110	60	40	27	26	25	25	21
" 12	90	57	36	26	24	22	22	19

An experiment on a larger scale at Poughkeepsie gave similar results. Some of the clay obtained from one of the deposits on the Esopus Watershed

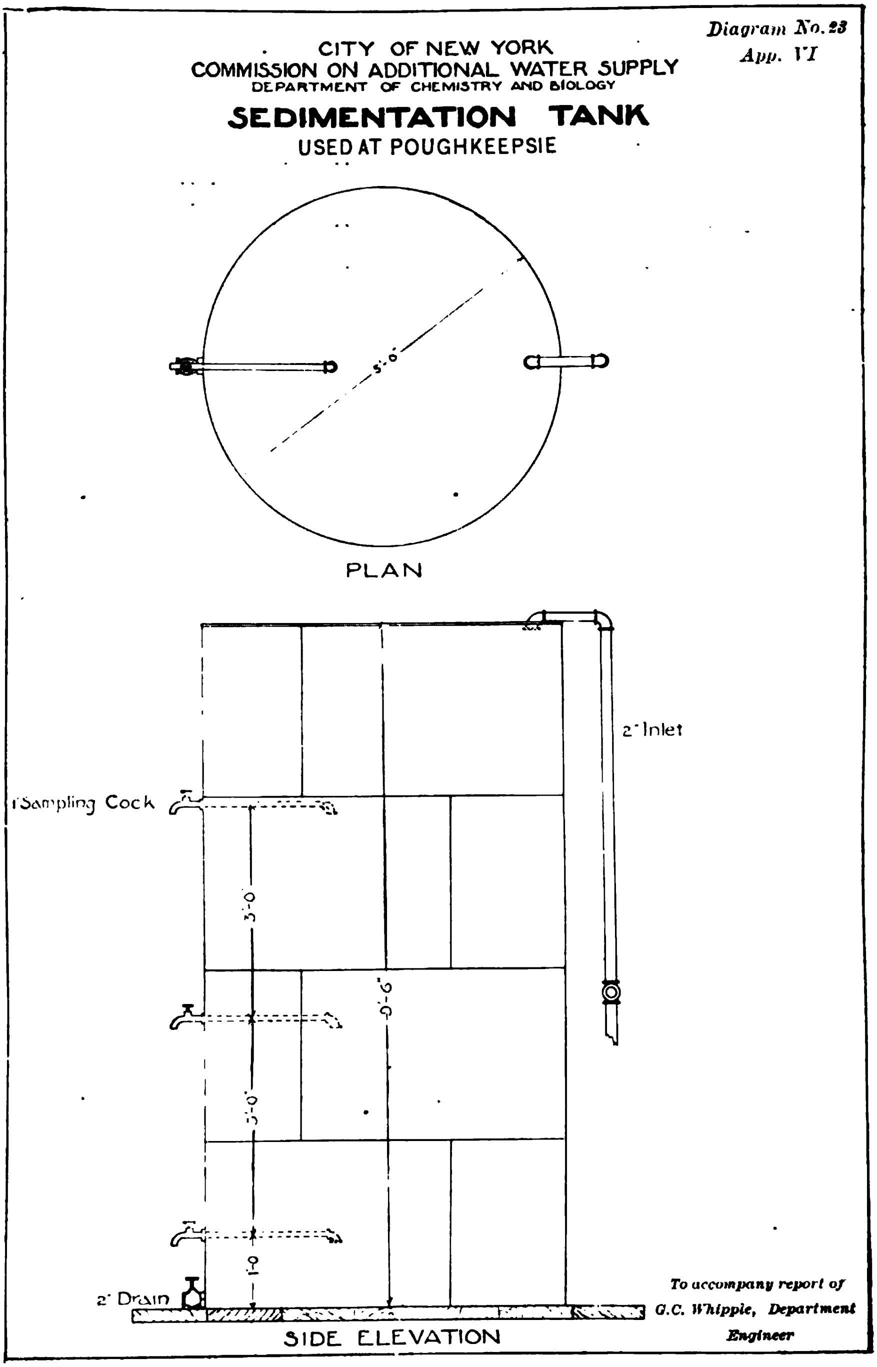


Diagram No. 23
App. VI
CITY OF NEW YORK
COMMISSION ON ADDITIONAL WATER SUPPLY
DEPARTMENT OF CHEMISTRY AND BIOLOGY
SEDIMENTATION TANK
USED AT POUGHKEEPSIE
5'-0"
PLAN
2" Inlet
1 Sampling Cock
3'-0"
9'-6"
3'-0"
1'-0"
2" Drain
SIDE ELEVATION
To accompany report of
G.C. Whipple, Department
Engineer

was mixed with water in a large tank and allowed to stand for about a month, during which time the turbidity of the mixture was carefully observed. The tanks, two in number, made of galvanized iron, 5 feet in diameter and 10 feet high, were located on the shore of the Hudson at the dock of the Gas, Heat, Light and Power Company, and were intended primarily for sedimentation experiments in connection with the Hudson River water. A sketch of the tank is shown in Diagram 23. The original suspension had a turbidity of 1,500, and after a month's subsidence, the liquid still had a turbidity of a little more than 100. The rate at which subsidence occurred is shown by Figure 24.

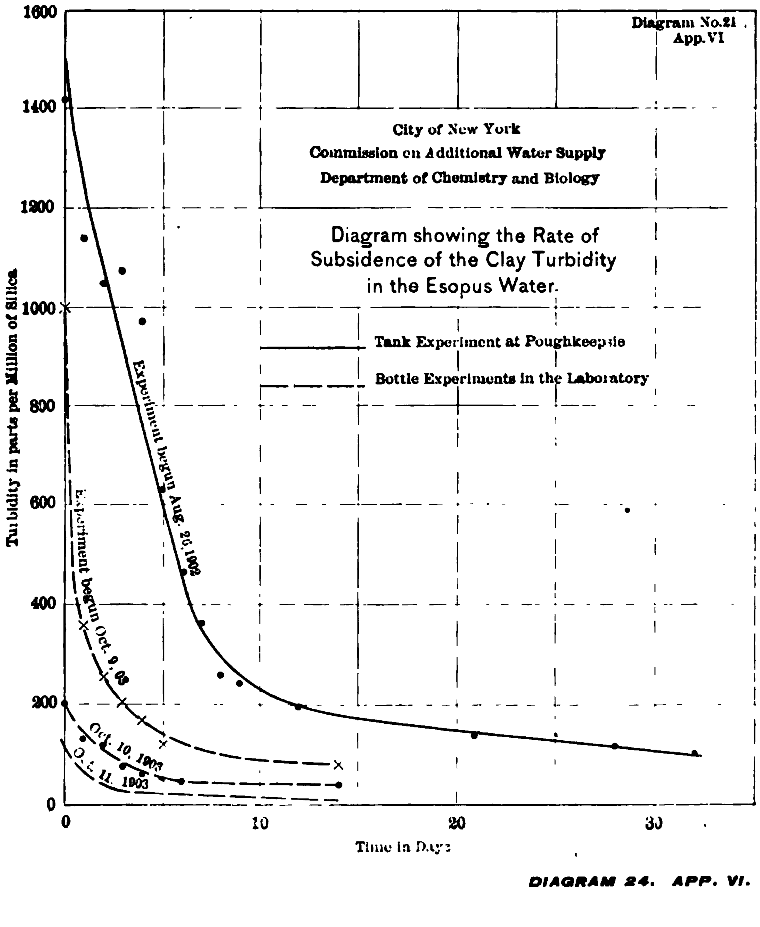


DIAGRAM 24. APP. VI.

The slow rate of subsidence of this clay, when finely divided, as it might become in an impounding reservoir, emphasizes the desirability of preventing the clay from entering the stream instead of depending on measures for removing it after it has become mixed with the water.

A careful sanitary survey of the Esopus Watershed above Shokan was made by the volunteer inspectors, supplementing inspections made by Mr. Nickerson for Mr. W. H. Sears, Department Engineer of the Catskill Department. The detailed results of these inspections are on file in the Department records.

The permanent population on the watershed is estimated as 5,200, or about 20 per square mile. The region is a favorite one for vacationists, and during the summer the population is sometimes as high as 4,300, making 36 per square mile. The population is chiefly confined to the villages. The slopes are practically a wilderness. The construction of the reservoirs will wipe out many hotels, but it is probable that many of the inhabitants will move to other houses or build elsewhere on the watershed, as summer guests who have formed attachments for particular locations will be loath to spend their vacations elsewhere. Therefore, unless wholesale land purchases are made, the development of the stream as a source of public water supply is not likely to materially reduce the population. There are a few villages, such as Pine Hill, Phœnicia, Chichester, etc., where it will be necessary to provide sewerage systems and disposal works. The first two of these now have public water supplies for a portion of their inhabitants.

The most serious nuisances are the summer hotels and boarding houses, which are found in all of the important villages and some of which accommodate upwards of one hundred guests. These generally have cesspools, and the contents find their way more or less directly into the stream. Places of this character would need careful supervision. The subject of nuisances, however, is by no means a serious one. By purchase and removal of the most objectionable hotels, by proper regulation of the others, by the construction of a few sewage disposal systems, the sanitary conditions can be made so satisfactory that after storage in the impounding reservoirs the water can be looked upon as safe even without resorting to filtration.

Rondout Creek.

Rondout Creek rises in Denning, Ulster County, and flows in a general southeasterly direction and joins the Wallkill River about 10 miles above its mouth. The combined streams then flow northeasterly into the Hudson River at Kingston. The total watershed of this stream is about 387 square miles, but it is only the upland region that has been considered as a possible source of supply.

The watershed is hilly, and the upper portions of it are well wooded. There are, however, a number of swamps, one of the most important being located on a tributary above Ellenville. The rocks in the upper portion of the watershed are mostly conglomerate and sandstone, but below Napanoch the creek flows through a strip of limestone, bordered by sandstone and shale. Between Napanoch and Rosendale there are some deposits of clay. There were two sample stations located upon this stream—one at Rosendale just above the point where it enters the Wallkill River, and one at Napanoch, several miles farther up. These stations were located before any plans for developing these sources of the stream had been made. The Rosendale station was maintained from March 15 to September 1, and the Napanoch station from March 23 to August 13.

A complete sanitary inspection of this watershed was not made, but from the census returns and from the number of houses depicted upon the United States geological maps, it was estimated that the total population on the watershed above Rosendale is about 11,000, which is about 35 per square mile. The greater part of the population is widely scattered. The village of Ellenville, however, has nearly 3,000 inhabitants.

The daily observations made at Napanoch showed that the water is ordinarily clear. The average turbidity for the period was 4, and the minimum 50. At Rosendale, however, the turbidity of the water was considerably more than this on account of the clay deposits mentioned above. The average turbidity for the period was 8 and the maximum 175. The water at both stations was ordinarily low colored. The average during the period was 23 at Napanoch and 20 at Rosendale, and the maximum 48 and 38 respectively. The higher color at Napanoch was due to the effect of the swamp on the Good Beaverkill, which enters the main stream at Ellenville.

The water at both stations was comparatively soft, but the hardness tends to increase downstream. Thus the average alkalinity during the period was 21 at Napanoch and 26 at Rosendale. The probable average hardness of the water at Rosendale is shown on page 491. The normal chlorine for this region is about 0.7 per million.

Wallkill River.

Wallkill River rises in New Jersey, and flows in a general northeasterly direction, entering the Hudson River just below the City of Kingston. About 10 miles above its mouth it receives the waters of Rondout Creek, a stream equal in importance to itself. Another important tributary is the Shawangunk. The total drainage area of the Wallkill River above its junction with Rondout Creek is about 779 square miles. The watershed of the Rondout, as mentioned above, is about 387 square miles, while the watershed of the Shawangunk is about 149 square miles. About 212 square miles of the watershed is outside of the State of New York. The most important natural feature on the watershed of the Wallkill River is the immense swamp area, located in its upper portion, and commonly known as the "Drowned Lands." This wonderful swamp has an area of upwards of 50 square miles, and the peat or muck deposits form a black highly carbonaceous soil (70 to 95 per cent. organic), which varies in depth from 5 to 50 feet. Water standing in contact with this peaty matter soon acquires a dark brownish color and a distinct vegetable odor.

The watershed also contains considerable limestone and extensive deposits of clay. The sample station on this stream was located at New Paltz, and was maintained from March 18 to August 31. The observations made at this station showed that the water is naturally hard, high colored and somewhat turbid. The average turbidity for the period was 5 and the maximum 150.

The following table shows the frequency of the occurrence of the high turbidities:

Turbidity	Number of Days of Occurrence.	Turbidity.	Number of Days of Occurrence.
0	0	10	13
1	5	11-15	14
2	11	16-20	5
3	16	21-30	15
4	10	31-40	5
5	15	41-50	2
6	3	51-100	18
7	0	101-150	7
8	3	160	1
9	1		

The average color of the water for the entire period was 38, and the maximum was 86. During the month of July, however, the average color was 58. The average alkalinity during the period was 65 parts per million, and the maximum 104. The total hardness exceeded this by only a small amount. The normal chlorine for the region was about 0.8 per million.

No detailed sanitary survey was made for this stream, but from the census returns the total population on the watershed above the entrance of Rondout is about 50,000, or 63 per square mile. For the most part the population is scattered, but there are a number of large towns which drain directly or indirectly into the stream. Among these may be mentioned Middletown (population 15,000), Walden (population 3,000), Goshen (population 3,000), Warwick (population 1,700), Wallkill (population 1,500), Chester (population 1,200).

Taken as a whole, this stream is not one from which a satisfactory supply can be obtained without depending to a great extent upon artificial methods of purification. Even after filtration through sand sufficient to render the water safe from the sanitary standpoint, the water would have an objectionable color and a hardness higher than that of any of the water to be obtained from the Catskill Mountain region.

Moodna Creek.

The watershed of the Moodna Creek is east of that of the Wallkill. The stream flows in a general easterly direction and enters the Hudson near Cornwall. No daily sample station was maintained on this stream, but a number of samples were collected at various places. They show a probable hardness of about 35 parts per million, and the color is about 30.

No sanitary survey was made of this watershed.

Schoharie Creek.

Schoharie River rises in Hunter, in Greene County, and flows in a general northerly direction into the Mohawk River. It drains the northwestern part of the Catskill Mountain region, and includes in its watershed most of the popular summer resorts. The general character of the upper portion of the watershed is similar to that of the Esopus. The mountain slopes are steep and thickly wooded, while the valleys are to some extent devoted to agricultural pursuits. A few deposits of clay are found.

A sample station was maintained at Prattsville from March 25 to September 1. The daily samples which were collected show the water to be low in color and turbidity and to have a probable average annual hardness of 23 parts per million. The maximum color observed was 30 and the average 14. The maximum turbidity observed was 30.

A detailed sanitary survey was made over the upper portions of the watershed by the volunteer inspectors which supplemented a previous inspection made by Mr. A. D. Nickerson for Mr. W. H. Sears, Department Engineer of the Catskill Division. The results of these inspections indicated that the permanent population on the watershed above Prattsville is about 6,275, which is equivalent to 28 per square mile. During the summer this population is more than double this on account of the influx of summer visitors.

In order to show the relation between the winter and summer population, the following figures are presented:

Town.	Winter Population.	Additional Summer Population
Tannersville	593	2,600
Hunter	431	1,600
Windham	400	300
Hensonville	250	100
Ashland	180	
Lexington	125	600

These centres of population are a serious menace to the water supply resources of the upper Schoharie, and if it should be decided to utilize the waters of this stream it would be necessary to make extensive provision for the disposal of the sewage of these communities. It might even be necessary to construct a sewer to remove the sewage from the watershed. In addition to the villages mentioned, there are isolated summer hotels and boarding houses on the watershed, and these also would need careful attention.

Considered as a whole, the sanitary problems which would be involved in utilizing waters of this stream are more serious than those found elsewhere on the streams which have been proposed as sources of water supply for New York.

East Delaware River.

Northwest of the watershed of the Esopus Creek is that of the east branch of the Delaware River. Above Margaretville this has a drainage area of 167 square miles.

A sample station was maintained at this point from March 9 to July 3. The observations show the water to be ordinarily clear and of very low color. The maximum turbidity observed was 80, and the maximum color 25. The water was quite soft, the average alkalinity being 19 and the maximum 34.

No sanitary survey of this watershed was made.

Neversink River.

The watershed of the Neversink River is adjacent to that of the Rondout and immediately west of it. A sample station was maintained on this river at Cuddebackville from March 7 to June 30. The results of daily observations made at that point show the water to have an average turbidity of 2, an average color of 20 and an average alkalinity of 11. The water, therefore, may be said to be clear, very soft and with moderate color.

No sanitary survey was made of this watershed.

Ramapo River.

The watershed of the Ramapo River lies south of that of the Moodna. The river flows in a general southerly direction into the Passaic River.

Inside of the State of New York the drainage area is about 119 square miles. No sample station was maintained on this watershed, but a number of samples were collected at various points for analysis. They indicate the water to be of comparatively low color and moderately soft. The probable average annual hardness is estimated at 30 parts per million and the average color 20.

7. LONG ISLAND.

East of the present watershed of the Brooklyn Water Supply of Long Island, there are a number of small streams in Suffolk County which flow southward into the Atlantic Ocean. Were it not for legal restrictions, these streams would be available as a source of additional water supply for the Borough of Brooklyn.

No regular sample stations were maintained in this region, but a number of samples were collected from the most important streams in Suffolk County. The results of these analyses are summarized in Table 43. In general they show that the quality of the surface water in Suffolk County does not differ materially from that of the water in the eastern part of the present Brooklyn Watershed. The normal chlorine for the region is probably between 4 and 5 parts per million. The hardness was generally found to lie between 20 and 30 parts per million; but of this hardness a large proportion was due to sulphates and only a comparatively small amount to carbonates.

The density of the population was not determined for the watershed of each particular stream; but taking the region as a whole, the population per square mile above a line marking the probable location of the extended aqueduct is 105.

As a rule direct sources of pollution are rare. In view, however, of the probable increase of population in this region, these streams cannot be considered as offering a permanently satisfactory source of public supply, as sooner or later the inevitably increasing pollution would demand that the waters be filtered.

8. SPECIAL STUDIES.

In addition to the regular analyses and sanitary investigations which have been described, a number of special investigations were made upon subjects incidental to the main project. The most important of these were:

(1) The preparation of a normal chlorine map of the State of New

York. (This was made by Mr. D. D. Jackson, Chief Chemist of the Department of Water Supply, Gas and Electricity, as a part of a more extensive study of normal chlorine, covering the eastern coast of the United States.)

(2) A method of estimating the probable annual average hardness of the upland water, from observations not extending over the entire year.

(3) Estimate of the probable hardness of the upland waters.

(4) Estimate of the value of a soft water to the City of New York.

The Normal Distribution of Chlorine in the Natural Waters of the State of New York.

By Daniel D. Jackson, Chief Chemist, Department of Water Supply, Gas and Electricity, New York City.

There is little occasion for a discussion of the sanitary significance of normal chlorine determinations, as it is already well understood by engineers and sanitarians who have to do with problems relating to water supply. It is well known that normal, unpolluted waters which are near the sea, are high in chlorine (common salt) contents, and that the salt found gradually decreases as waters more and more remote from the sea-coast are examined.

If, then, we draw lines connecting regions having an equal amount of common salt in the water we shall find that in a general way these lines follow the coast, and increasingly diverge from each other as we go inland. A map so drawn, containing these lines of equal chlorine (isochlörs), will immediately show, within the area covered, how much salt may be found in a normal unpolluted water from any particular district. By a comparison of the salt contents of any water under examination with that to be expected from the figures for normal chlorine for that region, the excess of salt present over the normal is determined. In sea coast States this excess of salt only rarely comes from mineral deposits, but is almost invariably due to previous contamination from house or barn drainage. This is brought about by the well known fact that, in all animal economy, a certain amount of common salt is absorbed and later expelled. While this salt plays an important role in the blood, in the formation of gastric juice, and in many other physiological processes, it is unlike all other important elements in that it is practically all expelled from the body in exactly the same state in which it is absorbed.

This salt, which is so soluble in water, forms a part of the drainage of the region in which it is expelled, and must eventually become mixed with the general run-off for that region. The average amount of salt entering the drainage of any particular district is so constant for each inhabitant that it has even been claimed that the number of people living on a drainage area may be very closely estimated from the average run-off and the excess of chlorine over the normal.

New York produces more salt than any other State in the Union, and it would be natural to suppose that these salt deposits would interfere materially with the estimation of pollution. Such, however, has not been found to be the case. The salt beds are pockets which have only a local influence, and normal waters may be found within a very narrow range of these deposits. This, unfortunately, does not hold true in States further inland, where the natural salt in the soil has had less opportunity to be washed into the sea. In the inland States, these pockets are apparently of so wide an area, and exert so broad and variable an influence, that the determination of chlorine, except in special cases, is practically valueless for sanitary purposes. In such States no chlorine maps are possible, and the normal chlorine is of necessity practically zero. Artifical normals for any lake or stream may, however, be used to advantage in determining pollution, as, for instance, the determination of the amount of chlorine added to a river by any particular city on its banks. The difference between the chlorine in the river above and below the city gives valuable data as to the extent of contamination brought about by the city drainage.

In an estimate of the extent of pollution in a water, there is one important point which must be noted. While the water may contain a considerable amount of salt, due to pollution, the dangerous elements of this pollution may have been entirely removed, and it is necesary to bring to bear various other chemical as well as biological data in making a proper judgment as to the value of the water for drinking purposes.

To draw properly the isochlors for any State, it is necessary to first obtain a large number of analyses for chlorine in waters taken at different seasons over the entire area to be covered. The largest amount of data is required near the sea-coast, where the variations in a limited area are greatest. The presence of mountains or of islands near the coast have a tendency to deflect the isochlors toward the sea. Areas exposed to the prevailing winds from the ocean receive a proportionately larger amount of salt, and the isochlors are deflected away from the coast. The natural conclusion from these observations is that the lower layers of the atmosphere from which the moisture is more easily precipitated, contain by far the greater portion of the salt.

The normal chlorine map of New York State, which accompanies this article (Plate XI.), is the result of analyses made over a period of six years, and represents the ideas drawn from several thousand samples of water. The largest number of samples were examined on Long Island, Staten Island and near the coast on the main land, where the differences of chlorine were greatest over a limited area.

The isochlors for Vermont were drawn from figures kindly submitted by Mr. C. P. Moat, Chemist of the Vermont State Board of Health. The Massachusetts lines are only slightly changed from those published in the Report on the Examination of Water Supplies, Massachusetts State Board of Health, 1890. The Connecticut lines are practically the same as those published in the 1902 Report of the Connecticut State Board of Health, by Dr. Herbert E. Smith, Chemist for the Board, and Dr. Frederick S. Hollis.

The four, five and six lines which have been added to the Connecticut map are partially from data recently submitted by Dr. Smith. Valuable figures and suggestions have also been received from Dr. H. E. Barnard, Chemist of the New Hampshire State Board of Health. Some figures obtained by Dr. W. S. Myers, of the New Jersey Geological Survey, have also been used to advantage.

It will be seen that the Catskill and Adirondack Mountains cause deflections in the isochlors toward the coast, due to the precipitation on their southern slopes of the rains in the lower layers of the atmosphere.

It will also be noted that Long Island has a remarkable effect in lowering the chlorine on the main land. The lowest isochlor on the main land is three parts per million, whereas if it were not for the protecting influence of the Island it would undoubtedly be six parts per million. Artesian wells in Manhattan Borough have been found which have a chlorine content of as low as two parts per million, but these may be considered to be below normal and to consist of water from some distance north of the point from which they are drawn.

The following is a list of some of the waters which have had an influence upon the establishment of the isochlors for New York State:

Name.		Chlorine, Parts per Million.
Saranac Lake Village	Saranac Lake	0.3
" "	Saranac River	0.3
Kashaqua	Kashaqua Lake	0.3
Oswego	McKenzie's Pond	0.3
"	Silver Lake	0.3
Watertown	Water Supply	0.3
Sonyea	Spring	0.3
Glens Falls	Hudson River	0.4
Grand Hotel Station	Ulster County	0.4
Troy	Lake Ida	0.4
Ashland	Batavia Kill	0.4
Oak	Catskill Creek	0.4
Cooksburg	"	0.4
East Durham	"	0.5
Shokan	Esopus Creek	0.5
Hasbrouck	Neversink River	0.6
Glen North of Rifton	Black Creek	0.6
Prattsville	Schoharie Creek	0.6
Clinton Hollow	Little Wappinger Creek	0.6

Name.		Chlorine, Parts per Million.
Liberty, Sullivan County	Spring No. 1	0.6
" "	Spring No. 2	0.7
" "	Spring No. 3	0.6
Kingston	Esopus Creek	0.8
Randall Bridge	Rondout Creek	0.8
Middleton	Mohegan Lake	0.9
"	Highland Lake	1.0
Millerton	Webotuck Creek	1.0
Fishkill	Whalen Pond	1.0
"	Sprout Pond	1.0
Boyd's Corner Reservoir	Cold Spring Brook	1.0
" "		1.2
White Lake		1.2
East Branch Reservoir		1.3
" "	Tonetta Brook	1.3
Middle Branch Reservoir		1.4
Sodom Reservoir		1.4
Suffern	Mahwa River	1.4
"	Ramapo River	1.4
Kirk Lake		1.4
Lake Gilead		1.4
Hillburn	Ramapo River	1.4
Muscoot Reservoir		1.5
Croton Lake		1.5
Tuxedo Park	Spring	1.7
Katonah	Cross River	1.8
Williamsbridge	Reservoir	2.2
Kensico Reservoir		2.2
Glen Park Pumping Station		2.2
Rye Pond		2.6
Yonkers	Grassy Sprain Reservoir	2.8
Tarrytown	Spring	2.9
Staten Island Waters.		
Stapleton	Water Supply	6.0
Clifton	"	6.0
Tottenville	Water Tap	6.0
Richmond Turnpike Station	Crystal Water Supply Co	6.2
Long Island Waters.		
Hempstead	Well 1½ miles northeast	3.0
"	Stream at source	3.8
Massapequa	Stream upper end	4.0
Great River	Connetquot Stream	4.0
Babylon	Stream	4.0
"	Stream 2 miles north	4.6
"	Waterworks	4.8
"	Sumpawampus Creek, 1½ miles north	4.9
"	Well	5.0
"	Pond	5.1
Central Islip	Well one-half mile north	4.0
Islip	Stellenwerf Stream	4.0
"	Well one mile south	4.0
"	Beaver Brook, 1½ miles north	4.1
"	Bayshore supply	4.4
"	Orowoc Creek	4.4
"	Doxie's Stream	4.4

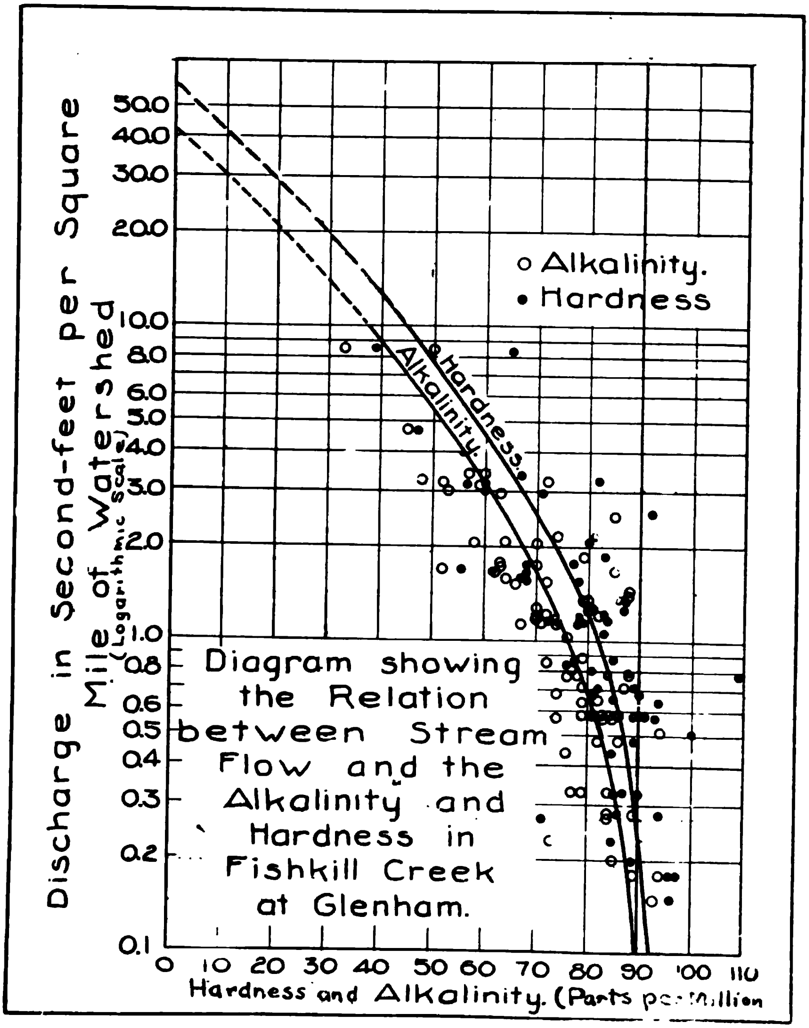


DIAGRAM 24A. APP VI.

Name.		Chlorine, Parts per Million.
Patchogue	River	4.0
"	Swan Creek	4.4
"	Water Supply	4.4
"	Pond two miles north	4.6
"	Tuttle Creek	5.2
"	Well	6.1
Deer Park	Well two miles north	4.2
Mellville Station	Well	4.2
Mellville	Well 1½ miles southeast	4.7
Smithtown	Stream one mile south	4.2
Port Jefferson	Town Water Supply	4.4
Ronkonkoma	Lake one mile north	4.4
Sumpawampus Creek		4.6
Brookhaven	Connetquot River	4.6
Roslyn	Nassau Light and Power Company	4.6
East Meadow Stream	Source	4.8
Manor	Well 1½ miles south	4.9
"	Well, 1 mile north	6.4
"	Stream	7.6
Sayville (tap)	Patchogue Water Supply	5.0
"	Edward's Creek	6.8
East Moriches	Mastic River one-half mile	5.0
Moriches	Well	7.4
Medford Station	"	5.1
Selden	Well 1½ miles east	5.2
Long Pond	Pond	6.0
Northport	Town Water Supply	6.0
Huntington	" "	6.2
"	Stream 1 mile southeast	7.0
Greenlawn	Stream	6.7
Kings Park	"	7.0
Wading River	Spring	10.0
Mattituck	Pond	12.9
Montauk	Well one-half mile east station	15.8
Aquebogue	Well	16.4
Amagansett	Well near station	16.5
Sag Harbor	Spring 1½ miles southeast	17.2
Bridgehampton	Well 1½ miles southeast of station	30.8
Greenport	Well	61.8

Method of Estimating the Probable Annual Average Hardness from a Limited Number of Observations.

It is a well known fact that the hardness of surface water varies greatly at different seasons of the year. It is highest in the summer when the streams are low, and lowest during the period of spring freshets, when frozen ground and melting snows reduce the percentage of ground water to a minimum. In general the hardness varies inversely as the stream flow, but the ratio is not constant and is different for different streams.

The analyses of samples which have been collected from the exact sites of the proposed reservoirs have been all made during the present summer, and some of them have covered a very limited period. They do not truly represent, therefore, the hardness of the water which would be collected in impounding reservoirs constructed on the streams. In order to obtain the probable hardness of the water collected in such reservoirs, it is necessary to take into consideration the hardness at all seasons of the year, and, in addition, the seasonal changes in stream-flows. Fortunately in the present instance the data for making such an estimate were at hand.

In the fall of the year 1901 the United States Geological Survey began a series of gaugings of several of the streams which at various times had been suggested as possible sources of water supply for the City of New York. These included the Housatonic River, the Ten-Mile River, Fishkill Creek, Wappinger Creek, Rondout Creek, Wallkill River, Catskill Creek, etc. In connection with these gaugings, determinations of turbidity, color, alkalinity and hardness were made by the hydrographers, the work being done at Mt. Prospect Laboratory, by methods which are therefore strictly comparable with the analyses made this summer.

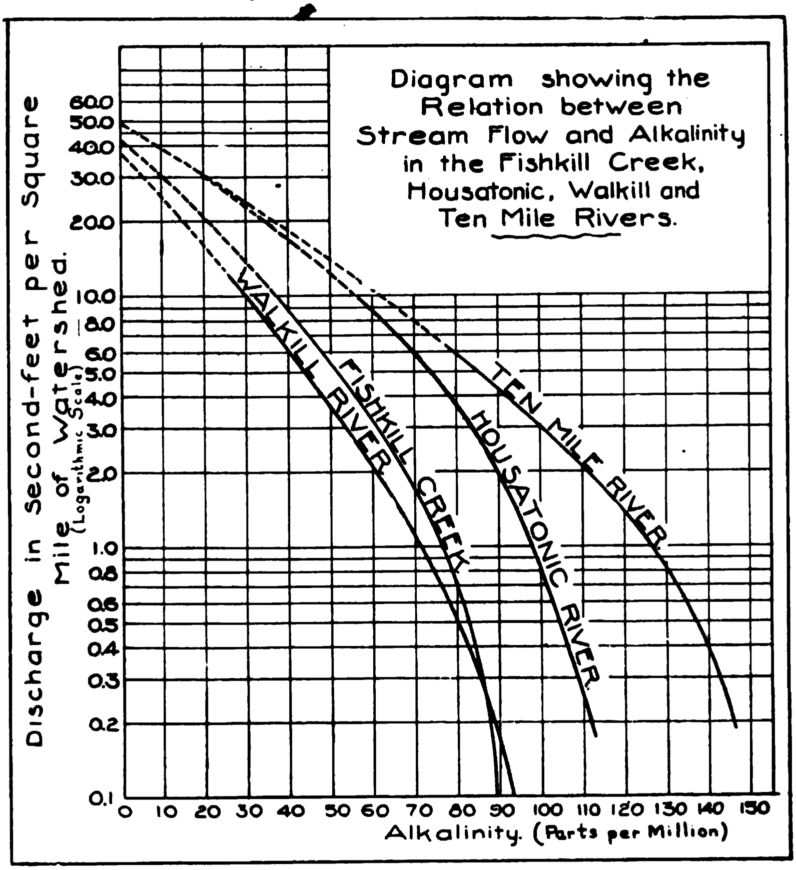


DIAGRAM 25. APP. VI.

Mr. H. E. Pressey, in his report of the investigations (Observations on the Flow of Rivers in the Vicinity of New York City, by Henry Albert Pressey, Water Supply and Irrigation Paper No. 76, United States Geological Survey), gave diagrams showing the relation between the flow of the various streams, expressed in second feet, and the alkalinity of the water. The curves there given were most interesting, but they failed to show their true value, because the sizes of the drainage areas were not taken into account. For that reason they have been redrawn and their accuracy increased by the use of data obtained during the years 1902 and 1903, the recent observations being kindly furnished by Mr. Robert E. Horton, hydrographer in charge of the work. As they now appear, the abscissas represent the alkalinity (or hardness) in parts per million, and the ordinates the discharge in second feet per square mile. The use of cross section paper with logarithmic ordinates materially improved the curves obtained. For various reasons the points do not fall on the lines of a perfect curve, but they are so arranged that a representative curve may be fairly drawn through them, as shown in Diagram 24A, which represents the relation between the discharge of the Fishkill Creek and the alkalinity and total hardness of the water. When the curves for the different streams had been drawn it was found that, if extended, they converged and cut the axis of the alkalinity scale at about the same point, which was not far from a discharge of 50 second-feet per square mile (see Diagram No. 25). Interpreted strictly, this would mean that when the discharge of the stream reached that figure the water had no alkalinity. As a matter of observation this is nearly, but not exactly, true. The alkalinity never wholly disappears from the water, even during spring freshets, and the curves strictly should not cut the axis of the alkalinity. Their general convergence toward that point, however, indicates that the greater the discharge, the less effect has the character of the watershed upon the alkalinity of the water.

Since the alkalinity curves for the Ten-Mile River, the Fishkill Creek at Glenham, the Housatonic River and the Wallkill River almost meet, if produced, at a point which represents a discharge of 50 second-feet per square mile, this point may be assumed as the axis of other alkalinity curves, similar in character, for neighboring watersheds; and if a short portion of the curve for known discharges can be well located for any particular stream, the remainder of the curve may be drawn with a reasonable assurance of accuracy.

The analyses which have been made during the present summer, taken in connection with the stream-flows obtained from the United Stated Geological Survey, have furnished the data necessary for drawing the alkalinity curves which represent the various streams at the sites of the proposed

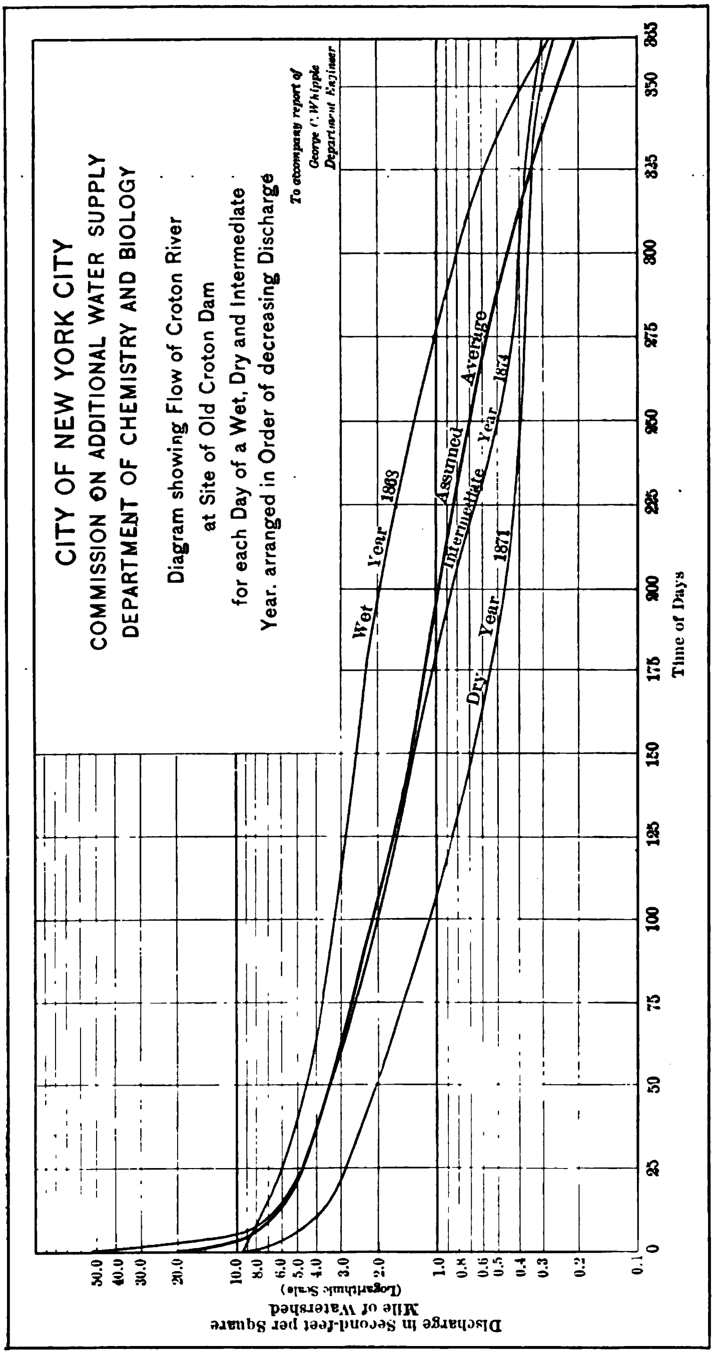


DIAGRAM 27. APP. VI.

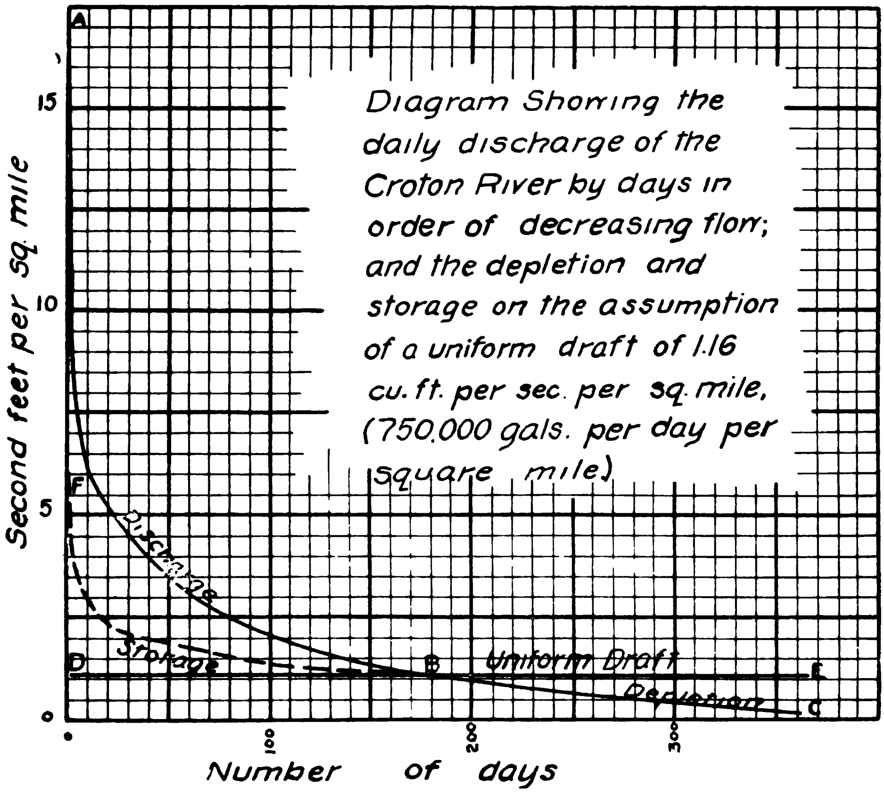
From this daily discharge curve and the alkalinity curve given in Diagram No. 26, the alkalinity of the water may be estimated for each day of the year at the various reservoir sites, and by weighting these alkalinities in proportion to the flow of the stream, a figure may be obtained which represents the average alkalinity of all the water discharged during the entire year. That is, the alkalinity for each day is multiplied by the stream discharge for the same day, and the sum of these products divided by the sum of the daily discharges gives the weighted annual average alkalinity. The results obtained by these calculations are as follows:

Stream.	Locality.	Average Alkalinity.
Fishkill Creek	Glenham	61
"	Brinckerhoff	66
"	Stormville	94
Sprout Creek	Billings	51
Wappinger Creek	Manchester Bridge	62
"	Hibernia	82
"	Clinton Hollow	63
Roeliff Jansen Kill	Silvernails	100
Wallkill River	New Paltz	54
Ten Mile River	Dover Plains	99
Housatonic River	Gaylordsville	81
Catskill Creek	Cairo	33
Esopus Creek	Shokan	16
"	Kingston	20
Rondout Creek	Rosendale	18

If the streams were to be utilized without storage, that is, if a definite and constant amount of water were taken from the stream each day, the average annual alkalinity could be obtained by simply finding the average of the alkalinities for each day of the year. In the case of the Fishkill at Stormville, this would amount to 103 parts per million. If there were storage reservoirs large enough to impound all of the water discharged during the entire year, the average annual alkalinity would be represented by the weighted average already mentioned. As a matter of fact, reservoirs are not built large enough for this, consequently some of the water is wasted, and the greatest waste usually, but not always, occurs during the periods of the greatest stream flow, when the alkalinity is low. Consequently the average annual alkalinity of the water stored and utilized is greater than the average for all the water running. To accurately estimate the amount of water wasted and its alkalinity is an impossibility, because this involves many indeterminate factors, such as the size and shape of the storage reservoir, the circulation of the water in it, the regularity of the draft, the seasonal distribution of the rainfall, etc. The following method will, however, give a fair approximation of the result.

Let it be assumed that the amount to be drawn from the reservoir is 750,000 gallons per square mile a day, or 1.16 second-feet per square mile, that when the natural flow of the stream is less than this no water will be wasted, and that the deficiency will be made up on the other days of the year in proportion to the amount of water discharged. This may be illustrated by Diagram No. 28, in which the line A, B, C represents the daily discharge, the line D, B and E a uniform draft of 1.16 second-feet, the line F, B, C, the amount of water collected.

DIAGRAM 28. APP. VI.



The alkalinity of the water having been found each day, and the figures weighted according to the line F, B, C, the result represents the average alkalinity of the water collected during the year.

In this manner the figures given on page — were obtained. The assumptions are not entirely correct, and the resulting figures for alkalinity are somewhat too high. They furnish, however, a fair basis of comparison.

The following table, also compiled from the curves, shows the probable alkalinity of the water in the different streams under different conditions of flow:

	Alkalinity (Parts per Million).				
	Stormville.	Billings.	Hibernia.	Clinton Hollow.	Silvernails.
During droughts..........	118–120	60–61	105–106	90–92	117–119
Dry weather flow........	113–118	59–60	102–105	85–90	114–117
Ordinary summer flow.....	109–113	57–59	97–102	80–85	112–114
Ordinary spring flow......	97–109	52–57	83– 97	63–80	103–112
Spring flood flow..........	68– 97	38–52	58– 83	38–63	78–103
Freshets................	28– 68	14–38	23– 58	13–38	32– 78

Calculations similar to those described were made for Esopus, Rondout and Catskill Creeks--waters which were much softer than those of the streams east of the Hudson River. The curves for these streams differed somewhat from the others, showing less variations with stream flow (see Digram No. 29). In the case of the Catskill Creek, the curve was concave instead of convex to the axis of alkalinity. For this no adequate explanation has yet appeared.

Hardness of Available Water Supplies.

Chemical analyses indicate that the available sources of supply east of the Hudson River, taken as a whole, would have a probable annual average hardness of 95 parts per million, of which all but 4 parts would be due to carbonates and bicarbonates. This hardness is more than twice the average for Croton water. The various reservoirs, however, would differ among themselves to a considerable extent, as shown by the following figures:

Reservoirs.	Estimated Daily Yield in Million Gallons.	Estimated Alkalinity.	Estimated Hardness.	Product of Yield and Alkalinity.	Product of Yield and Hardness.
Stormville............ ...	37	98	102	3,626	3,774
Billings	24	53	58	1,272	1,392
Hibernia	68	87	91	5,916	6,188
Clinton Hollow	20	62	67	1,240	1,340
Silvernails..............	112	104	107	11,648	11,984
Total	261	91	95	23,702	24,678

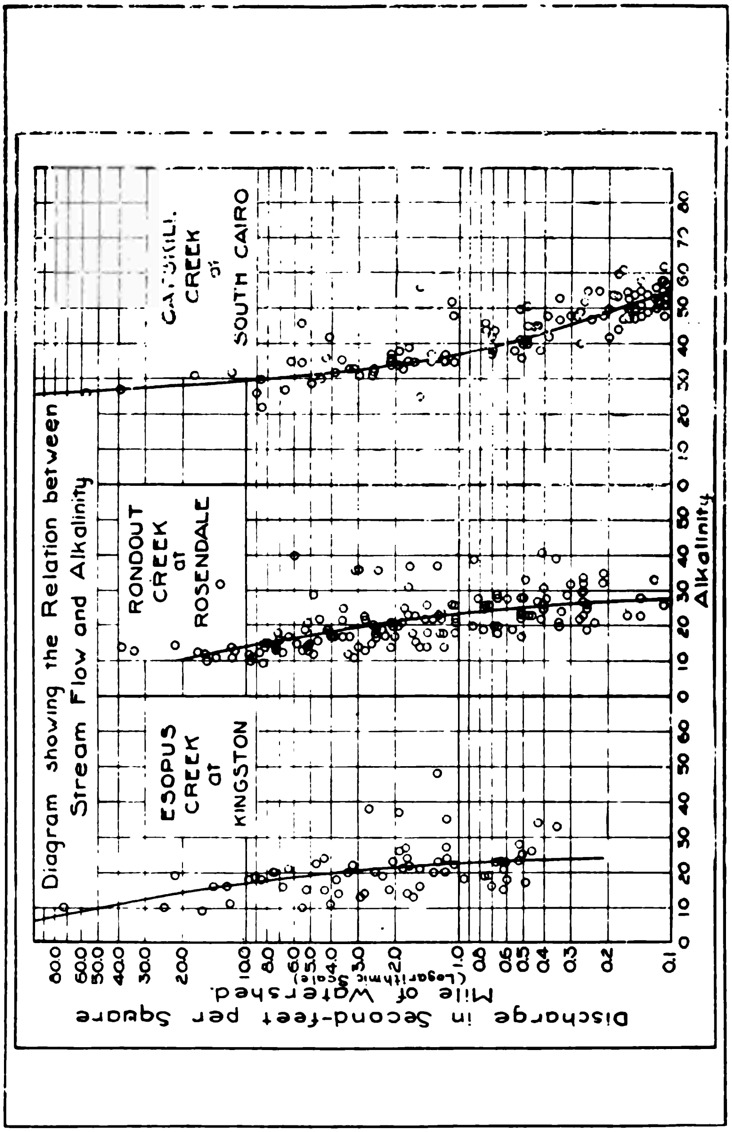


DIAGRAM 29. APP. VI.

The water in the streams west of the Hudson is much softer than that on the east side, as shown by the following estimated figures:

Stream.	Station.	Estimated Daily Yield in Million Gallons.	Estimated Alkalinity.	Estimated Hardness.	Product of Yield and Alkalinity.	Product of Yield and Hardness.
Esopus..........	Shokan..........	255	16	20	4,080	5,100
Rondout........	Rosendale........	100	18	23	1,800	2,300
Catskill........	So. Cairo........	123	33	36	4,059	4,428
Schoharie.......	Prattsville.......	171	17	21	2,907	3,591
Total.....	....	649	20	24	12,846	15,419

If all of the streams east of the Hudson were used, and in addition the Esopus Creek, the resulting hardness would be 58 parts per million, or 45 per cent. more than the average for the Croton water.

By taking water from the first two of the east side streams and the balance from the Esopus and Rondout Creeks, it would be possible to obtain 500 million gallons per day which had a hardness of 40, which is the average for Croton water. By taking water from the Fishkill Creek on the east side and Esopus Creek and Rondout Creek on the west side of the Hudson, the resulting hardness would be only 29.

If with the present Croton water (yield 275 million gallons per day and hardness 40), were mixed the 267 million gallons from the streams east of the Hudson, which have an average hardness of 95, the resulting waters would have a hardness of 67. If to this mixture were added 255 million gallons of Esopus water (hardness 20) the resulting hardness would be 52. By omitting the Roeliff Jansen Kill water and using the water from Fishkill Creek, Wappinger Creek, Esopus Creek and Rondout Creek, the hardness would not be charged from the present figure, namely, 40. By using 500 million gallons of water from west of the Hudson and mixing this with the present supply, the resulting hardness would be 30.

For comparison with these figures it may be stated that the hardness of the Hudson River water, filtered at a point somewhere near Hyde Park, would be about 50. The hardness of the Housatonic River water would have been 86, that of the Ten Mile River 105, that of the Wallkill 59, that of the Ramapo 30. All of these sources have been proposed at one time or another as possible sources of supply.

For further comparison the following table may be introduced. It shows the ordinary hardness of the water in a number of important cities of the United States and Great Britain:

Table Showing the Alkalinity and Hardness of Various Public Water Supplies.

State.	City or Town.	Parts per Million.		
		Alkalinity.	Permanent Hardness.	Total Hardness.
Maine	Augusta	15	5	20
"	Waterville	12	3	15
New Hampshire	Concord	..	..	9
"	Keene	..	..	7
"	Nashua	..	..	15
"	Milford	..	..	30
"	Hanover	..	..	70
"	Exeter	..	..	21
Vermont	Bennington	..		15
"	Burlington	..	..	45
"	Brattleboro	..	..	78
"	Rutland	..	..	38
Massachusetts	Boston	..	..	12
"	Cambridge	..	..	33
"	Fall River	..	..	6
"	Dedham	..	..	46
"	Lexington	.	..	52
"	Lowell	..	..	10
"	Lawrence	..	..	16
"	Springfield	..	..	8
"	Worcester	..	..	6
"	Waltham	..	..	34
"	New Bedford	..	..	6
"	Lynn	..	..	17
"	Pittsfield	..	..	50
"	North Adams	..	..	58
Rhode Island	Providence	..	..	59
Connecticut	New Haven	..	..	35
"	Norwich	..	..	8
"	New London	..	..	8
"	Waterbury	..	..	16
"	Meriden	..	..	13
New York	Syracuse	..	..	79
"	Albany	..	..	64
"	Oswego	98	93	191
"	Watertown	23	11	34
"	Middletown	27	6	33
"	Binghamton	45	10	55
"	Elmira	60	..	..
New Jersey	Trenton	37	22	59
"	Jersey City	36	5	41
Pennsylvania	Philadelphia	116	63	179
"	York	22	8	30
"	Canton	16	6	22
"	Lancaster	..	..	121
"	Pittsburg	12	4	16
"	Reading	70	7	77
"	Allegheny	..	..	40
District of Columbia	Washington	80	18	98
Virginia	Norfolk	7	58	65
"	Petersburg	40	10	50
"	Lynchburg	66	7	73
"	Old Point Comfort	27	33	60

State.	City or Town.	Parts per Million.		
		Alkalinity.	Permanent Hardness.	Total Hardness
West Virginia	Parkersburg	17	33	50
Florida	Starke	154	9	163
Alabama	Birmingham	37	..	37
Ohio	Toledo	150	50	200
"	Columbus	200	135	335
"	Dayton	..	..	288
"	Warren	..	..	578
"	Cincinnati	45	33	78
Kentucky	Louisville	65	18	83
Tennessee	Knoxville	50	..	..
Louisiana	Shreveport	120	240	360
"	New Orleans	79	14	93
Indiana	Vincennes	40	126	166
Illinois	Quincy	90	13	103
Minnesota	St. Paul	..	..	143
"	Minneapolis	..	..	122
California	San Francisco	21	12	33
Great Britain	Cheltenham	122	29	151
"	Edinburgh	..	..	57
"	Dublin	..	..	19
"	Glasgow	..	..	21
"	Leeds	21	43	54
"	Leicester	193	57	250
"	Liverpool	14	57	71
"	London—			
	Chelsea Company	172	43	215
	East London Company	193	50	243
	Grand Junction Co	172	43	215
	Kent Company	280	21	301
	Lambert Company	172	43	215
	New River Company	179	43	222
	Southwark Company	179	50	229
	West Middlesex Co	172	43	215
"	Manchester	24	19	53
"	Sunderland	300	129	429

The Value of Soft Water to New York City.

Everyone knows that a soft water is more desirable for purposes of a public supply than a hard water. A hard water wastes soap in the laundry, compels the use of washing soda or other chemicals which injure fabrics, making the washing of clothes a longer, more troublesome and more expensive process. It forms an unsightly "curdle" with soap when used for the toilet and affects the skin unpleasantly. It forms a coating on the inside of the tea kettle, and sometimes deposits a sediment at the bottom. It is unsatisfactory for cooking. Vegetables, especially potatoes, are not as thoroughly softened by boiling. Tea is less perfectly steeped, the resulting color being darker, but the aroma not as strong. Hard water is objectionable for boilers, as it produces scale, wastes coal and diminishes the life of the boiler.

It is objectionable in many of the industries, especially when used in connection with chemical processes, as for example, in paper mills.

Some physiologists claim that hard water is less desirable for drinking purposes than soft water, and agents for various forms of distilling apparatus have magnified these supposed objections to an absurdity. There does seem to be plausible reasons for believing that water highly charged with mineral salts is less satisfactory than soft water for some people, and the change from a soft to a hard water often occasions temporary intestinal derangements, but there is no statistical evidence to show that the differences in hardness found in ordinary public supplies have any great practical significance on the public health.

The point at which a water becomes objectionably hard has never been exactly defined. Standards of hardness vary in different parts of the country, as may be inferred by perusing the table on page 492, which shows great sectional differences. The boiler fireman considers a water soft if he does not find it necessary to blow his boilers frequently or use a boiler compound; the laundress considers a water soft if she does not have to use washing soda to obtain satisfactory results; the ordinary person, washing his hands, considers it soft if common toilet soap will quickly produce a "suds" without "curdling." As a rule, these conditions obtain when the total hardness of the water does not exceed 25 or 50 parts per million. The limit cannot be placed exactly, because the character of the hardness, *i. e.*, whether it be due to sulphates or merely to carbonates, must be taken into consideration. Speaking broadly, however, a water which has a hardness above 50 is well entitled to the appellation "hard," and above 100 the water may be called "very hard." The difference between 25 and 100 can be detected by the taste.

Frequent attempts have been made by scientific writers to express the money-loss to a community from using a hard water, but the data for making an exact calculation of that kind are not at hand. It has been assumed by one, for example, that the quantity of water decomposed by soap was equal to 10 gallons per capita per day; another has placed this at 11 gallons; another at 3 gallons. All of these figures would appear to be too high for a city like New York. Two gallons, or even one gallon, would probably be nearer the truth, for the fact is, that in most domestic uses all of the hardness of the water is not decomposed by the soap. This was illustrated by an experiment made to determine the amount of soap used in the simple operation of washing the hands.

Twelve persons, laborers, clerks and professional men, were asked to wash their hands in a basin, using a small cake of ivory soap and as much water as they ordinarily used for the purpose, the water having a hardness of 24.5 The following day the same persons were asked to wash their hands in a water which had a hardness of 126, using the same cake of soap and the same volume of water as they used in the first instance. In each case the quantity of the water was measured, the hardness of the water was determined before and after the experiment, and the loss of soap was ascertained by carefully weighing the cake before and after being used.

The amount of water used varied from 700 to 1,700 c. c., the average being 1,100 c. c. The quantity of soap varied from .03 gram to .73 gram in the case of the softer water, and averaged 0.34 gram; while in the case of the harder water it varied from 0.17 to 1.60, and averaged 0.67 gram. Only 41 per cent. of the hardness of the softer water was decomposed by the soap, and only 48 per cent. of the hardness of the harder water. In round numbers, it may be said, therefore, that one-half of the hardness was used up. In tub-bathing it was found that a much smaller percentage of the hardness was used up.

From the results obtained in the experiment just related, it has been calculated that a person washing his hands once a day would use 0.27 pounds soap annually to decompose the hardness of the softer water, or 0.5 pounds in the case of the harder water. This does not, of course, represent the total consumption of soap, as much soap is wasted without doing effective work. The difference between the two figures given, however, represents the effect of the different waters. While one-quarter of a pound of soap per person annually seems an insignificant amount, it amounts to 130 tons a year for a million people, which at 7 cents per pound, amounts to $18,200 per annum. This sum capitalized at 4 per cent. gives $455,000.

Hand washing represents, of course, but a small part of the water with which soap is used in any household. Dish washing, laundry uses, bathing, etc., would raise the average quantity to at least one gallon per capita daily, in which all the hardness was used up by soap. In some communities the quantity might be larger than this, but for a cosmopolitan city like New York one gallon may be considered as a fair estimate.

Table 15 shows the amounts of water of different degrees of hardness which will be softened by one pound of standard castile soap and by some of the soaps commonly used. From this it will be seen that the average soap will completely soften about 97 gallons of Croton water, which has an average hardness of 40, that is about 0.01 pound per gallon. At the rate of 1 gallon per capita daily, this amounts to 1,825 tons per annum for one million people, which at 5 cents per pound, would cost $182,500. It has been calculated that to double the hardness of the present Croton water would increase the consumption of soap in the Borough of Manhattan by about $270,000 annually. This sum capitalized at 4 per cent. gives $6,750,000.

TABLE 15.

Table Showing the Relation Between the Hardness of Water and the Amount of Soap Required to Soften it.

Hardness. (Parts per Million).	Number of C.C. of Standard Soap Solution for 50 C.C. Water.	Number of Grams of Standard Soap per Gal. of Water.	Number of Gallons of Water Softened by One Pound of: Standard Castile Soap.	Ivory Soap.	Babbitts Laundry Soap.	Sapolio.	Bon Ami.	Gold Dust.	Pearline.	Pear's Hand Soap.	Colgate's Cerosa Toilet Soap.	Average (Omitting the Standard Castile Soap.)
20	2.1	1.11	409	195	138	102	143	105	167	187	215	167
25	2.4	1.27	358	174	121	90	125	145	147	164	206	147
40	3.6	1.91	238	115	80	59	83	96	98	109	137	97
50	4.3	2.28	200	96	67	50	70	81	82	92	115	82
75	6.1	3.24	140	67	47	35	49	57	58	64	80	57
80	6.4	3.49	130	70	44	33	45	52	53	60	75	54
100	7.8	4.13	110	53	37	27	38	44	45	50	63	45
125	9.5	5.04	90	43	30	25	31	36	37	41	52	37
150	11.1	5.89	77	37	26	19	27	31	32	35	44	31
175	12.7	6.74	67	32	23	17	23	27	28	31	38	27
200	14.3	7.59	60	29	20	15	21	24	25	27	34	24

The above estimate takes into account only the cost of soap used for domestic purposes, and does not include the incidental losses and inconveniences attendant on the use of a hard water in the household. These, if they could be expressed in terms of dollars and cents, would probably more than equal the cost of soap.

Another important item in connection with hard water is that which relates to its use in steam boilers. Data are not at hand for making a fair estimate of what it would cost the owners of steam boilers if the hardness of the Croton water were doubled, but the following statements have some slight value. There are in round numbers about 9,000 steam boilers in Manhattan and Bronx (there were 13,037 in the entire City in 1902), with horse powers from 10 to 500 and averaging, perhaps, 75 horse power operated for 10 hours per day. At the rate of 30 pounds of water per horse power per hour, this would indicate the use of 24 million gallons per day used for steam making.

It has been stated elsewhere that the present Croton water is a comparatively satisfactory boiler water. The sulphates are low—only about 5 parts per million—and below the point at which it becomes necessary to use a compound to prevent the formation of a hard scale. The carbonates present are largely precipitated in the boiler and may be readily blown off. No boiler compound need be used unless it is desired to add a small amount of caustic alkali to neutralize the carbonic acid liberated from the carbonates.

The proposed new supplies, whether they be taken from the streams east or west of the Hudson, will not increase at all the sulphates in the water. Hence their use will not increase the necessity for using soda ash as a boiler compound. The only effect of the increase of carbonates will be to increase the amount of sludge and soft scale in the boilers and to liberate quantities of carbonic acid in proportion to their hardness. The latter is the most serious consideration, as carbonic acid is a corrosive agent. When the bicarbonates are changed to carbonates and thrown out of solution, carbonic acid is set free. If this takes place in a boiler to any great extent it will tend to cause pitting, the dissolved oxygen in the water doubtless assisting in the process. It is necessary, therefore, to neutralize the carbonic acid, if present in large amounts, with caustic soda or caustic lime. For a temporary hardness of 35, the present Croton figures, 1.6 grains per gallon of caustic soda, or 1.5 grains of lime, would be needed for the full reaction, and these amounts would be increased in proportion to the alkalinity of the water. It is seldom necessary or even desirable to add enough caustic alkali to fully complete the reaction, as the addition of lime increases the amount of soft scale and sludge, while an excess of soda causes a boiler to foam.

The present hardness of the Croton water is not far from the dividing line, below which it is not expedient to use chemicals, but above which it may be desirable. Consequently, any increase of hardness over the present amount may be considered as adding to the cost of boiler operation. Calculations show that to neutralize the carbonic acid liberated from ten parts per million of carbonates there would be required for all the boiler water used in Manhattan 591,300 pounds of 48 per cent. caustic soda per annum, which, at two cents per pound, would cost $11,826. In all probability this would be used not as a crude chemical but in connection with tannin, etc.—*i. e.*, in the form of a "boiler compound"—so that the sum actually paid to accomplish the desired result would greatly exceed the figures stated. It is a fact which should be more generally known by steam users that most boiler compounds are sold for many hundred per cent. more than their cost of manufacture.

Including all uses of water, both domestic and industrial, it may be considered a conservative estimate that for every increase of ten parts per million in the alkalinity of the public water supply the consumers in the Borough of Manhattan would be compelled to expend at least $100,000 annually for soap, boiler compounds, etc., assuming the consumption to remain the same. This capitalized at 4 per cent. gives $2,500,000. If the sulphates increased in the same proportion, this amount would be materially larger. This, however, will not be the case.

Using this as a basis of calculation, it can be shown that for an increased supply of 250,000,000 gallons per day the Esopus water (alkalinity 20) would be worth $330,000 per year more to the consumers of Manhattan than the water from the streams east of the Hudson (alkalinity 90) at the present rate of consumption, or $630,000 when the consumption has increased in proportion to the supply provided. The average of these two figures is $480,000, and this sum capitalized at 4 per cent. gives $12,000,000. That is, 250 million gallons of Esopus water are worth $12,000,000 more to the citizens of New York than water from the eastern streams from the standpoint of hardness alone.

Computation.

275 (present yield of Croton) x 35 (alkalinity present Croton).....	9,575
250 (yield of Esopus) x 20 (alkalinity of Esopus)..............	5,000
525)	14,575
Resulting alkalinity............................	28
275 (present yield of Croton) x 35 (alkalinity of Croton)..........	9,575
250 (yield of eastern streams) x 90 (alkalinity eastern streams)....	22,500
525)	32,075
Resulting alkalinity............................	61

61—28=33 (difference in alkalinity between Esopus water mixed with present Croton water and water from eastern streams mixed with present Croton).

33 x $100,000 x 1/10=$330,000.

For an increased supply of 500 million gallons per day, a supply all derived from west of the Hudson would be worth, in capital expenditure, $10,000,000 more than a supply derived half from the eastern streams and half from the Esopus Creek.

An increased supply of 250 million gallons daily, taken from the Hudson River at a point near Hyde Park, would give a resulting alkalinity of 38. The Hudson River would be worth $3,750,000 less than the Esopus supply, from the standpoint of hardness, or $5,000,000 less for an additional supply of 500 million gallons.

III.—Probable Quality of the New Sources of Water Supply.

The investigations made by the Department of Chemistry and Biology have shown that the quality of the water which can be obtained from the Esopus and Rondout and Fishkill Creeks and which are recommended for the additional supply of New York City, taken as a whole, will conform very closely to the requisites of an ideal public water supply. The populations upon the watersheds are sparse, and the few sources of pollution which exist are easily controllable. These facts, combined with the long storage which the water will receive in the impounding reservoirs, will assure a reasonably safe supply even without filtration—one that may be considered as better than the present Croton water. Filtration, moreover, will make safety doubly sure and wili lessen the care needed to be bestowed on the sanitary condition of watersheds.

The average color of the combined waters before filtration will be considerably less than that of the present Croton supply. Filtration will further reduce the color to a point where it will be scarcely noticed by the water-taker, even when used in a porcelain bath tub.

Unless filtered, the water may contain a slight but occasionally noticeable amount of suspended matter, consisting chiefly of microscopic organisms and amorphus, organic and mineral matter. Filtration will remove this completely, and will render the water perfectly clear.

The water will be practically tasteless and colorless if filtered, or if the storage reservoirs are thoroughly cleaned by the removal of the vegetation and top soil from the flooded areas. Either one or the other method of avoiding objectionable odors due to microscopic organisms should be adopted. The chemical characteristics of the water will be satisfactory in all respects, and the hardness will be only about three-quarters of that of the present Croton supply. The amount of nitrates, chlorine and iron in the water will be very low. Because of its low hardness and the small amounts of other mineral constituents, it will be an excellent boiler water—better than that of the present Croton supply and considerably better than the present Brooklyn supply, which is high in chlorines, nitrates and sulphates.

Nor is it going too far to state that the available water sources, if properly conserved, are capable of furnishing to the City of New York a public supply, the quality of which will be second to that of no other large city in the world. It has been shown that even now the typhoid fever death-rate of New York is lower than that of any American city of the first rank. The filtration of the present Croton water and the addition of the new supplies ought to still further reduce the typhoid fever death-rate. Thus, while equaling any of our public supplies in sanitary quality, the future supply of New York will be more generally satisfactory for domestic and industrial uses than that of any large city as it exists to-day. This statement is confirmed by analyses which have beeen collected from leading American cities during the past year.

The ground water sources on Long Island can never be made equal to the upland water sources as boiler waters. The normal chlorine on Long Island is much higher than in the Catskill Mountains, and so are the sulphates. The inevitable extension of population on Long Island will cause the nitrates to be relatively high, and will otherwise cause an increase of mineral matter. Thus, while the total solids may not exceed those in the upland waters, their general character will not be as satisfactory. Aside from these considerations, however, the water on Long Island is capable of being developed so as to produce a most excellent water—absolutely safe from the sanitary standpoint—clear, colorless, odorless, tasteless, and with practically no microscopic organisms. It will have one desirable quality, moreover, which the upland sources will not possess, one which will be much appreciated by the consumer, namely, a cool, equable temperature. This presupposes, of course, the elimination of the surface waters from the supply, and the covering of the distribution reservoirs.

TABLE 16.

Comparison of Analyses of Existing Supplies with Estimated Analysis of Proposed Additional Supply.

Physical Examination.	Present Croton Water at 135th Street Gate House.	Croton Water after Filtration (Estimated.)	Additional Upland Supply from Esopus, Rondout and Fishkill Creek before Filtration (Estimated.)	Additional Upland Supply after Filtration (Estimated.)	Present Brooklyn Supply at Ridgewood Pumping Station 5 years.	Brooklyn Supply after Filtration or Abandonment of Surface Waters and Elimination of Salt Wells (Estimated.)
Turbidity	5	0	3	0	4	0
Color	24	15	18	12	13	5
Odor	3 v + 1 m	2 v	2 v	1 v	3 v +	0
Chemical Analysis.						
Albuminoid Ammonia	.157	.078	.070	.035	.044	.015
Free "	.032	.010	.035	.010	.029	.020
Nitrites	.004	.000	.001	.000	.003	.001
Nitrates	.14	.20	.10	.15	1.14	1.00
Chlorine	2.0	2.0	1.0	1.0	19.6	7.0
Hardness	37.4	37.4	29.0	29.0	38.1	35.0
Alkalinity	32.7	32.7	25.0	25.0	17.8	17.0
Permanent Hardness	4.7	4.7	4.0	4.0	20.3	18.0
Iron	.28	.10	2.0	0.5	.58	.70
Microscopical Examination.						
Microscopic Organisms	1,058	0	250	0	123	0
Bacteriological Examination.						
Number per C. C.	1,848	50±	200±	50±	375	25±
Per cent of Postive Coli Tests	18.7	0	2	0	10	0

The figures in Table 16 show the probable quality of the upland water recommended for the additional supply as compared with that of the present supplies of Manhattan and Brooklyn. The estimate for the new supply assumes a mixture of the water to be obtained from the Fishkill, Esopus and Rondout creeks, in proportion to the water expected to be taken from each source. The table also shows the probable quality of the water which may be expected from Long Island after the elimination of the brackish wells and the filtration or abandonment of the surface supplies. The estimates of turbidity, color, chlorine and hardness may be considered as reasonably correct. The other quantities in the nature of the case are less reliable, and are presented merely to show what is likely to be found under the expected conditions.

IV.—The Hudson River as a Source of Water Supply for New York City.

The water of the Hudson River, taken at a point between Hyde Park and Kingston, can be filtered so as to make it a safe, wholesome and generally satisfactory source of supply for New York City. All depends, however, upon the efficiency of the filtration and upon the subsequent treatment of the filtered water. Without filtration, or with imperfect filtration, the water would be unsafe and at times would possess undesirable physical qualities. Even with the most perfect sand filter, used as it naturally would be without a coagulant, the quality of the effluent would have a color and a hardness which would closely approach what is considered as a desirable maximum limit.

Our investigations indicate that the Hudson River water after filtration would have an average turbidity below 2, and possibly 1, and an average color of about 25, and only a very faint vegetable odor. The average hardness would be 50, of which 5 or 6 would be due to carbonates. The average chlorine would be 3.0. If stored in covered reservoirs it would be entirely free from objectionable microscopic organisms, with their accompanying bad odors. For purposes of comparison, it may be stated that the quality of the filtered water would be about the same as that of the Croton at present, save that it would be less turbid and with less odor, but somewhat deeper colored and a little harder. From the sanitary standpoint there would be a slight margin in favor of the filtered Hudson water, as compared with the present unfiltered Croton water, but that would depend wholly upon the efficiency of the filtration.

When compared with the upland sources east of the Hudson in point of quality, the advantages lie all with the latter, save in the one item of hardness, and the qualities of the available sources in the Catskill region are superior in every way to those of the filtered Hudson water.

While, therefore, the Hudson River water must be looked upon as a satisfactory possible source of supply, and one which may be required in the future, yet, speaking from the standpoint of quality, it is not the best source which is now available.

The subjects which were investigated in arriving at this conclusion were:

(1) The inflow of the sea water, its limits and effects.

(2) The pollution of the Hudson River and its tributaries.

(3) The character of the water near the probable location of the intake with reference to its turbidity, color, organic matter, bacterial contents, hardness, etc.

(4) Present use of the river water as a source of supply.

General Description.

Whether viewed from the historical, commercial, economic or picturesque standpoint, the Hudson is one of the greatest rivers in America, and there is something attractive in the thought that this great river might become the source of water supply for the city which it helped to build. Yet when one considers the cities located upon its stream, with their sewerage systems and industrial wastes emptying untreated into the water, the picture has another aspect. These and other impressions are quite likely to affect popular opinion as to the desirability of this source of supply, but sanitary science and hydraulic engineering must be the guides to the final judgment in the matter.

The Hudson River rises in the Adirondack Mountains and flows in a general southerly direction for about 300 miles, into New York Harbor, but its influence does not end there; it affects the water in the Atlantic Ocean for many miles off the coast. It has a total drainage area of about 13,268 square miles. Near the middle of its course it receives the waters of the Mohawk River, which is the natural waterway leading to the Great Lakes and the West, just as the northern portion of the Hudson leads to Lake Champlain and the St. Lawrence Valley.

At Troy, a few miles below the mouth of the Mohawk, is the State dam, at Glens Falls, about 40 miles above the Mohawk, the river flows over a high ledge. These two places, Glens Falls and the Troy Dam, subdivide the river course into the three sections, which have been mentioned on a previous page, namely, the Upper Hudson, the Middle Hudson and the Lower Hudson. The first two have been already considered in connection with the stream investigations, and it only remains to consider the third. The words " Upper Hudson " stand for mountains and forests, " Middle Hudson," for manufacture and agriculture, and " Lower Hudson," for commerce. When filtration of the Hudson is mentioned, it always refers to the waters of the Lower Hudson, but in connection with this subject the upper watersheds are important, as they largely control the quality of the water in the lower river. The Upper Hudson, for example, contributes coloring matter and the Middle Hudson turbidity, hardness and pollution.

The most important feature of the Lower Hudson is its tidal character. This portion of the river is really an elongated arm of the sea, where the tides ebb and flow, even to the foot of the Troy Dam. This statement does not mean that the sea water reaches the Troy Dam, but only that at that point the surface of the water rises and falls under tidal influences.

Obviously that portion of the river affected by the sea water is an unfit source of water supply, and one of the first facts necessary to be determined was the probable maximum distance up the river that the salt water is likely to extend. Existing testimony of river men is almost, but not entirely, unanimous that the water of the river is always fresh at Kingston, and it is well known that it occasionally becomes brackish at Poughkeepsie. As no data were in existence for ascertaining the conditions necessary to allow the salt water to run up to Poughkeepsie and beyond, steps were taken to obtain such data as completely as possible with the time and means at our disposal.

These data included:

(1) Knowledge of the geography of the basin of the lower Hudson.

(2) Knowledge of the flow of the stream, as represented by the daily discharge over the Troy Dam, and the flow of the tributary streams on the watersheds of the lower river.

(3) Knowledge of the time and elevations of the high and low tides in New York Harbor, at Albany and at intermediate points, especially in the vicinity of Poughkeepsie and Kingston.

(4) Knowledge of the meteorological conditions, especially those relating to the direction and velocity of the wind.

(5) Knowledge of the amount of salt in the river water at various points as indicated by chemical determinations of chlorine.

(6) Knowledge of extreme conditions of those factors tending to produce a high run of salt water, such as extreme drought, high tides, an east wind, etc., and the probability of these factors existing concurrently.

Geography of the Lower Hudson.

The present mouth of the Hudson River may be considered as being at the Battery, but the bed of the river as indicated by the contours of the bottom, can be followed for a considerable distance out into the harbor. At the Battery, the river has a width of about 4,900 feet, and is about 60 feet deep at the deepest point at mean low tide.

This section is maintained with but slight variations for about 20 miles. Opposite Fort Washington, there is the first of a series of deep "pockets," which are found at intervals along the course of the river, the location of which may be seen on Plate XI. The deepest place in this pocket is about 150 feet deep. Between Dobb's Ferry and Haverstraw, the river widens to about three miles, and forms what is known as Tappan Sea and Haverstraw Bay, the two being separated by Croton Point. At the same time, the river makes a slight bed, which throws the main channel from the left to the right bank, as indicated by the dotted lines on the map. At the upper end of Haverstraw Bay the maximum depth is only about 30 feet. Between this point and Cornwall, the river passes with several curves through the "Highlands," and in this section the contours of the river bed are no less interesting than the rocky and precipitous shores are picturesque. Here the stream becomes deep and narrow. There are three well marked pockets. The Haverstraw Pocket (100 feet deep), the Peekskill Pocket (170 feet deep) and the West Point Pocket (210 feet deep). In the reach just below Newburgh, the Hudson widens to about 700 feet, and becomes only about 40 feet deep. Between New Hamburg and Kingston it becomes narrow again and deeper. In this reach there is another series of pockets which, however, are not as deep as those of the Highlands. Taken in order, they may be named the New Hamburg Pocket, the Barnegat Pocket, the Hyde Park Pocket and the Dinsmore Pocket. Above Kingston the river becomes somewhat wider, but the depth gradually decreases, until at Albany, it is about 15 feet. For a number of miles below Albany the river passes through a wide, flat valley, and at times of high water the shores are overflowed, and the surrounding territory flooded. At Troy, the tidal waters meet an insurmountable obstacle, the State Dam.

The distance from the Troy Dam to the Battery is about 150 miles, and the relative locations of the other important cities along its course are as follows:

Distance from the Battery in Miles.	City or Town.	Distance from the Troy Dam in Miles.
16	Sandy Hook	166
7	Fort Hamilton (Tide Gage Station)	157
1	Governor's Island	151
0	Battery	150
5	Sixty-second Street, Pier A (Tide Gage Station)	145
10	Fort Washington	140
12	Spuyten Duyvil	138
16	Yonkers (Tide Gage Station)	134
17	Alpine	133
20	Hastings	130
22	Dobb's Ferry	128
24	Piermont-Irvington	126
26	Tarrytown	124
27	Nyack	123
30	Scarboro	120
32	Ossining	118
33	Croton Point	117
36	Haverstraw	114
38	Oscawana (Tide Gage Station)	112
39	Crugers	111
39	Stony Point	111
40	Verplank's Point	110
42	Caldwells	108
45	Iona Island	105
45	Anthony's Nose	105
50	Garrison	100
52	West Point (Tide Gage Station)	98
52	Constitution Island	98
56	Cornwall	94
59	Fishkill	91
60	Newburg	90

Distance from the Battery in Miles.	City or Town.	Distance from the Troy Dam in Miles
64	Carthage	86
66	New Hamburg	84
69	Barnegat	81
75	Poughkeepsie (Tide Gage Station)	75
78	Crum Elbow Point	72
79	Griers Point	71
80	Hyde Park	70
83	Esopus Island	67
86	Esopus Light	64
90	Kingston	60
90	Rhinecliff (Tide Gage Station)	60
100	Tivoli	50
106	North Germantown (Tide Gage Station)	44
111	Catskill	33
115	Hudson City	35
122	Coxsackie (Tide Gage Station)	28
125	Stuyvesant	25
129	New Baltimore	21
134	Castleton	16
143	Albany (Tide Gage Station)	7
150	Troy Dam	0

The capacity of the bed of the Hudson River below the level of mean low water is shown in Table 17. The results were obtained from the soundings given in the charts of the United States Coast and Geodetic Survey. The table shows the average width and depth of sections one mile long, with the surface area, the volume below the level of mean low water and the total volume of the river from the mouth to and including each section. The average width, depth and volume for each section from the Battery to the Troy Dam, are shown geographically in Diagram No. 30.

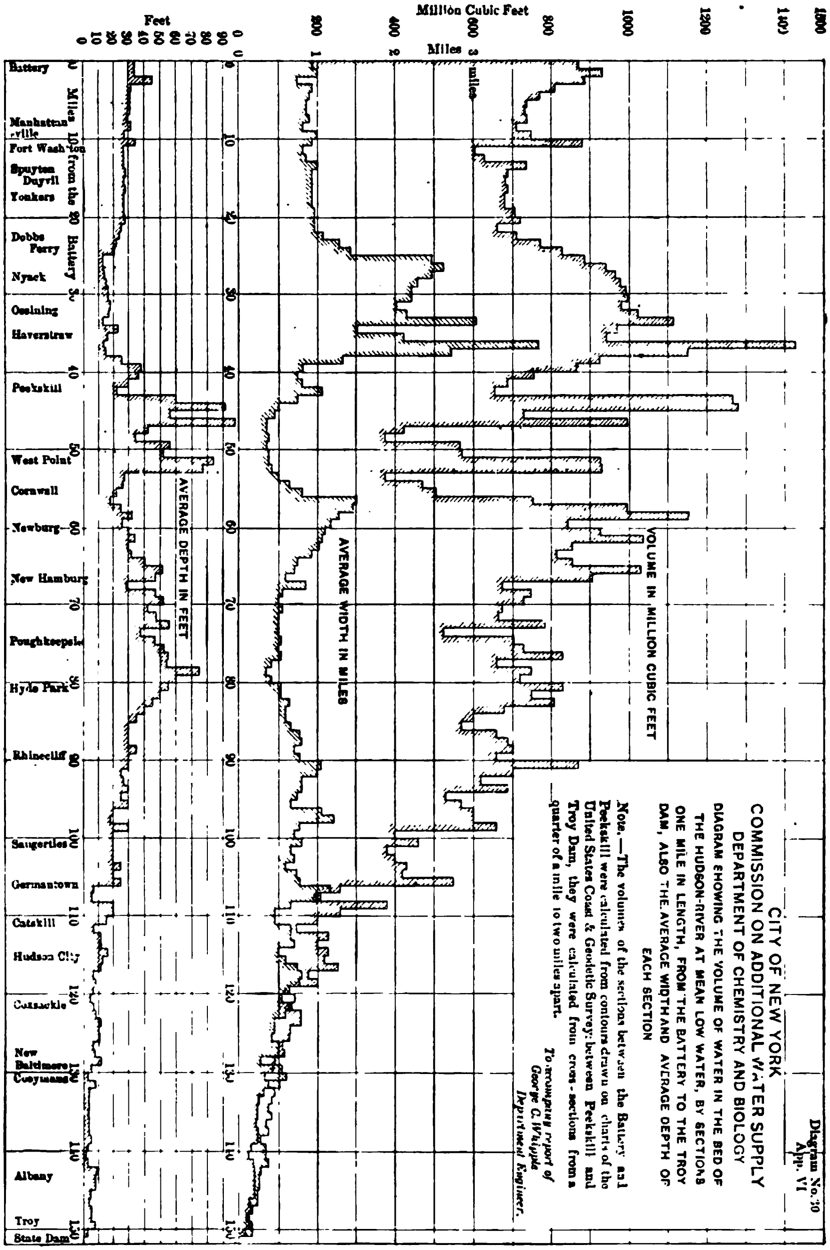


DIAGRAM 30. APP. VI.

TABLE 17.

Table Showing the Volume of Water in the Bed of the Hudson River at Mean Low Water and the Surface Area and Mean Width of the Hudson River at Mean Low Water, by Sections One Mile in Length, from the Battery to Albany.

Section (Miles from the Battery).	Average Width (Miles).	Surface Area (Million Square Feet)	Average Depth (Feet).	Volume (Million Cubic Feet).	Total Volume from the Battery to the Upper Limit of the Section (in Million Cubic Feet).	Station Near Upper Limit of Section (distance from the Battery Given in Miles).
0–1	0.93	26	33.5	870	870	Duane street.
1–2	1.00	28	33.3	932	1,802	Christopher street.
2–3	0.72	20	44.3	886	2,688	Eighteenth "
3–4	0.93	26	31.2	811	3,499	Thirty-fifth "
4–5	0.90	25	30.7	769	4,268	Fifty-fifth "
5–6	0.86	24	30.7	737	5,005	Seventy-fifth "
6–7	0.86	24	30.6	735	5,740	Ninety-fifth "
7–8	0.90	25	29.5	738	6,478	One Hundred and Fourteenth street.
8–9	0.82	23	30.9	711	7,189	Manhattanville (8.8).
9–10	1.00	28	26.7	749	7,938	One Hundred and Fifty-fifth street.
10–11	0.93	26	33.8	879	8,817	Fort Washington Point (11.1).
11–12	0.82	23	26.3	604	9,421	Linwood (11.7).
12–13	0.86	24	26.2	629	10,050	Inwood (12.5).
13–14	1.00	28	26.3	736	10,786	Spuyten Duyvil (13.6).
14–15	0.93	26	26.5	690	11,476	Riverdale (15.0).
15–16	0.93	26	26.2	682	12,158	Mount St. Vincent (15.7).
16–17	0.93	26	26.5	690	12.848	Yonkers.
17–18	0.93	26	26.2	682	13,530	Alpine (18.0).
18–19	0.93	26	26.2	683	14 213	
19–20	0.97	27	26.2	708	14,921	Harriman (20.0).
20–21	0.97	27	26.7	721	15,642	
21–22	0.97	27	24.5	661	16,303	Hastings (21.6).
22–23	1.07	30	23.8	714	17,017	Dobbs Ferry (23.0).
23–24	1.29	36	21.5	773	17.790	Ardsley (23.8).
24–25	1.43	40	20.7	829	18,619	Piermont (24.6).
25–26	2.47	69	12.8	885	19,504	Irving (26.3).
26–27	2.62	73	12.9	940	20,444	Tarrytown (27.4).
27–28	2.47	69	14.0	965	21,409	Lower Nyack (28.0).
28–29	2.29	64	15.3	979	22,388	Upper Nyack (28.8).
29–30	2.22	62	16.0	995	23,383	
30–31	2.22	62	16.1	1,000	24,383	Scarboro (31.1).
31–32	2.01	56	17.5	982	25,365	Sparta (31.8).
32–33	2.15	60	17.1	1,023	26,388	Ossining (32.6).
33–34	3.04	85	13.1	1,114	27,502	Croton Point (33.7).
34–35	1.51	42	23.1	971	28.473	Snedeker's Landing (34.8).
35–36	2.11	59	16.0	942	29,415	Haverstraw (35.9).
36–37	3.84	107	13.3	1,427	30,842	
37–38	2.72	76	15.1	1,150	31,992	
38–39	1 33	37	25.0	926	32,918	Cruger's Point (38.9).
39–40	0.82	23	37.7	867	33,785	Verplanck's Point (40.2).
40–41	0.75	21	35.9	755	34,540	
41–42	0.82	23	29.9	689	35,229	
42–43	1.07	30	21.9	657	35,886	Peekskill (43.0).

TABLE 17—*Continued.*

Section (Miles from the Battery).	Average Width (Miles).	Surface Area (Million Square Feet).	Average Depth (Feet).	Volume (Million Cubic Feet).	Total Volume from the Battery to the Upper Limit of the Section (in Million Cubic Feet).	Station Near Upper Limit of Section (distance from the Battery Given in Miles).
43–44	0.75	21	60.3	1,265	37.151	
44–45	0.50	14	91.5	1,280	38,431	Iona Island.
45–46	0.47	13	56.2	731	39,162	Anthony's Nose (45.7).
46–47	0.36	10	98.6	986	40,148	
47–48	0.36	10	42.2	422	40,570	
48–49	0.39	11	34.1	375	40,945	
49–50	0.36	10	56.7	567	41,512	
50–51	0.39	11	52.0	572	42,084	Phillipses Landing (51.2).
51–52	0.39	11	84.4	928	43,012	West Point (51.6).
52–53	0.43	12	77.5	930	43,942	Constitution Island (52.6).
53–54	0.50	14	26.8	375	44,317	Little Stony Point (54.3).
54–55	0.65	18	26.1	470	44,787	
55–56	0.82	23	22.0	506	45,293	Cornwall (55.8).
56–57	1.51	42	17.9	755	46,048	
57–58	1.47	41	24.3	995	47,043	New Windsor (58.2).
58–59	1.29	36	32.0	1,153	48.196	
59–60	1.18	33	25.6	844	49,040	Newburg (60.1).
60–61	1.11	31	29.9	928	49,968	
61–62	1.07	30	33.9	1,017	50.985	Balmville (61.7).
62-63	1.04	29	29.5	855	51,840	
63–64	0.93	26	31.3	815	52,655	Carthage (64.0).
64–65	0.75	21	40.5	853	53,508	Danskammer Point (65.3).
65–66	0.72	20	51.0	1,031	54,539	New Hamburg (66.2).
66–67	0.61	17	47.5	807	55,346	
67–68	0.86	24	28.1	675	56 021	
68–69	0.57	16	46.8	750	56,771	Barnegat (69.2).
69–70	0.50	14	52.1	731	57,502	
70–71	0.57	16	42.1	675	58,177	Milton (70.7).
71–72	0.50	14	47 4	665	58,842	Eagans (72.2).
72–73	0 50	14	56.1	787	59,629	
73–74	0.50	14	37.5	525	60,154	Poughkeepsie (74–75).
74–75	0.54	15	46.9	703	60,857	New Platz.
75–76	0.50	14	52.2	732	61,589	
76–77	0.54	15	55.3	830	62,419	Roosevelt (76.6).
77–78	0.43	12	55.0	660	63,079	
78–79	0.36	10	75.0	750	63,829	Greers Point (78.9).
79–80	0.43	12	60.0	720	64.549	Hyde Park (80.1).
80–81	0.54	15	55.3	830	65,379	
81–82	0.54	15	50.0	750	66,129	
82–83	0–65	18	45.0	810	66,939	
83–84	0.61	17	40.0	680	67,619	
84–85	0.61	17	35.3	600	68,219	Cave Point (84.8).
85–86	0.68	19	30.0	570	68,789	Esopus Light (85.8).
86–87	0.79	22	30.0	660	69,449	Ellerslie (87.4).
87–88	0.82	23	30.0	690	70,139	
88–89	0.72	20	35.0	700	70,839	Port Ewan (88.8).
89–90	0.79	22	30.0	660	71,499	Rhinebeck (89.7).
90–91	1.04	29	30.0	870	72,369	
91–92	1.00	28	25.0	700	73.069	Clifton Point (91.9).
92–93	0.82	23	27.0	620	73,689	
93–94	0.82	23	30.0	690	74,379	

TABLE 17—*Continued.*

Section (Miles from the Battery).	Average Width (Miles).	Surface Area (Million Square Feet).	Average Depth (Feet).	Volume (Million Cubic Feet).	Total Volume from the Battery to the Upper Limit of the Section (in Million Cubic Feet).	Station Near Upper Limit of Section (distance from the Battery Given in Miles).
94-95	0.75	21	25.2	530	74,909	Astor's Point (94.8).
95-96	0.68	19	30.0	570	75,479	
96-97	1.07	30	20.0	600	76,079	
97-98	1.22	34	17.6	600	76,679	Glasco (98.1).
98-99	0.79	22	30.0	660	77,339	Tivoli (99.3).
99-100	0.72	20	20.0	400	77,739	Saugerties (100.3)
100-101	0.82	23	20.0	460	78,199	
101-102	0.68	19	20.0	380	78,579	Malden (101.9).
102-103	0.72	20	20.0	400	78,979	Evesport (103.0).
103-104	0.61	17	25.3	430	79,409	West Camp (103.8).
104-105	0.75	21	20.0	420	79,829	Germantown (105.0).
105-106	0.79	22	25.0	550	80,379	
106-107	1.18	33	7.9	260	80,639	DeWitt's Point (106.8).
107-108	1.04	29	6.9	200	80,839	
108-109	0.68	19	20.0	680	81,219	
109-110	0.47	13	20 0	260	81,479	
110-111	0.47	13	15.4	200	81,679	Catskill (110.9).
111-112	0.68	19	7.9	150	81.829	
112-113	0.68	19	12.1	230	82,059	
113-114	0.72	20	10.0	200	82,259	Hudson City.
114-115	0.50	14	16.5	231	82,490	Athens.
115-116	0.61	17	12.9	220	82,710	
116-117	0.75	21	11.8	248	82,958	
117-118	0.82	23	7.8	178	83,136	Stottville.
118-119	0.79	22	9.1	200	83,336	Four Mile Point.
119-120	0.65	18	7.2	130	83,466	Judson Point.
120-121	0.72	20	5.5	110	83,576	
121-122	0.65	18	7.7	139	83,715	Coxsackie.
122-123	0.61	17	9.4	160	83,875	
123-124	0.47	13	12.3	160	84,035	Coxsackie Light.
124-125	0.47	13	10.4	135	84,170	Stuyvesant.
125-126	0.43	12	10.8	130	84,300	
126-127	0.50	14	8.0	112	84,412	
127-128	0.50	14	8.5	119	84.531	Matthews Point.
128-129	0.29	8	11.8	94	84,625	New Baltimore.
129-130	0.54	15	6.0	90	84,715	Coeyman.
130-131	0.61	17	4.1	70	84,785	
131-132	0.39	11	9.5	104	84,889	
132-133	0.47	13	5.2	67	84,956	Mulls.
133-134	0.43	12	4.0	55	85,011	
134-135	0.39	11	4.8	53	85.064	Castleton.
135-136	0.43	12	4.4	53	85,117	Cedar Hill.
136-137	0.36	10	4.7	47	85,164	Wemple.
137-138	0.39	11	4.8	53	85,217	
138-139	0.29	8	6.5	52	85,269	Stone Light.
139-140	0.36	10	3.4	34	85,303	Glenmont.
140-141	0.36	10	3.0	30	85,333	Bogart Light.
141-142	0.39	11	3.7	41	85,374	Green Bush.
142-143	0.21	6	9.5	57	85,431	Albany.
143-144	0.21	6	9.0	54	85,485	

The following table shows the calculated capacity of the bed of the Hudson River at mean low water, between the Troy Dam and the Hudson, and also the increased volume for each additional foot above mean low water. This volume is naturally greater for each foot as the river rises and spreads out, and this is allowed for in the last four columns.

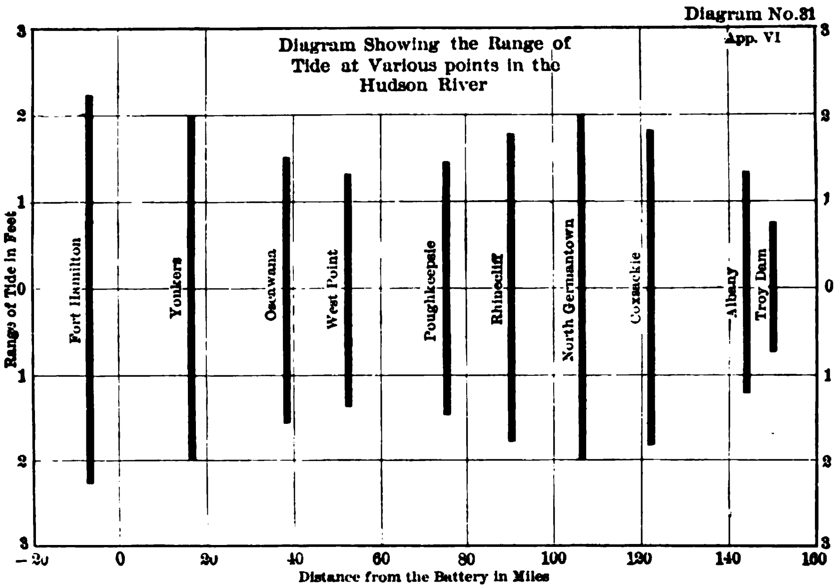
Table Showing the Volume of Water in the Bed of the Hudson River at Mean Low Water by Sections One Mile in Length from the State Dam at Troy to Hudson City, and also the Increase in Volume for One Foot Rise of the Water Surface.

Section.		Volume (Million Cubic feet).	Increased Volume for One Foot Rise (Million Cubic Feet).			
Miles from the Battery.	Miles from the Troy Dam		0 Ft. to 5 Ft.	5 Ft. to 10 Ft.	10 Ft. to 15 Ft.	15 Ft. to 20 Ft.
150–151	0– 1	19	5	6	7	8
149–150	1– 2	36	4	5	6	7
148–149	2– 3	26	4	5	6	7
147–148	2– 3	26	4	5	6	77
146–147	4– 5	31	7.	8	12	16
145–146	5– 6	41	7	10	12	16
144–145	6– 7	54	6	7	8	11
143–144	7– 8	55	6	7	8	9
142–143	8– 9	57	6	6	10	12
141–142	9–10	41	10	12	15	25
140–141	10–11	30	10	15	25	30
139–140	11–12	34	12	15	18	22
138–139	12–13	52	10	13	17	22
137–138	13–14	53	11	12	12	13
136–137	14–15	47	11	12	13	14
135–136	15–16	53	13	15	16	17
134–135	16–17	53	15	18	19	20
133–134	17–18	55	12	13	14	15
132–133	18–19	67	14	15	16	17
131–132	19–20	104	11	13	15	15
130–131	20–21	70	18	20	21	22
129–130	21–22	90	15	17	19	19
128–129	22–23	94	8	10	11	12
127–128	23–24	119	15	16	17	17
126–127	24–25	112	15	15	17	17
125–126	25–26	130	12	12	14	15
124–125	26–27	135	13	13	13	14
123–124	27–28	160	13	13	13	14
122–123	28–29	160	17	18	18	19
121–122	29–30	139	18	18	18	19
120–121	30–31	110	20	20	20	20
119–120	31–32	130	19	19	19	19
118–119	32–33	200	25	25	25	25
117–118	33–34	178	23	24	25	25
116–117	34–35	248	22	22	22	22
115–116	35–36	...	..	..	..	..

NOTE.—Data compiled from the charts of the United States Coast and Geodetic Survey, from charts of United States Army Engineers and the maps of the United States Geological Survey. In some cases these were complemented by new measurements and soundings.

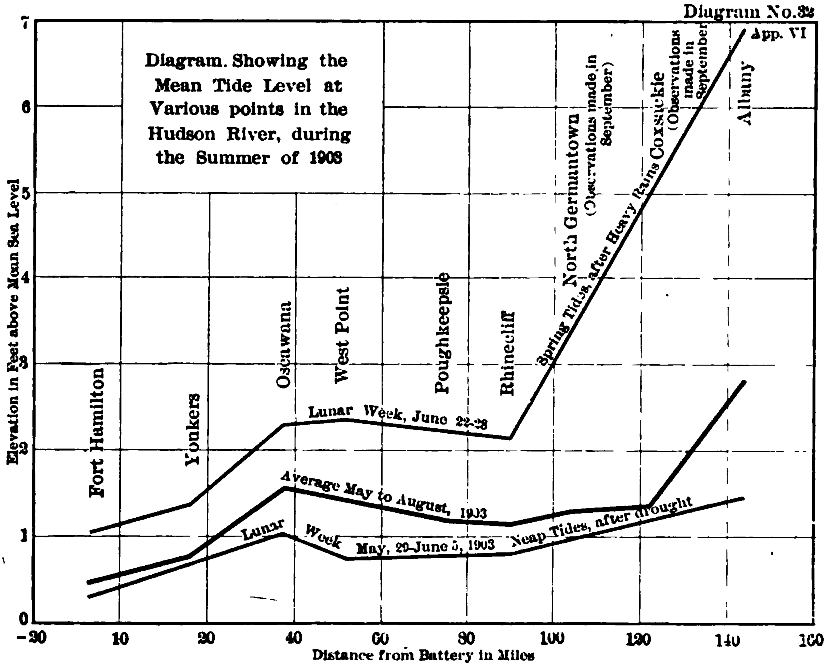
Tidal Phenomena.

The water of New York harbor rises and falls with the tide over an average range of about 4.8 feet. At Albany the average range is only about 2.5 feet. Between Albany and the Battery the average range is between these two limits, and varies according to locality, as shown in Table No. 18 and Diagram No. 31. It will be seen that near West Point the tidal range reaches a minimum, and near Germantown it reaches a maximum. The Germantown maximum is due chiefly to the meeting of the inflowing and outflowing tidal crests; the West Point minimum, to the effect of the constriction of the section below the tide-gauge.



The mean tide level of the water at Albany (excluding flood conditions) is in round numbers about 2.5 feet above the mean sea level of New York harbor. From Albany down to a point near Rhinecliff the river under ordinary conditions has a gradually decreasing slope, which averages about .03 feet per mile. Below Poughkeepsie the mean tide level increases slightly, due apparently to the constriction of the river bed in the vicinity of West Point, where the river passes through the Highlands. From Haverstraw Bay to the ocean the water surface slopes gradually at an average rate of about 0.025 feet per mile. There are, therefore, three natural divisions of the lower Hudson which differ in the slopes of their mean tide levels. This is shown by Diagram No. 32, which gives the average mean tide level from May to

August, 1903, the mean tide level during the lunar week from May 29 to June 5, when the river was unusually low, and the mean tide level during the lunar week June 22 to 28, when the river was high. It will be noticed that in all three cases the profiles are similar in character.



It may be inferred from these profiles—and with a considerable degree of probability—that the influence of the salt water will not be felt in the third section of the river where the slope of mean tide level is seaward. The lower boundary of this section probably lies somewhere between Rhinecliff and North Germantown, as may be seen from the tidal ranges as well as from the profiles. The boundary is naturally not an exact one, but varies according to different conditions.

It takes about nine hours fifty minutes for the crest of the tidal wave to run from Fort Hamilton to Albany, but the trough of the waves moves more slowly, requiring eleven hours and twelve minutes to reach Albany. The difference is due to the flow of the stream. In New York harbor the flood and ebb tides are of about equal duration, but as one goes up the river he will find the duration of the ebb tide increasing, until at Albany the tide falls for seven hours eighteen minutes and rises for four hours forty-two minutes in each half day. These differences are shown for different places in Table 18. When the crest of the wave has reached the Troy dam it recedes, and at a certain point down the river it meets the crest of the next tidal wave; and in a similar way the troughs meet. There are indications that the difference of tidal range shown in Diagram 31 are due in part to this phenomenon, although the variations in the capacity of the river bed along its course, and perhaps other factors, also affect this.

The tidal observations obtained during the past summer are so voluminous that time has not permitted them to be completely worked up in time for this report.

Five self-registering tide gauges made by Mr. J. P. Frieze, of Baltimore, Md., were maintained at Yonkers, Oscawana, West Point, Poughkeepsie and Rhinecliff from the middle of May to the last of October, except that on September 1 the Oscawana and Yonkers gauges were transferred to North Germantown and Coxsackie respectively. In addition to these we have been kindly furnished with the records of the United States Coast and Geodetic Survey gauges at Fort Hamilton, the records of the Dock Department gauge at Pier A, North River, and of the War Department gauges at Albany. In addition to these continuous records, many staff-gauge readings were made at various times and places in connection with current studies and chlorine determinations.

TABLE No. 18.

Summary of Tidal Observations, 1903.

Distance from the Battery in Miles.		Lunatidal Interval.		Differences of Time from Fort Hamilton.		Length of Flood Tide.	Length of Ebb Tide.	Height in Feet.			
		High Water.	Low Water.	High Water.	Low Water.			High Water.	Low Water.	Half Tide Level.	Mean Range.
				H. M.	H. M.	H. M.	H. M.				
7	Fort Hamilton †	7–16	1–42	0	0	6–04	5–56	2.97	—1.88	0.50	4.85
16	Yonkers ††	9–10	3–15	1–36	1–33	5–55	6–05	2.74	—1.22	0.78	3.96
38	Oscawana ††	10–23	4–41	2–37	2–39	5–42	6–18	3.68	— .60	1.58	3.08
52	West Point ††	11–23	5–39	3–37	3–57	5–44	6–16	2.73	— .01	1.44	2.72
75	Poughkeepsie ††	0–44	7–05	4–58	5–23	5–39	6–21	2.69	—0.14	1.20	2.83
90	Rhinecliff ††	1–08	7–48	5–12	6–36	5–20	6–40	2.99	—0.57	1.17	3.56
105	North Germantown *	1–48	8–35	6–03	6–53	5–14	6–46	3.29	—0.70	1.31	3.99
122	Coxsackie *	2–56	9–51	7–10	8–09	5–05	6–55	3.22	—0.42	1.38	3.64
143	Albany †††	5–36	0–54	9–50	11–12	4–42	7–18	4.05	—1.56	2.81	2.49

† April to July, inclusive. †† May to August, inclusive. ††† May to July, inclusive. * September only.

It was found that the wind exerted a very important influence upon the tides in the harbor and in the Hudson. A wind blowing for several hours from the east at a velocity of 20 miles per hour would tend to raise the tide level more than a foot above what it otherwise would have been. This is shown in Diagram No. 33, on which are plotted the height of the predicted and observed tides at Fort Hamilton for each day of the month of February, and also the velocity of the wind reduced to its east and west components and its north and south components. This month was selected because of the frequency of the east and west winds. Similar observations continued through the summer are on file. They show that the east and west winds exerted a greater effect than the north and south winds for a considerable distance up the river. During April, when a strong east wind blew for four days, the mean tide level in the harbor was raised 2.5 feet, and that at Poughkeepsie 1.5 feet. At times the effect of the wind more than outweighs the astronomical conditions which govern the height of the tides. Thus a heavy easterly storm occurring at time of neap tides will cause higher tidal levels than are found ordinarily at time of spring tides. The exceptionally high tides happen when a long easterly gale occurs at time of spring tides. This was the cause of the phenomenal high tides which occurred on October 9 and 10, 1903, and which did so much damage in New York harbor.

A formula showing the relation between wind and height of tide at various points in the river is being prepared, but is not yet ready for publication.

Computations have been made to show the quantity of water discharged by the Hudson River at the Troy Dam and at the Battery. These were based upon data kindly furnished by Mr. Robert E. Horton, hydrographer of the United States Geological Survey, which included the daily discharge of the Hudson River at Mechanicsville, the Mohawk River at Cohoes, and several of the smaller tributaries below the Troy Dam. The results of these computations are on file among the records of the department.

They show that during the past summer unusual hydrographic conditions have prevailed over the Hudson River Valley—conditions which have not been favorable for acquiring information relative to the upward run of salt water in the river. Taken as a whole, the season has been an unusually wet one. May, however, was an exceptionally dry month, and by the 1st of June the flow of the Hudson had approached its ordinary summer minimum. At one time in March the flow of water over the Troy Dam was as high as 101,000 second feet, and the discharge at the Battery was estimated as 150,000 second feet, but in May the minimum yield at the Troy Dam was estimated as 3,000 second feet and at the Battery 4,200 second feet.

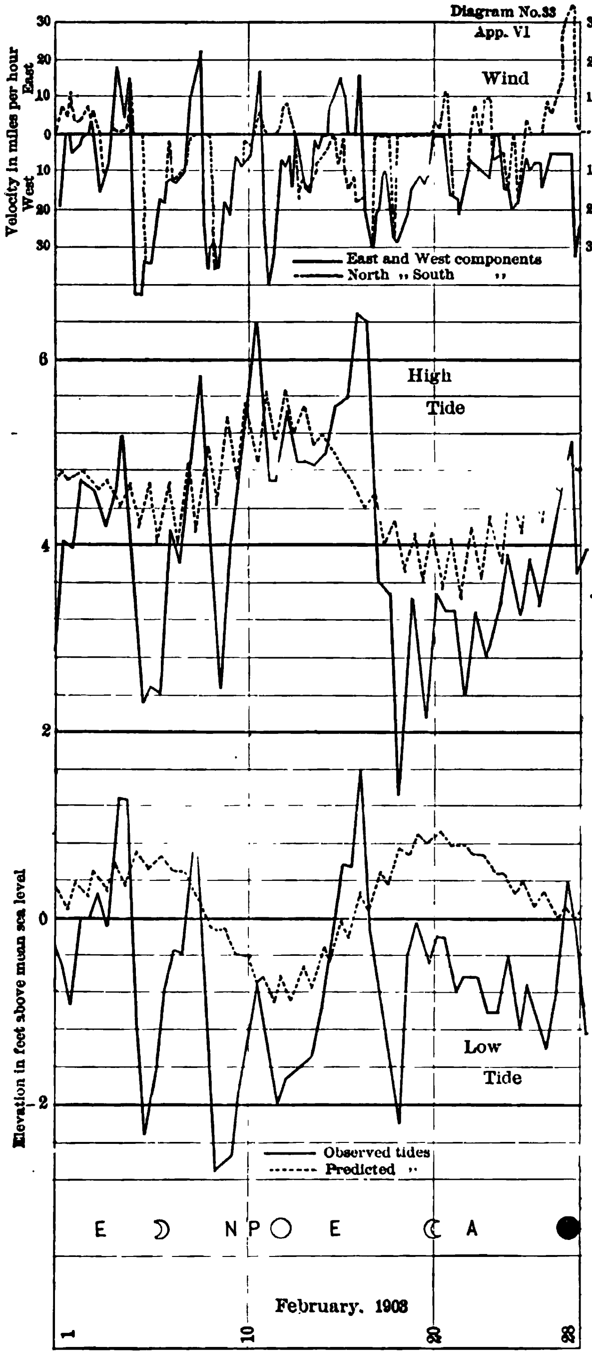


Diagram Showing the Effect of the Wind on the Tide Elevations in New York Harbor (Fort Hamilton)

During June there was a series of heavy rains, which caused the flow to increase to 48,000 second feet at the Troy Dam and 85,000 second feet at the Battery. Frequent rains fell at intervals during the rest of the summer, so that at no time did the river shrink to its usual dry weather volume. Consequently the upward run of salt water was less than usual.

Saltness of the Hudson River Water.

Ordinary sea water, collected off the coast opposite New York, at such a distance as not to be affected by fresh water from the land, contains about 18,500 parts per million of chlorine. In the harbor, however, the chlorine is much less than this. It seldom exceeds 16,000, and is often less than 10,000, even at the Narrows. That is, the Harbor water is at times only about one-half sea water, and is seldom more than 85 per cent. as salt as the water of the ocean.

The salinity of sea water is not a constant quantity. It varies in different localities and changes according to currents and seasons. Near the coast it is influenced by the fresh water discharged by numerous streams.

TABLE 19.

Table Showing the Salinity of Sea Water at Various Places in the Atlantic Ocean and Mediterranean Sea.

1903 Date of Collection.		Latitude.	Longitude.	Chlorine Parts per Million.	Remarks.
Date.	Hour.				
April 15	7.00 p. m.	......	....	21,350	Mediterranean Sea, 25 miles west of Tschia, Italy.
" 15	6.30 "	40° 10	12° 40′ E.	20,850	Mediterranean Sea, 60 miles west of Tschia, Italy.
" 15	12 00 m.	39° 42′	11° 33′ E.	21,250	Mediterranean Sea.
" 14	" "	38° 09′	4° 57′ E.	20,850	" " "
May 3	" "	37° 31′	4° 02′ E.	20,650	" " " 35 miles north of Cape Bengut, Algeria.
April 13	" "	36° 45′	1° 24′ W.	21,300	Mediterranean Sea, 27 miles east of Cape Merede Roldan, Spain.
May 4	" "	36° 38′	1° 59′ W.	20,200	Mediterranean Sea, 5 miles from coast of Spain.
" 5	" "	36° 28′	7° 30′ W.	20,750	25 miles from Cape St. Mary, Portugal.
April 12	" "	36° 37′	7° 44′ W.	20,700	21 " south of " " "
" 11	" "	37° 57′	14° 09′ W.	20,400	
" 10	" "	38° 55′	20° 38′ W.	20,350	
" 9	" "	39° 47′	27° 31′ W.	19,950	45 miles north of Graciosa, Azores.
" 8	" "	40° 27′	34° 12′ W.	19,850	
" 7	" "	40° 38′	40° 49′ W.	19,850	
May 11	" "	39° 40′	46° 16′ W.	20,150	In the Gulf Stream.
" 12	" "	40° 50′	53° 04′ W.	20,150	" " "
April 6	" "	40° 32	48° 07′ W.	20,150	" " "
" 5	" "	40° 08′	55° 09′ W.	19,950	" " "
" 4	" "	40° 35′	62° 00′ W.	20,500	" " "
May 14	" "	40° 12′	66° 40′ W.	19,850	120 miles east of Nantucket.
April 3	" "	40° 10′	68° 44′ W.	18,150	
" 2	11.00 p. m.	40° 13′	72° 20′ W.	18 100	50 miles off coast.
" 2	9.00 "	40° 20′	73° 00′ W.	17,800	25 " " "

Samples collected by William Hanks, Captain of the "Sicilian Prince," Prince Line.

TABLE 20.

Table Showing Salinity of Sea Water at Various Places in Long Island Sound and Off New England Coast.

Date of Collection, 1903.	Hour.	Specific Gravity.	Chlorine Parts Per Million.	
Mar. 31 ..	5.45 p. m..	1.0166	12,075	Just outside Hell Gate.
" 31 ..	7.00 " ..	1.0187	13,325	Off Sands Point, Long Island Sound.
" 31 ..	8.30 " ..	1.0191	13,725	Off New Haven.
Apr. 1 ..	7.00 a. m...	1.0242	17,425	Off Nantucket.
" 1 ..	8.30 " ..	1.0245	17,575	Off Monomoy Point.
" 1 ..	10.30 " ..	1.0245	17,575	Off North Point, Cape Cod.
" 1 ..	12.00 m	1.0252	18,275	About 30 miles northeast of Northern Point, Cape Cod.
" 1 ..	1.30 p. m..	1.0251	18,475	About 40 miles east of Cape Ann.
" 1 ..	3.30 " ..	1.0238	17,250	About 30 miles east of Cape Porpoise, Maine.
" 1 ..	5 00 " ..	1 0223	16,500	Off point of Cape Elizabeth, Maine.

Through the courtesy of Captain William Hanks, of the Prince Line, we have had an opportunity to analyze samples of sea water, collected at various points in the Atlantic Ocean and Mediterranean Sea, between New York and Tschia, Italy. The results of chlorine determinations are given in Table No. 19. They show that the salinity is somewhat greater in the Mediterranean Sea than in the Atlantic Ocean; that it is greater in the Atlantic Ocean near the European coast than it is near the American coast; that it is greater in the Gulf Stream than in the adjacent regions either east or west of it; and that it decreases as the American coast is approached.

Another set of samples was kindly furnished by Mr. Arthur W. Walker, extending from New York to Portland, Me., through Long Island Sound. The results of chlorine determinations on these samples are given in Table No. 20. They show that the salinity of the water in the Sound is much less than in the Atlantic Ocean off the coast. Mr. H. W. Clark, chemist to the Committee on the Charles River Dam, Boston, Mass., states in his report to that Committee that on November 11, 1902, a sample collected 6 miles east of Boston Light off the Massachusetts coast contained 18,130 parts per million of chlorine. In 1865, 1867 and 1871, specific gravity determinations of sea water in Long Island Sound gave densities which were equivalent to the following salinities:

Year.	Location.	Parts per Million of Chlorine.
1865	"In 'the Race' at eastern end of Sound"...................	16,300
1871	" "	17,300
1865	"In Vineyard and Nantucket Sounds"........................	16,000
1867	"On Chord of Great Bay between Nantucket and the Cape of Delaware"..	17,300

From such observations as are available it seems probable that the normal salinity of the sea water off the coast opposite New York, and at such a distance as to be unaffected by the influence of rivers, is about 18,500 parts of chlorine per million, and this may be taken as a fair standard of comparison for estimating the per cent. of fresh water in the water of New York Harbor and the Hudson River.

The following is a chemical analysis of the mineral constituents of sea water, as given by Prof. Vivian B. Lewis:

	Parts Per Million.
Sodium chloride	26,430
Magnesium chloride	3,150
Magnesium sulphate	1,783
Calcium sulphate	1,330
Silica	120
Calcium carbonate	56
Magnesium carbonate	tr.
Oxide of Iron	tr.
Total	32,869

While this analysis is far from complete, it serves to give an idea of the most important constituents.

Sea water is characterized by its salt and bitter taste. The former is due chiefly to the sodium chloride and the latter to the magnesium chloride present. In order to determine what degree of dilution of sea water could be recognized by the taste, a series of experiments upon different individuals was made. It was found that 500 parts per million of pure sodium chloride (containing 300 parts of chlorine) gave a distinct recognizable salt taste, while 100 parts per million of magnesium chloride (containing 50 parts of chlorine) gave a distinct bitter taste. Sea water diluted to such a point that it contained 100 parts per million of chlorine gave a bitter taste easily recognized as due to sea water. Calcium carbonate gave an alkaline taste with 400 parts per million, and magnesium carbonate with only 200 parts per million.

Sea water, when diluted with the fresh water of the Hudson River, may be divided for convenience into classes according to the degree of dilution—thus:

No.	Chlorine in Parts per Million.	Name of Class.
1	0 to 5	Fresh.
2	5 to 20	Sub-muriatic.
3	20 to 100	Muriatic.
4	100 to 1,000	Sub-brackish.
5	1,000 to 5,000	Brackish.
6	5,000 to 18,500	Salt.

In the first class, the chlorine is too low to cause any trouble in a public water supply; in the second, it would cause some trouble in boilers; in the third, it would cause much trouble; in the fourth, it would cause the water to taste salt and bitter; in the fifth and sixth, it would render the water entirely unpalatable.

The amount of salt water in New York Harbor varies, of course, in different parts and at different times. This is shown by the chlorine determinations in Table 21. A study of these results and other data on file in the laboratory in connection with the movement of the water in the harbor and its effect on the problem of sewage disposal would be interesting, but would lead too far afield.

TABLE 21.

Table Showing the Salinity of Sea Water in New York Harbor Together with the Turbidity, Color, Albuminoid and Free Ammonia.

Date of Collection.		Chlorine.	Turbidity.	Color.	Nitrogen as		Per Cent. of Fresh Water in Sample.	State of Tide.	Remarks.
Date.	Hour.				Albuminoid Ammonia.	Free Ammonia.			
Feb. 27	1.45 a. m.	16,250	1	7	.076	.064	12	Flood.	Atlantic Ocean, 3 miles southeast of Sandy Hook Lightship.
" 26	11.45 p. m.	14,700	2	8	.092	.052	21	Ebb.	Lower Bay, opposite Sandy Hook Light.
" 27	2.55 a. m.	15,300	1	10	.108	.072	17	Flood.	Lower Bay, opposite Sandy Hook Light.
" 27	3.50 "	14,850	2	11	.088	.096	20	Flood.	Lower Bay, Rockaway Bell Buoy.
" 26	11.10 p. m.	12,450	3	11	.132	.128	33	Ebb.	" West Bank Light.
" 26	10.35 "	11,950	5	13	.112	.132	36	Ebb.	New York Harbor, Narrows.
" 27	5.10 "	9,800	5	18	.180	.144	47	Flood.	" "
" 26	10.05 "	11,225	4	11	.140	.084	39	Ebb.	New York Harbor, Robbins Reef Light.
" 27	5.40 a. m.	11,225	9	23	.260	.170	39	Flood.	New York Harbor, Robbins Reef Light.
" 26	9.00 p. m.	9,800	5	21	.152	.124	47	Ebb.	Hudson River, at Battery.
" 27	6.15 a. m.	8,150	7	22	.180	.144	56	Flood.	" "
" 26	8.20 p. m.	7,200	8	19	.164	.168	61	Ebb.	Hudson River, opposite Thirtieth street.

On February 26 high water occurred Governor's Island 7.28 p. m.
On February 27 low water occurred Governor's Island 1.48 a. m.
On February 27 high water occurred Governor's Island 7.42 a. m.

Observations made in January showed that the water of the Hudson River was fresh down to a point somewhere below the Tappan Sea. On January 10, 1.00 P. M., a sample collected at the surface of the water off One

Hundred and Twenty-fifth street contained only 1,600 parts per million of chlorine. On January 20 samples collected between Yonkers and Tarrytown gave the following results:

Date.	Hour.	Chlorine. (Parts per Million.)	Locality.
January 20, 1903..........	11.30 A. M..........	129	Yonkers.
" "	1.00 P. M..........	106	Hastings.
" "	2.00 P. M..........	116	Dobbs Ferry.
" "	3.15 P. M..........	82	Irvington.
" "	4.00 P. M..........	38	Tarrytown.

On January 27, the chlorine at Fort Washington at 12.15 P. M. was 5,900 parts per million, and on January 30 the sea water had so far run up the river that at Piermont, the water contained 1,200 parts per million. It then retreated, until on February 6 samples collected at Yonkers contained less than 100 parts. On February 10 samples at One Hundred and Twenty-fifth street contained from 1,200 to 3,000 parts per million. From February 17 to 20 a series of hourly samples was collected at Sneden's Landing, and the chlorine was found to vary from 10 to 90, according to the state of the tide.

During March the discharge of the river was large. The river water at Yonkers contained but little salt, and even at Fort Washington the chlorine did not exceed 1,000 parts per million.

TABLE 22.

Table Showing the Amount of Chlorine in the Water of New York Harbor at Various Places and at Different Hours on March 3, 1903.

Chlorine Parts Per Million.

Time and Hour.	Narrows.	Hudson River at Battery.	Hudson River at 130th Street.	Hudson River at Spuyten Duyvil.	Hudson River at Alpine.	Hudson River at Hastings.	East River at Brooklyn Bridge.	East River at Blackwell's Island.	Harlem River at First Avenue.	Harlem River at Spuyten Duyvil.
8 a. m ...	4,700	2,020	101	23.6	7.3	15.6	7,350	11,600	8,900	21.
9 a. m ...	5,000	2,100	79	11.3	17.6	21.3	7,650	10,950	8,100	27.3
10 a. m ...	9,300	2,310	199	21.3	12.6	18 3	7,500	9,100	6,200	19.
11 a. m ...	10,150	2,820	174	39.3	16.0	16.6	9,450	8,150	3,400	14.
12 noon ..	10,100	3,350	299	90.3	19.3	18.3	9,300	6,750	2,350	142.
1 p. m ...	8,050	3,750	486	194.	21.0	11.3	9,000	7,200	4,975	174.
2 p. m ...	8,050	3,250	876	242.	26.0	11.3	7,750	8,800	8,250	115.
3 p. m ...	8,550	4,025	240	170.	34.3	15.3	7,200	10,700	9,600	116.
4 p. m ...	7,200	3,375	206	148.	35.0	15.6	5,750	11,200	10,250	178.
5 p. m ..	7,600	2.475	352	92.	26.0	16.0	7,700	11,300	10,650	2,575.
6 p. m ...	7,600	1,725	164	46.	20.0	15.6	5,450	11,600	10,300	328.
7 p. m ...	8,050	2,000	26	24.6	20.0	13 6	5,300	12,150	9,750	1,080.
Average..	7,852	2,767	267	99.2	21.3	15.7	7,435	9,958	7.727	433.

On this date high water occurred at Fort Hamilton at 10.12 a. m. and 10.46 p m.

Table 23.

Table Showing the Amount of Chlorine in the Water of New York Harbor at Various Places and at Different Hours on May 28, 1903.

Chlorine Parts per Million.

Time and Hour.	Fort Hamilton.	Hudson River at Battery.	Hudson River at Spuyten Duyvil.	Hudson River at Yonkers.	Hudson River at Hastings.	Hudson River at Croton Point.	Hudson River at Peekskill.	East River at Brooklyn Bridge.	Harlem River at 135th Street	Harlem River at Spuyten Duyvil.
8 a. m....	13,500	11,900	8,650	5,950	4,500	2,300	1,200	12,500	11,300	8,500
9 a. m....	13,600	11,800	8,650	5,950	4,600	2,200	1,200	12,500	10,500	8,500
10 a. m...	13,900	13,050	8,350	6,450	4,700	2,450	1,150	12,800	10,000	8,600
11 a. m...	14,050	12,850	7,750	7,350	5,250	2,400	1,150	12,850	10,500	8,300
12 m	14,000	13,250	7,800	7,000	5,350	2,400	1,100	12,750	11,300	7,750
1 p. m....	14,200	13,250	7,150	7,100	5,800	2,450	1,100	12,800	12,150	7,800
2 p. m....	14,000	13,350	7,150	6,950	5,650	2,400	1,100	12,750	12,600	7,150
3 p. m....	14,410	12,100	8,350	6,850	5,450	2,450	1,050	12,350	13,000	7,150
4 p. m....	14,100	12,100	8,900	6,200	5,200	2,350	1,050	13,000	13,000	8,300
5 p. m....	13,800	11,150	9,500	5,750	5,050	2,400	1,050	12,350	12,850	8,900
6 p. m....	14,100	11,150	7,300	5,400	4,700	2,450	1,050	12,450	12,650	9,500
7 p. m ...	13,500	12,150	......	4,450	4,250	2,300	1,100	12,500	12,650	......
Average..	13,946	12,517	7,955	6,283	5,041	2,379	1,108	12,646	11,958	8 247

On this date high water occurred at Fort Hamilton at 8.48 a. m. and 9 13 p. m.

About the middle of April the discharge of the river began to diminish rapidly, and during May, because of the drought, it continued to diminish. This caused the salt water to run up the river. From March 23 until the middle of September, series of samples were collected almost every week from New York City to Poughkeepsie, at intervals of about one mile. Generally

Table No. 24.

Table Showing the Distance from the Battery in Miles at which Different Amount of Chlorine Were Found in the Hudson River.

(Samples Collected at the Surface.)

Chlorine in Parts per Million.	March 23.	April 3.	April 23.	May 28.	June 13.	June 30.	July 11.	July 22.	July 25.	August 1.	August 8.	August 15.	August 22.	August 29.	September 5.	September 12.
5000...............	2	0	3	20	15	0	8	13	18	5	11	4	17	2	9	4
1000...............	9	12	39	50	42	15	10	34	35	29	34	19	32	22	26	17
500...............	13	14	44	55	45	18	11	35	41	36	35	26	34	26	32	19
100	26	17	50	58	55	19	20	43	43	41	50	36	51	35	35	29
20	28	19	51	66	60	20	32	45	45	50	51	51	54	38	41	32
5...............	35	29	55	71	69	42	41	62	71	66	66	60	59	54	66	66

two sets of samples were taken, one at high tide and one at low tide. The time schedule of the steamers did not permit them to correspond exactly with the times of high tide and low tide, but followed them with a fair degree of approximation. The results of these analyses are on file in the Department records, and in place of their voluminous tables, a summary is given in Table 24, which shows the distance up the river in miles from the Battery, where the chlorine was found equal to certain quantities.

The salt attained its highest run during the last of May and the early part of June, before the heavy rain came. On May 28 the water was brackish nearly to West Point, and it was submuriatic at New Hamburg, which is only about nine miles below Poughkeepsie. When the discharge of the river increased in June, the brackish water fell back to Fort Washington, and no submuriatic water was found above the Tappan Sea. Later in the year the brackish water ascended the river to Croton Point, and the submuriatic water to West Point, but at no time was there a suspicion of sea water at Poughkeepsie. It must be remembered, however, that the summer of 1903 was unusually wet, and that with the ordinary dry weather flow of the stream the water at Poughkeepsie frequently becomes muriatic, and probably at times sub-brackish.

The above figures for chlorine all refer to surface samples, and most of them were collected in the centre of the stream. It is a well-known fact, however, that the salt water runs up the stream faster at the bottom than at the surface, so that in a vertical section the chlorine increases from top to bottom. This phenomenon, known as the "under-run," is especially noticeable on the floodtide. Many observations have been made to determine the extent of the under-run in the Hudson River, the results of which are on file in the Laboratory.

The earliest studies on the phenomenon of the under-run of the salt in the Hudson River were made by Prof. Mitchell and H. L. Marinden, and published in the reports of the United States Coast and Geodetic Survey for 1873 and 1887. Further investigations of the subject were made by Mr. John R. Freeman on the Charles River, at Boston, Mass., in connection with his investigations on the Charles River Dam. Both of these investigations, however, were confined to the lower portions of the streams where the water contained relatively large amounts of chlorine. The observations made during the present summer corroborate most of the earlier results, but show that the phenomenon is confined to those portions of the river where the chlorine is comparatively high, and decreases in importance upstream.

On January 27, 1903, samples collected at Fort Washington gave the following results, the tide being at three-quarters ebb:

TABLE 25.

Table Showing the Amount of Chlorine at Different Depths at Fort Washington on January 27, 1903.

Depth in Feet.	Temperature (Fahr.).	Chlorine Parts per Million.
0	33	5900
15	33	9150
30	34	8900
45	36	10200
55 (bottom)	36	12300

In the early researches on the under-run in the Hudson much stress was laid on the effect of the "pockets" on the salt problem. It was claimed that the under-run of the sea water caused these pockets to become filled with brackish water, which was left unchanged when the under-run retreated. The theory is an interesting one, and deserves further investigation, but although many observations were made in the pockets during the past season, in only one instance was the water found to be other than fresh. On January 17 the water in Peekskill pocket had one to two parts of chlorine at all depths down to 125 feet. The same was true of the West Point (180 feet) and New Hamburg (80 feet) pockets on January 21 and 22. On January 22 the Poughkeepsie pocket (60 feet deep) contained 2.0 parts of chlorine at all depths. On February 11 samples were taken every 10 feet from 0 to 90 feet in the New Hamburg pocket, and the chlorine was 1.6 parts per million in all cases. On the same day the chlorine in the West Point pocket varied from 1.2 at the surface to 1.4 at the bottom (150 feet). In June, after the salt had run for a considerable distance up the river and then retreated, all the pockets were reinvestigated and found to contain no large amounts of chlorine. The following observations were made at that time:

Date, 1903.	Hour.	Pocket.	Chlorine.			
			Surface.	50 feet deep.	100 feet deep.	150 feet deep.
June 23...	4.30 P. M.	Peekskill	6	6	6	6
" 24...	7.15 A. M.	West Point	7	8	6	5
" 24...	11.10 A. M.	New Hamburg	7	10	8	*

* Sample lost, but it was not salt.

Samples taken at various places across the stream showed that the chlorine is often higher near the shore than in the centre of the stream. The differences were not marked, however, except during the time of ebb tide, when the strongest outward flow was passing down the main channel. At times during flood tide the water in mid-stream contained the higher chlorine.

To establish a relation between the tidal and hydrographic conditions of the Hudson River has been found a difficult matter, as the phenomena are subject to endless complications, and the final results here presented, even though based upon observations covering a period of several months, must be accepted with some hesitation. The controlling influence upon the in-run of sea water is the stream flow. The tides exert but a secondary influence, although daily fluctuations in the saltness of the water may be caused by them. If there is enough water flowing over the Troy Dam and from the watershed of the Lower Hudson, the influx of sea water may be kept below any desired point between Poughkeepsie and Kingston.

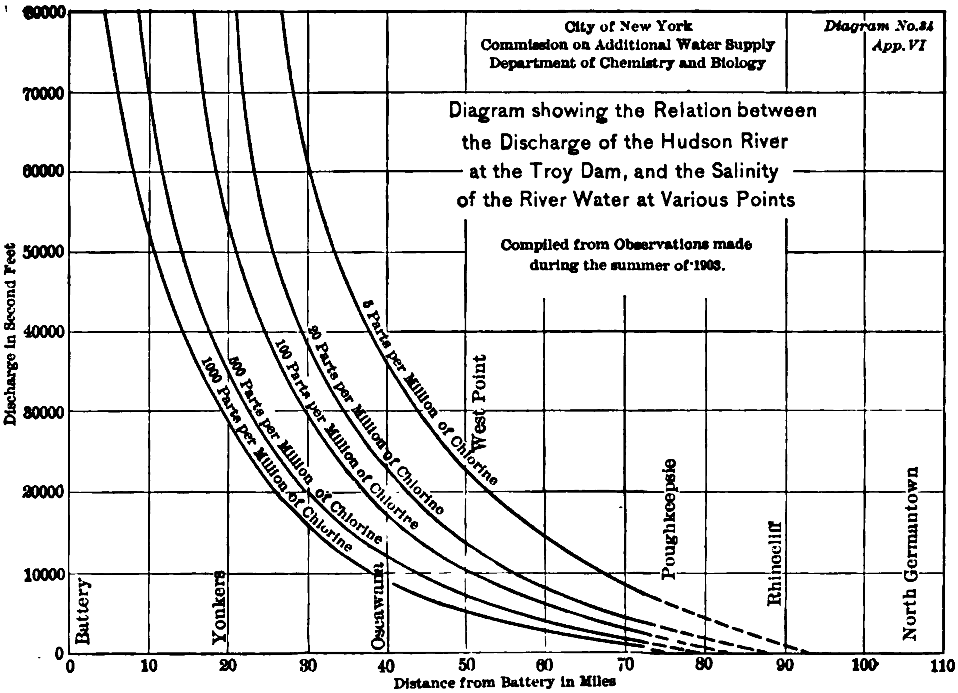


DIAGRAM 34. APP. VI.

This is illustrated in Diagram No. 34, which represents the probable limits of the influx of salt water under ordinary unfavorable tidal conditions for different stream flows. Under the conditions of dry weather flows, when the discharge at the Troy Dam falls to about 3,000 second feet, the water of the Hudson at Poughkeepsie may contain 20 parts per million of chlorine. With smaller discharges the chlorine may increase to 500 parts per million. The practical northerly limit of the sea water influx probably lies a short distance below Rhinecliff. It is not likely that the water above that point is ever likely to become objectionably muriatic, although under phenomenal conditions, such as might occur once or twice in a generation, there seems to be no reason why the influence of the sea water may not extend nearly to North Germantown. Such a condition, however, would probably be of very short duration. It would be taking some risk to locate the intake of a water supply system for New York City south of Hyde Park, unless such provisions for storage were made as would allow pumping to be discontinued if the water became sub-muriatic, or unless compensating reservoirs could be built in the Upper Hudson sufficient to prevent the minimum flow at the Troy Dam from falling below 2,000 or 2,500 second-feet.

The effect of the tide on the inflow of salt is potent during short periods of time, but it does not permanently affect the conditions. For example, the limit of the sub-brackish water may lie in the vicinity of West Point for several days, varying within slight limits as the tide rises and falls, when suddenly an exceptionally high tide, caused either by the wind or by a combination of favorable astronomical conditions, may force the sea water upward and carry the limit of sub-brackish water several miles higher up. This sometimes occurs in the space of a few hours.

Ordinarily the late summer, when the stream flow is lowest and when the general tidal elevations in the harbor are highest, is the most favorable time for a high run of salt. At other seasons some of the conditions tend to neutralize each other. Thus, during the recent storm of the 9th of October the effect of the easterly gale and high tide in the harbor was more than offset by the great discharge of the stream. This effectually prevented an influx of sea water.

During the winter, however, a condition sometimes exists in the river which offers most favorable conditions for the in-run of salt water. When an ice-jam forms at some point near New Baltimore, for example, the cakes slide under each other and become lodged so as to form a sort of submerged dam which materially reduces the flow of the stream. Under these conditions the discharge of the river at Poughkeepsie may be even lower than the ordinary dry weather flow, and if a spring tide and a high easterly wind should occur at a time when the river was thus closed with ice, the effect upon the salinity of a water supply taken from a point below Rhinecliff might be serious. The condition, however, is largely a preventable one, and naturally would be one of short duration.

If, as there is reason to believe, the land in the vicinity of New York is settling at the rate of something like a foot in a century, the inflow of the sea water in the Hudson River will tend to increase. No precise statement of the effect of such changed condition can be made before the results of the tidal observations have been worked up in detail. Certain it is, however, that its effect would be by no means a negligible quantity. This fact will be readily appreciated by a careful study of the diagram showing the river slopes (Diagram No. 34).

Should the use of the Hudson River water as a source of supply for New York ever be determined upon, it would be necessary to study more minutely the tidal condition in the vicinity of Hyde Park. At least a dozen automatic gauges would be needed between Poughkeepsie and Albany, with elevations carefully determined by a line of precise levels.

Pollution of the Hudson River.

That the water of the Hudson River is polluted needs no scientific demonstration, but the ocular evidences are abundantly confirmed by chemical and bacteriological analyses of the water and by statistical studies of the population on the watershed and the prevalence of typhoid fever. The fact is equally true, however, that the effects of pollution can be removed by proper filtration, and the water made safe and wholesome. Both of these propositions have been given much study.

Data have been collected at all the important centres of population on the watershed above Poughkeepsie, covering the nature of the water supplies and sewage systems, the character and extent of the industrial establishments and the nature of their waste products, all of which are on file in the department records. From the sanitary standpoint the most important sources of pollution are the sewers of the large cities, which directly contaminate the water with fecal matter. Most of the large cities are provided with sewers, and practically all of the manufacturing establishments situated near the stream have water-closets which discharge directly or indirectly into the water. The urban population per square mile of watershed furnishes, therefore, a fair index of the degree of pollution of the stream.

The results obtained by a comparison of the population statistics and size of the drainage area above certain points on the river is shown by Diagram No. 35. This is similar in character to that drawn for the Mohawk River (see Diagram No. 19).

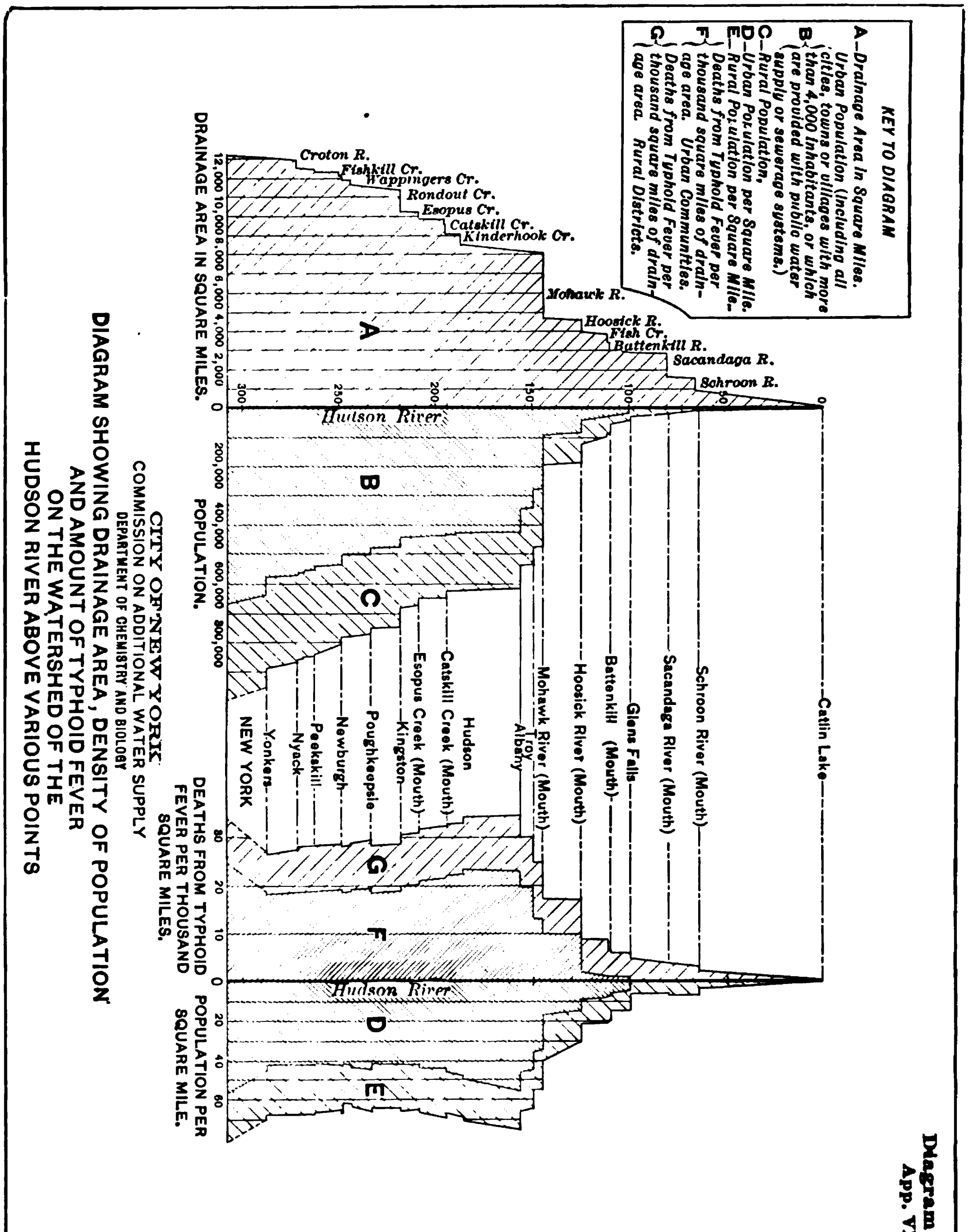


DIAGRAM SHOWING DRAINAGE AREA, DENSITY OF POPULATION AND AMOUNT OF TYPHOID FEVER ON THE WATERSHED OF THE HUDSON RIVER ABOVE VARIOUS POINTS

TABLE 26.

Deaths from Typhoid Fever in Cities and Towns in Hudson River Valley.

Town.	Miles by Water Above Battery.	Population.		Deaths from Typhoid Fever.										
		1890	1900	1894	1895	1896	1897	1898	1899	1900	1901	1902	Average.	Per 100,000 Population.
Rome	270	14,991	15,343	2	..	2	6	5	3	1	3	3	2.8	18
Utica	250	44,007	56,383	12	8	9	8	16	11	12	11	16	11.4	21
Frankfort	238	2,291	2,264	..	..	1	..	1	..	..	..	..	0.2	9
Ilion	236	4,057	5,138	..	..	..	1	2	2	..	1	..	0.7	14
Little Falls	225	8,783	10,381	1	12	4	2	2	2	14	3	4	4.9	49
Fort Plain	211	2,804	2,444	..	2	1	1	2	3	2	2	..	1.4	55
North Adams, Mass.	211	16,074	24,200	21	38	2	9	10	19	62	37	10	23.1	102
Williamstown, Mass.	207	4,221	5,013	..	9	5	18	13	4	29	12	..	11.3	233
Gloversville	201	13,684	18,349	5	8	6	6	6	4	10	1	10	6.2	36
Bennington, Vt.	199	3,971	5,656	1	3	4	6	3	2	1	2	1	2.6	49
Johnstown	199	7,768	10,130	2	2	7	3	6	2	3	..	2	3.0	31
Glens Falls	194	9,509	12,613	3	2	4	6	3	3	6	9	5	4.6	38
Saratoga Springs	194	11,975	12,409	7	6	12	5	6	5	6	10	1	6.4	52
Ballston Spa	194	3,527	3.923	2	2	..	1	1	2	..	2	..	1.1	28
Hoosick Falls	187	7,014	5,671	2	1	1	1	2	..	3	1	..	1.2	20
Amsterdam	185	17,336	20,929	10	7	4	5	28	4	3	5	4	7.8	39
Schenectady	171	19,902	31,682	11	14	24	7	1	9	6	19	8	11.0	*26
Mechanicsville	162	2,679	4.695	1	..	3	4	1	1	5	2	2	2.1	49
Cohoes	151	22,509	23,910	12	18	13	13	28	21	27	14	32	19.8	84
Lansingburg	151	10,550	12,595	3	5	6	5	7	11	17	10	5	7.7	64
Green Island	148	......	4,770	6	3	..	2	3	1	6	4	..	2.8	59
Troy	147	60,956	60,651	35	38	28	20	51	48	76	32	32	40.0	66
Watervliet	147	12,967	14,321	18	11	11	13	6	15	11	8	9	11.3	80
Albany	143	94,923	94,151	52	162	97	84	94	82	38	20	29	73.1	**31
Rensselaer	142	7.301	7,466	8	6	10	5	11	8	7	5	8	7.6	102
Middletown	129	11,977	14,522	2	4	8	4	6	3	2	3	8	4.4	31
Ellenville	119	2,881	2,879	..	4	..	..	3	..	..	..	..	0.8	28
Hudson	116	9,970	9,528	4	2	4	4	7	6	9	4	8	5.3	55
Catskill	110	4,920	5.484	1	2	1	1	..	9	1	5	3	2.6	48
Saugerties	101	4,237	3,697	1	..	1	1	..	1	..	1	1	0.7	18
Kingston	91	21,261	24,535	8	2	6	3	1	7	2	3	4	4.0	17
Poughkeepsie	74	22,206	24,029	14	10	5	10	5	6	11	10	4	8.3	35
Newburg	60	23,087	24,943	4	7	15	6	4	12	11	6	12	8.6	35
Fishkill Landing	59	3.617	3.673	3	3	2	1	2	..	2	1	..	1.6	44
Matteawan	57	4,278	5,807	3	3	2	1	2	..	2	1	..	1.6	29
Peekskill	44	9,676	10,358	..	1	1	2	2	..	1	3	3	1.4	14
Haverstraw	36	5.070	5.935	3	2	1	2	..	2	..	1	2	1.4	24
Ossining	32	10,058	10,895	2	3	2	..	..	1	2	3	3	1.8	17
Nyack	29	4,111	4,275	..	..	..	4	2	1	1	1	..	1.0	24
Tarrytown	28	3,562	4.770	..	..	..	..	..	..	..	..	..	..	..
Yonkers	22	32,033	47,931	11	8	5	5	6	5	2	7	4	5.9	13

The prevalence of typhoid fever on the watershed and especially in the several towns, must have a marked effect on the dangerous character of the pollution. Of two sewered cities equal in size that one will be most dangerous as a source of pollution which has the highest typhoid fever death-rate. Hence, careful attention was given to the history of typhoid fever in the Hudson Valley. The general results are embodied in the diagram already referred to, in which the number of deaths for typhoid fever per 1,000 square miles of drainage area is shown. Table 26 also shows the death rates for some of the most important cities on the watershed. The diagram

* 1897–1902 inclusive; 1894–1896 rate was 63: source of water supply changed from Mohawk river to springs in 1897.

** 1900–1902 inclusive; 1894–1899 rate was 101; filters installed in 1900.

shows one fact which is contrary to the popular idea—namely, that the degree of pollution of the river between Hyde Park and Kingston is no greater than it is above the City of Albany, where the water is taken for public supply. This is because the addition of relatively pure water to the river from the subsidiary watersheds more than makes up for the sewage pollution received at Albany and elsewhere. In this statement, however, no account is taken of the possibility of pollution being carried upstream from New York harbor and the cities and towns along the lower river. An intake so located as to be above the northerly limit of the salt water inflow would practically escape the danger of pollution from the harbor, and would be but slightly affected by any of the downstream sources. Should the river be selected as a source of supply for New York City, it would be a wise course to provide all the cities on the Lower Hudson with proper systems of sewage disposal in order to reduce to a minimum the danger from immediate pollution. It would be advisable also to control as far as possible the discharge of fecal matter into the river from boats on the river. At present several thousands of people are daily carried up and down the river to West Point, Newburgh and Poughkeepsie. Above that point there is less traffic. Canal boats, however, ply the whole distance between Albany and the harbor.

Quality of the Hudson River Water between Poughkeepsie and Kingston.

For the greater part of each year the water of the Hudson River cannot be considered as very turbid. It is never clear, however—samples collected below Albany seldom exhibiting a turbidity less than 4 or 5 on the silica scale. During the spring, the turbidity sometimes rises to more than 500. At Albany, where turbidity records have been kept for almost four years, the average turbidity has been found to be about 40. Tables 27A, B, C and D show the detailed results of these observations, taken in part and recalculated from the published reports of the Albany Water Works and in part from data kindly furnished by Mr. Leonard M. Wachter, Chemist of the City Filter. From the standpoint of filtration, it is chiefly the high turbidities and the length of the turbid periods that control the design of a filter plant. Data concerning the low turbidities are more valuable in connection with the operation of a filter than with its construction. Thus, with relatively clear water no sedimentation before filtration is necessary, with moderate turbidities and occasional high turbidities sedimentation basins are necessary, and their capacity must be regulated according to the length of the turbid periods, and the amount and character of the suspended matter. With very high turbidities, even sedimentation may not suffice, and a preliminary roughing filter or coagulation may be needed.

TABLE 27A.

Turbidity of Hudson River Water at Albany, N. Y.

(Parts per Million—Silica Standard.)

1900.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug	Sept.	Oct.	Nov.	Dec.
1	20	18	50	20	20	15	10	18	15	15	20	90
2	20	20	40	25	22	18	10	10	15	15	15	75
3	18	20	50	120	20	20	10	10	15	15	15	60
4	15	20	50	120	20	18	10	10	15	12	15	50
5	15	20	40	100	20	15	10	10	15	10	15	50
6	15	15	35	120	20	12	15	10	15	10	15	55
7	15	15	25	130	25	20	18	18	15	10	18	55
8	15	25	20	150	25	22	20	18	15	15	18	50
9	10	70	20	120	22	18	20	18	15	15	19	50
10	10	55	22	80	22	10	20	18	15	15	20	48
11	10	40	25	70	20	20	20	18	15	15	20	45
12	10	45	30	60	20	20	120	18	15	10	20	45
13	10	570	25	48	20	21	70	18	15	10	20	40
14	10	400	20	40	20	20	65	18	15	15	18	35
15	10	175	18	30	22	18	50	18	15	15	18	35
16	12	150	18	30	25	15	30	20	15	15	18	35
17	15	80	20	35	25	10	20	30	15	15	18	30
18	22	30	30	100	25	10	20	20	15	15	19	25
19	35	40	50	155	22	10	20	20	15	10	20	20
20	80	40	70	150	20	10	20	20	15	10	20	20
21	140	40	80	100	15	15	20	20	15	8	20	20
22	100	50	70	70	15	15	20	18	15	8	22	20
23	90	75	65	65	20	15	20	18	15	12	22	20
24	60	65	65	65	20	12	18	18	15	12	22	19
25	40	50	50	50	18	10	18	19	15	12	22	18
26	40	45	40	40	18	10	18	18	15	15	70	19
27	35	35	35	35	15	10	18	18	15	15	140	20
28	30	30	30	30	15	10	18	18	15	18	175	20
29	20	..	30	30	25	15	18	17	15	18	140	20
30	20	..	30	20	15	10	18	15	15	20	120	20
31	20	..	25	..	15	..	18	15	..	20	..	22
Average	31	81	38	73	20	15	25	17	15	14	37	36

TABLE No. 27C.

Turbidity of Hudson River Water at Albany, N. Y.

(Parts per Million—Silica Standard).

1901.

Day.	Jan	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	..	13	13	98	20	..	16	11	..	10	13	..
2	16	13	13	13	68	20	15	11	..	10	13	18
3	16	..	..	64	20	24	13	13	11	10	..	16
4	16	11	24	64	16	16	..	..	11	..	14	22
5	15	11	32	90	..	16	28	11	11	14	..	18
6	..	13	32	98	24	15	20	13	13	..	14	18
7	11	11	22	..	22	23	..	32	13	13	16	16
8	9	13	20	236	16	90	13	47	..	14	16	..
9	9	13	20	236	15	..	11	52	13	14	14	20
10	11	..	..	81	15	64	11	40	13	16	..	24
11	11	13	175	81	15	56	11	..	13	14	16	..
12	11	13	206	56	..	43	11	13	16	13	18	43
13	..	13	150	43	16	40	13	11	15	..	24	47
14	11	11	123	..	15	32	..	9	13	32	22	47
15	13	11	113	32	15	24	13	9	..	42	24	..
16	13	13	103	24	15	..	13	11	13	32	32	480
17	11	..	..	20	13	16	13	11	13	30	..	386
18	11	11	64	20	13	15	16	..	13	24	24	271
19	13	11	56	20	..	13	15	9	..	28	..	175
20	..	11	47	16	16	13	13	9	11	..	26	150
21	13	13	236	..	16	15	..	9	13	24	20	123
22	13	..	350	308	20	24	11	9	..	20	16	..
23	11	13	386	308	20	..	11	11	11	20	20	64
24	13	..	..	236	16	11	11	13	11	18	..	52
25	13	13	133	150	20	16	11	..	11	16	648	..
26	13	11	150	133	..	24	11	16	13	16	18	36
27	..	13	175	123	16	28	11	13	11	..	..	40
28	11	11	236	..	15	28	..	11	11	14	..	40
29	13	..	175	52	15	20	13	9	..	14	24	..
30	13	..	150	28	16	..	13	11	9	13	24	28
31	13	..	..	..	16	..	11	11	..	13	..	40
Average	12	12	123	103	17	27	13	16	12	19	47	91

TABLE 27C.

Turbidity of Hudson River Water at Albany, N. Y.

(Parts per Million—Silica Standard.)

1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	..	28	308	68	24	..	9	36	..	150	60	20
2	36	..	..	64	32	16	10	24	16	98	..	20
3	24	32	480	47	28	28	11	..	14	68	36	16
4	20	24	308	24	..	56	..	20	13	60	..	16
5	..	20	236	24	24	43	..	20	13	..	32	20
6	16	16	205	..	20	36		28	11	68	28	16
7	16	16	90	20	20	28	85	40	..	77	24	..
8	14	14	43	16	22	..	68	52	11	68	24	20
9	14	..	..	20	20	24	52	43	11	43	..	24
10	14	14	40	236	..	20	40	..	16	40	20	24
11	13	14	60	175	16	16	32	40	13	32	16	24
12	..	..	77	113	16	14	28	32	11	..	15	24
13	13	13	236	..	20	13	..	28	11	24	14	20
14	13	11	236	56	24	11	20	24	..	20	16	..
15	13	11	200	43	24	..	16	20	11	20	14	24
16	13	..	..	32	22	10	14	16	11	20	..	20
17	13	9	95	28	20	11	13	..	9	16	13	20
18	13	9	206	24	..	13	11	14	9	14	11	56
19	..	9	175	24	20	11	11	24	9	..	13	90
20	14	9	113	..	24	13	..	16	9	14	11	60
21	13	9	113	20	24	13	16	15	..	16	11	..
22	13	..	81	24	20	..	77	16	9	14	13	47
23	14	..	..	28	16	16	133	16	9	24	..	206
24	32	9	63	24	16	13	98	..	9	28	14	150
25	36	9	56	28	..	13	72	16	9	24	16	..
26	..	13	43	28	16	13	60	16	13	.	20	47
27	52	16	36	..	20	13	..	16	20	28	..	43
28	43	17	28	24	24	13	150	16	..	32	24	..
29	43	..	28	24	20	..	98	16	32	175	24	20
30	40	..	..	24	..	10	72	16	175	150	..	16
31	36	..	85	..	20	..	52	..	..	77	..	24
Average	22	15	140	48	21	19	50	24	19	52	20	41

TABLE 27D.

Turbidity of Hudson River Water at Albany, N. Y.

(Parts per Million—Silica Standard.)

1903.

Day.	January.	February.	March.	April.	May.	June.
1	..	..	..	90	16	14
2	13	52	386	98	14	14
3	13	60	236	68	..	16
4	..	68	150	60	13	14
5	16	77	98	..	13	14
6	32	60	90	40	13	14
7	32	43	56	43	11	..
8	24	..	..	40	11	14
9	16	32	175	98	9	11
10	16	16	308	60	..	14
11	..	16	308	47	9	16
12	16	32	271	..	11	13
13	14	56	236	36	11	14
14	14	60	206	36	10	..
15	14	..	..	32	10	52
16	13	40	60	32	11	43
17	13	47	43	28	..	40
18	..	28	40	28	11	36
19	13	16	36	..	11	32
20	13	14	32	24	11	28
21	16	13	32	20	13	..
22	14	..	..	20	11	108
23	16	11	236	20	11	98
24	16	11	308	16	..	85
25	..	11	271	16	13	81
26	16	13	123	..	13	64
27	16	36	77	20	13	40
28	16	..	56	20	14	..
29	16	..	..	20	14	24
30	16	..	43	16	..	20
31	77	..	43	..	..	..
Average	19	35	151	40	12	35

Table 28 shows the average number of days in a year when the turbidity of the water exceeds 25, 50, 100 and 200 at Albany. It will be seen from this that only for 7 per cent. of the time does the water have a turbidity above 50. The length of those periods, when the turbidity was above 50 or 100, are given in the following table (Table 29), from which it will be seen that the periods when the water has a turbidity above 100 are seldom more than one week long. Such a turbidity, however, continued for a week, is rather a heavy load for a slow sand filter to bear, and there have been times in the history of the Albany filter when the effluent was not perfectly clear. On the whole, however, the quality of the filtered water has been practically without turbidity.

TABLE 28.

TURBIDITY OF THE HUDSON RIVER AT ALBANY, N. Y.

An Estimate Based on Data Obtained from the Reports of the Albany Water Works for the Years 1889 to 1902, and from Information Furnished by Mr. Leonard M. Wachter, Chemist for the City Filter, During the Year 1903.

	Average Number of Days When the Turbidity of the River Water at Albany Exceeded			
	25	50	100	200
January	6	2	1	0
February	9	6	2	1
March	28	18	10	5
April	24	14	7	2
May	2	0	0	0
June	8	3	0	0
July	8	6	2	0
August	5	1	0	0
September	4	1	0	0
October	3	0	0	0
November	4	1	1	0
December	19	8	4	2
Total	120	60	27	10
Per cent. of entire year	32.9	16.5	7.4	2.7

Table 29.

TURBIDITY OF THE WATER OF THE HUDSON RIVER AT ALBANY, N. Y.

Table Showing the Number and Length of Periods When the Water Was Turbid, March, 1889, to September, 1903.

Length of Periods in Days When the Turbidity Exceeded 50.	Number of Periods.	Length of Periods in Days When the Turbidity Exceeded 100.	Number of Periods.
1	5	1	3
2	1	2	3
3	1	3	4
4	1	4	3
5	3	5	5
6	2	6	4
7	3	7	1
8	0	8	4
9	4	9	1
10	1	10	0
11	3	11	0
12	1	12	1
13	1		
20	1		
35	1		

Below Albany, the turbidity of the water decreases somewhat in amount, but the length of the turbid periods are slightly greater, due, probably, to the tidal character of the stream. The differences in turbidity between the two places, however, are not very great. It is certain, however, that the water of the Hudson, between Hyde Park and Rhinecliff, would not be less difficult to filter than the water at Albany. Whatever sedimentation occurs in the river below Albany is fully made up for by local additions of turbidity from the clay banks in the lower Hudson Valley.

After heavy rains, many small and apparently insignificant streams may be seen discharging large amounts of clay into the river, and it is common at such times to see the river clear in midstream, but with marginal strips of very muddy water. Ultimately through tidal action this suspended matter is disseminated through all the water.

It has been stated elsewhere that the greater part of the suspended matter borne by the water of the Hudson River is derived from the Mohawk. The progress of the turbid water down stream from Cohoes to Garrison is illustrated in Diagram No. 36, where the crest of the wave of turbid water was four days in passing from one to the other.

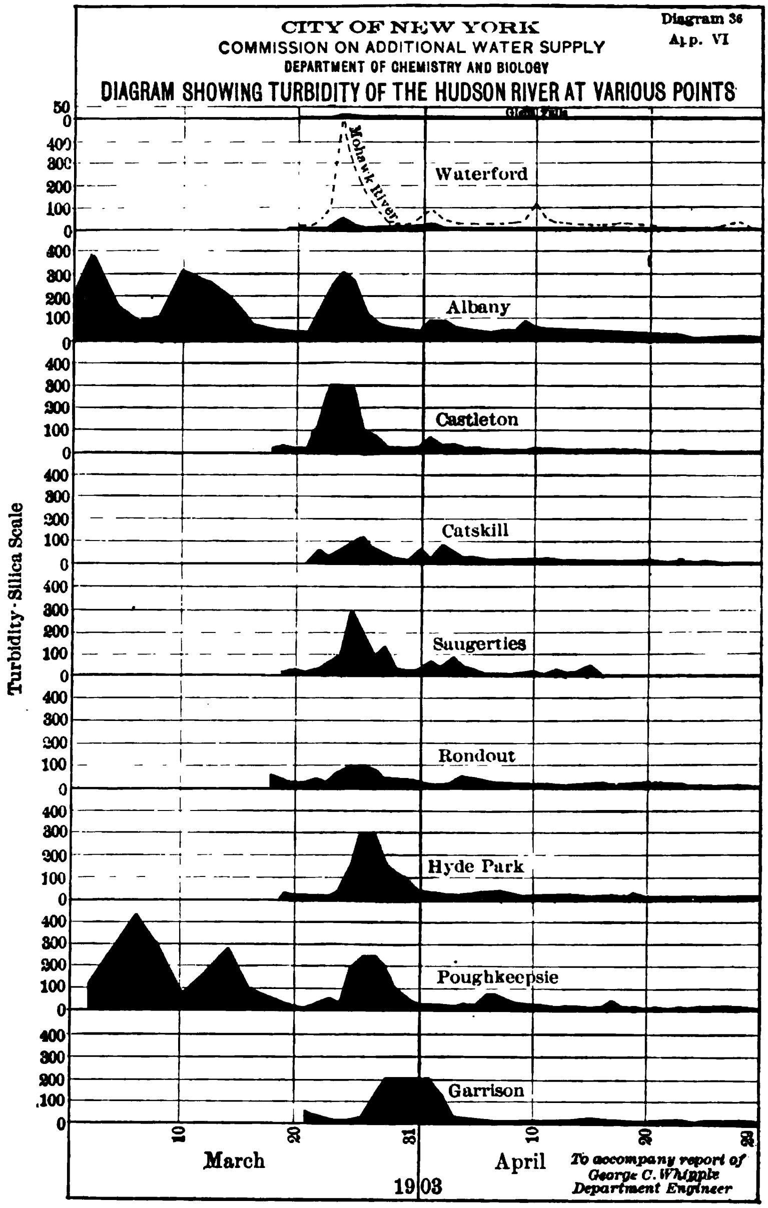


DIAGRAM 36. APP. VI.

There are evidences that much of the turbidity of the water in the vicinity of Poughkeepsie is derived not so much from the Middle Hudson as from local sources. This is evident from the averages given in the last column of Table No. .

Station.	Average Turbidity March to August, 1903.
Glens Falls	3
Schuylerville	8
Waterford	5
Cohoes (Mohawk River)	29
Albany	55*
Castleton	21
Catskill	11
Rondout	15
Saugerties	16
Hyde Park	23
Poughkeepsie	29†
Garrison	23

Between Glens Falls and Garrison, samples were collected daily at ten different stations. The results of turbidity observations are summarized in Table No. 30. From observations of samples in the laboratory, the suspended matter found at Poughkeepsie appears to be composed of somewhat finer particles than that at Albany, but precise data are lacking to support this statement. Anticipating the opportunity to study this subject on a large scale, two sedimentation tanks five feet in diameter and ten feet high were placed on the shore of the river at Poughkeepsie, but from April to October the river water was not sufficiently turbid to allow satisfactory experiments to be made, and the tanks were accordingly used for other purposes.

The water of the Hudson below Hyde Park has an average color not far from 30; after filtration the color would probably be between 20 and 25. (See Table 31).

The water had a persistent vegetable odor, which was very often accompanied by a moldy or disagreeable odor.

In addition to the daily samples mentioned, which were given only a physical examination, a series of weekly samples was taken at Newburg, Poughkeepsie, Hyde Park and Kingston. These samples were collected with

*February to June only—consequently its high average turbidity.

†February to August.

TABLE 30.

Summary of Daily Turbidity Observations at Sample Stations on the Hudson River from March to October, 1903; Showing the Average Turbidity for Each Month, the Maximum and Minimum for the Entire Period, and the Average During the Period Covered by the Observations, expressed in Terms of the Silica Standard.

Station.	Feb.	Mar.	April.	May.	June.	July.	August.	Min.	Max.	Average
Glens Falls	..	4	3	2	3	3	3	1	10	3
Schuylerville	..	21	3	4	5	8	7	1	110	8
Waterford	..	10	4	2	3	8	4	1	50	5
Albany	35	151	40	12	35	..	..	9	385	55
Castleton	..	89	12	5	9	4	7	1	300	21
Catskill	..	33	13	4	6	6	6	1	125	11
Rondout	..	46	18	6	11	6	7	1	95	15
Saugerties	..	67	13	4	6	5	5	2	275	16
Hyde Park	..	89	18	8	10	7	7	2	275	23
Poughkeepsie	29	125	20	8	10	8	8	3	440	29
Garrison	..	78	25	19	16	9	8	3	188	23

TABLE 31.

Summary of Daily Color Observations at Sample Stations on the Hudson River from March to October, 1903; Showing the Arerage Color for Each Month, the Maximum and Minimum for the Entire Period, and the Average During the Period Covered by the Observations, Expressed in Parts per Million of Platinum.

Station.	Mar.	April.	May.	June.	July.	Aug.	Min.	Max.	Ave.
Glens Falls	36	22	26	52	55	46	22	80	40
Schuylerville	31	32	28	41	40	44	23	50	36
Waterford	31	31	28	37	54	36	21	62	36
Castleton	29	29	28	33	38	39	25	68	29
Catskill	28	29	27	28	35	34	23	42	31
Rondout	28	28	24	27	44	37	17	52	31
Saugerties	26	27	25	30	29	34	10	39	28
Hyde Park	31	29	22	28	35	35	18	42	30
Poughkeepsie	25	28	30	23	35	34	18	46	29
Garrison	29	27	25	29	34	34	20	39	30

TABLE 32.

Summary of Daily Alkalinity Observations at Sample Stations on the Hudson River from March to October, 1903; Showing the Average Alkalinity for Each Month, the Maximum and Minimum for the Entire Period, and the Average During the Period Covered by the Investigations, Expressed in Parts per Million.

Station.	Mar.	April.	May.	June.	July.	August.	Min.	Max.	Average
Glens Falls	21	16	19	17	21	21	10	28	20
Schuylerville	21	17	23	23	24	23	12	33	21
Waterford	20	28	40	34	43	44	12	51	34
Castleton	52	39	63	53	51	56	30	71	47
Catskill	36	43	60	57	59	61	29	75	52
Rondout	34	42	51	52	50	59	29	67	41
Saugerties	36	37	52	52	56	58	16	69	48
Hyde Park	35	42	50	50	50	61	35	66	46
Poughkeepsie	35	41	46	50	43	48	35	57	43
Garrison	38	41	46	47	47	59	28	73	47

TABLE 33.

Daily Turbidity of the Water of the Hudson River at Poughkeepsie, N. Y., From February to August, 1903.

Day of Month.	February	March.	April.	May.	June.	July.	August.
1	..	....	28	9	4	5	6
2	..	....	20	8	6	7	8
3	5	20	17	5	3	8	5
4	8	300	24	5	5	7	11
5	10	....	34	7	2	8	9
6	30	440	37	6	3	7	12
7	..	400	54	10	3	9	19
8	..	....	38	11	10	10	8
9	35	....	28	9	10	9	11
10	35	80	21	8	10	13	9
11	33	70	22	7	15	11	12
12	35	90	18	15	18	5	6
13	40	....	19	23	16	8	6
14	40	280	17	20	11	11	7
15	..	240	15	19	21	12	8
16	..	90	15	23	21	10	9
17	30	80	23	18	20	22	8
18	40	....	18	12	13	12	6
19	50	25	16	8	14	10	12
20	50	20	9	6	8	7	10
21	25	5	12	5	6	5	10
22	..	10	13	5	9	6	8
23	..	20	12	6	12	6	7
24	20	8	11	7	11	8	7
25	25	90	13	5	10	9	8
26	30	140	12	4	8	4	9
27	20	210	20	5	12	6	14
28	35	130	16	5	7	5	9
29	..	80	16	4	9	5	11
30	..	50	..	4	7	6	10
31	..	32	..	3	..	..	9

TABLE 34.

Daily Color of the Water of the Hudson River at Poughkeepsie, N. Y., from February to August, 1903.

Day of Month.	February.	March.	April.	May.	June.	July.	August.
1	..	..	31	29	22	28	32
2	..	..	30	28	21	23	36
3	8	20	26	27	19	28	33
4	8	40	28	28	20	32	32
5	8	..	26	28	20	30	37
6	8	..	25	28	22	32	35
7	..	..	28	30	23	28	37
8	..	..	28	28	23	32	32
9	8	..	19	25	25	25	30
10	8	25	24	26	23	45	39
11	8	30	26	23	18	34	36
12	10	..	27	29	25	45	34
13	8	..	30	27	22	46	31
14	8	..	29	24	21	40	41
15	..	..	30	23	22	45	41
16	..	..	29	25	24	38	32
17	8	..	30	31	23	44	31
18	8	..	34	29	25	43	37
19	8	25	32	32	25	39	35
20	8	25	36	34	25	38	30
21	10	28	30	38	25	34	31
22	..	28	28	36	30	35	38
23	..	29	29	34	23	32	36
24	8	26	31	34	22	34	36
25	8	22	28	37	30	33	32
26	10	15	26	29	28	36	37
27	8	20	29	41	28	30	39
28	8	25	28	35	25	29	37
29	..	28	29	36	23	33	38
30	..	29	..	33	26	35	33
31	..	30	..	40	..	..	34

TABLE 35.

Daily Determination of the Number of Bacteria in the Water of the Hudson River at Poughkeepsie, N. Y., from April 9 to August 28, Inclusive.

Day of Month.	April.	May.	June.	July.	August.
1	.....	8,300	1,900	.....	11,250
2	.....	20,700	6,800	.....	.....
3	.....	.....	10,100	.....	2,500
4	.....	.....	.....	.....	2,300
5	.....	.....	3,500	.....	3,000
6	.....	.....	.....	.....	2,900
7	.....	8,200	.....	.....	3,500
8	.....	5,300	23,000	.....	3,400
9	26,800	6,000	5,700	.....	4,000
10	34,000	1,100	71,700	.....	3,500
11	.....	....	48,600	.....	3,700
12	.....	3,400	72,000	.....	4,500
13	48,000	8,900	5,300	.....	2,500
14	41,600	4,000	8,000	10,200	1,800
15	20,700	12,300	.....	.....	1,500
16	45,000	4,100	2,600	1,400	.....
17	29,000	.....	2,100	.....	1,400
18	13,400	27,000	4,100	1,200	1,900
19	.....	.....	6,100	.....	1,800
20	17,100	.....	52,400	1,900	7,500
21	33,900	.....	.....	2,300	2,000
22	40,000	.....	.....	2,700	2,500
23	61,400	.....	.....	2,250	.....
24	4,400	.....	.....	2,380	12,500
25	5,300	.....	.....	.....	1,800
26	.....	24,000	.....	.....	1,200
27	6,100	.....	.....	2,750	2,000
28	1,600	1,460	.....	2,800	2,400
29	7,800	1,250	.....	3,300	.....
30	8,000	.....	.....	3,500	....
31	.....	.....	.....	3,700	.....
Average	24,683	9,067	20,243	3,106	3,494

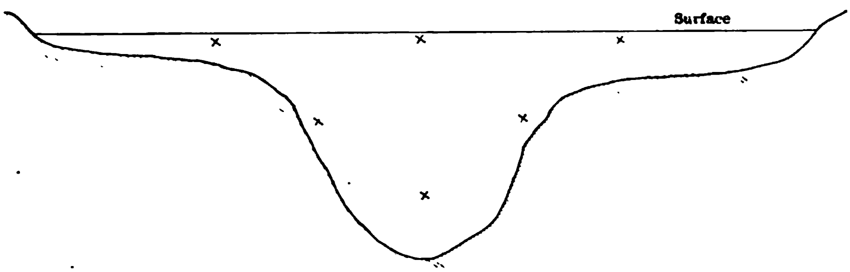
TABLE 36.

Daily Determination of the Number of Bacteria in the Tap Water of Poughkeepsie, N. Y., from April 9 to August 28, Inclusive.

Day of Month.	April.	May.	June.	July.	August.
1	....	....	120	....	205
2	....	....	40	...	....
3	....	....	920	....	150
4	....	....	....	....	135
5	....	....	60	....	180
6	....	....	70	....	140
7	....	90	....	....	170
8	....	20	185	....	130
9	1,100	20	100	....	160
10	9,200	105	80	...	135
11	....	100	520	....	140
12	....	25	70	....	60
13	1,400	70	80	....	210
14	1,200	35	....	....	120
15	160	40	340	185	125
16	230	....	140	....	....
17	270	....	80	105	125
18	180	80	230	....	100
19	....	60	55	....	105
20	200	40	60	100	40
21	230	....	...	80	....
22	120	35	....	100	105
23	120	....	....	180	....
24	70	75	....	....	70
25	40	195	....	....	90
26	90	80	....	....	110
27	80	....	....	200	120
28	100	40	....	165	90
29	70	50	....	210	....
30	70	....	....	285	....
31	....	....	....	205	....
Average	785	64	185	165	125

great care. Two gallon bottles were filled at each place, one at high-tide and one at low-tide, and each bottle was a mixture of smaller samples collected at the six points indicated on the accompanying sketch. (Diagram No. 37).

DIAGRAM 37. APP. VI.



Sketch showing Method of Integrating Hudson River Chemical Samples.

These samples were sent to Mt. Prospect Laboratory and analyzed chemically and microscopically. The results of the analyses, summarized by months, are given in Table 37.

TABLE 37.

AVERAGE ANALYSES OF WEEKLY INTEGRATED SAMPLES COLLECTED AT VARIOUS PLACES ON THE HUDSON RIVER.

Hudson River at Kingston.

High Tide.

Sample.	Physical Examination.			Chemical Analysis (Parts per Million).												
				Nitrogen as												
				Albuminoid Ammonia												
Place of Collection.	Turbidity. (Parts per Million of Silica.)	Color. (Parts per Million of Platinum.)	Odor.	In Solution.	In Suspension.	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Total Microscopic Organisms.	Amorphous Matter
Average May, 1903	12	24	2v+1d	.092	.022	.110	.043	.006	.17	98.0	1.7	51.4	46.2	.24	130	230
" June, "	24	32	2d	.112	.023	.135	.026	.011	.13	118.0	1.8	53.7	46.8	.42	106	132
" July, "	15	34	1v+1m	.140	.017	.157	.029	.020	.10	101.0	1.5	49.5	40.5	.50	70	143
" August, "	15	30	3v+2m	.114	.010	.124	.018	.014	.10	109.0	2.0	67.0	53.0	.35	55	85
Average	16	30	1y+m	.114	.018	.131	.029	.013	.12	106.5	1.7	55.4	46.6	.38	90	147

Low Tide.

Place of Collection.	Turbidity.	Color.	Odor.	In Solution.	In Suspension.	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Total Microscopic Organisms.	Amorphous Matter
Average February, 1903	30	36	2v	.092	.108	.200	...	.002	.15	115.0	1.2	39.0	30.0	.80	90	375
" May, "	11	25	3v+1m	.085	.019	.105	.046	.005	.13	101.0	1.7	49.2	44.6	.28	60	230
" June, "	24	31	2d	.120	.022	.143	.029	.017	.13	126.5	2.0	54.6	48.6	.54	148	151
" July, "	17	33	1v+1m	.135	.012	.147	.035	.018	.13	103.0	1.4	51.0	45.0	.65	85	175
" August, "	21	42	2v+1m	.119	.034	.153	.026	.004	.10	136.0	1.9	67.5	55.5	.55	260	135
Average	21	33	2v+1m	.110	.039	.149	.029	.009	.13	116.3	1.6	52.2	44.7	.56	108	213

TABLE 37—*Continued.*

Hudson River at Hyde Park.

High Tide.

Sample. Place of Collection.	Physical Examination. Turbidity. (Parts per Million of Silica.)	Color. (Parts per Million of Platinum.)	Odor.	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. In Solution.	In Suspension.	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Total Microscopic Organisms.	Amorphous Matter
Average April, 1903	16	26	2v	.102	.005	.107	.038	.004	.10	92.0	1.1	41.5	38.5	.24	160	85
" May, "	11	23	3v	.083	.048	.129	.035	.009	.18	105.0	1.1	47.0	44.0	.65	....	....
" June, "	24	29	2v+1d	.115	.021	.135	.024	.012	.14	135.0	1.6	52.0	44.8	.66	273	168
" July, "	16	36	2v+1 m	.134	.023	.157	.011	.018	.10	101.0	1.1	44.5	40.0	.60	78	160
" August, "	18	38	2v+1m	.115	.022	.137	.013	.006	.10	106.0	1.7	58.0	48.5	.30	90	143
Average	17	28	2v+1m	.109	.024	.133	.024	.009	.12	107.8	1.3	48.6	43.2	.49	150	139

Low Tide.

Place of Collection.	Turbidity.	Color.	Odor.	Alb. Amm. In Solution.	In Suspension.	Total.	Free Ammonia.	Nitrites.	Nitrates.	Total Solids.	Chlorine.	Hardness.	Alkalinity.	Iron.	Total Microscopic Organisms.	Amorphous Matter
Average March, 1903	90	30	2d	.208	.020	.228	.072	.002	.20	140.0	1.4	35.0	28.0	1.40	60	360
" April, "	18	25	2v	.086	.032	.118	.043	.024	.10	92.0	1.1	41.0	37.0	.20	55	95
" May, "	9	20	3v	.080	.043	.123	.052	.004	.08	62.0	1.7	34.5	30.0	.23	....	....
" June, "	28	29	2v+2d	.117	.031	.148	.025	.010	.13	137.0	1.8	51.1	46.0	.70	135	186
" July, "	20	37	2v+1m	.127	.042	.169	.012	.020	.10	114.5	1.3	44.5	41.0	.80	150	260
" August, "	19	38	2v+1m	.118	.016	.134	.014	.007	.10	111.0	2.0	56.0	50.0	.33	200	160
Average	31	29	2v+1m	.122	.030	.153	.036	.008	.12	109.6	1.5	43.7	38.6	.62	120	212

Hudson River at Poughkeepsie.

High Tide.

Average January, 1903	9	29	3v	.079	.008	.087	.013	.005	.23	105.5	1.6	59.2	49.0	.25	16	81
" February, "	20	36	2v	.124	.004	.128	.020	.002	.20	99.0	1.2	50.0	36.0	.35	145	375
" April "	18	25	2v	.083	.026	.109	.036	.005	.18	76.0	1.3	39.0	36.0	.30	70	185
" May, "	14	23	1d	.080	.022	.103	.033	.007	.18	92.0	1.6	48.0	43.0	.22	235	215
" June, "	21	31	2d	.124	.020	.144	.031	.008	.12	114.0	1.8	52.5	46.0	.50	157	167
" July, "	10	50	2v+2m	.116	.060	.176	.004	.005	.10	99.0	1.6	45.5	40.0	.40	70	230
" August, "	13	37	2v+1m	.119	.019	.138	.010	.003	.13	106.0	1.7	53.0	47.0	.28	132	157
Average	15	30	2v+1m	.103	.023	.126	.022	.005	.16	98.8	1.6	49.6	42.4	.33	117	201

Low Tide.

Average April, 1903	10	23	3v+1m	....	....	....	....	.004	.25	97.0	1.0	41.5	36.0	.42	....	....
" May, "	14	25	2d	.086	.026	.112	.034	.007	.15	99.6	1.6	47.5	43.0	.31	15	230
" June, "	18	31	2d	.126	.036	.162	.022	.008	.13	112.0	1.9	52.0	43.7	.60	159	126
" July, "	18	34	2v+1m	.124	.047	.171	.019	.008	.13	107.5	1.6	44.3	39.5	.55	73	242
" August, "	20	30	2v+1m	.124	.026	.150	.004	.003	.05	118.0	1.0	57.0	50.0	.40	155	185
Average	16	28	2v+1m	.115	.034	.149	.019	.005	.14	106.8	1.4	48.8	42.4	.45	100	195

Hudson River at Newburg.

High Tide.

Average April, 1903	23	24	2v+2d	.089	.009	.098	.023	.005	.20	91.0	1.1	41.0	36.0	.36	95	120
" May, "	15	22	1d	.080	.044	.124	.021	.003	.16	109.6	10.1	45.3	41.0	.24	190	415
" June, "	30	27	2d	.102	.040	.140	.019	.005	.37	148.5	14.0	53.6	46.2	.60	151	172
" July, "	20	35	2v+1m	.132	.012	.144	.016	.005	.10	117.0	1.2	44.5	44.0	.60	95	120
Average	22	27	2v+2d	.100	.026	.126	.019	.004	.21	116.5	6.6	45.1	41.8	.45	132	207

Low Tide.

Average April, 1903	18	25	3v	.076	.026	.102	.032	.004	.30	69.0	1.2	41.5	37.0	.20	....	....
" May, "	15	23	1d	.088	.036	.124	.021	.005	.20	88.3	1.5	46.1	41.0	.23	285	360
" June, "	36	27	2d	.112	.057	.169	.027	.005	.14	154.8	9.9	53.5	45.2	.80	134	350
" July, "	25	30	2v+1m	.104	.062	.166	.016	.003	.10	124.0	1.2	45.5	50.0	1.10	110	135
Average	23	26	2v+1d	.095	.045	.140	.024	.004	.18	109.0	3.4	46.6	43.4	.58	176	281

Speaking generally, these samples did not present striking differences, as may be seen from the following average figures:

Summary of Chemical Analyses—Hudson River Water.

	Nitrogen as								Chlorine.		Point of Collection.
	Albuminoid Ammonia.		Free Ammonia.		Nitrates.		Nitrates.				
	High Tide.	Low Tide.	High Tide.	Low Tide.	High Tide	Low Tide.	High Tide.	Low Tide.	High Tide.	Low Tide.	
Newburgh........	.125	.140	.019	.024	.004	.004	.21	.18	6.6*	3.4*	Just above city.
Poughkeepsie.....	.126	.149	.022	.019	.005	.006	.16	.14	1.6	1.4	400 ft. above Poughkeepsie Bridge.
Hyde Park.......	.133	.153	.024	.036	.009	.008	.12	.12	1.3	1.5	Just above R. R. Station.
Kingston..........	.131	.149	.029	.029	.013	.009	.12	.13	1.7	1.6	Opposite Kingston Point.

The differences between the high-tide samples and the low-tide samples were usually small and comparatively unimportant, except when affected by the sea water, as was the case at Newburg on several occasions.

Individual samples collected at the points shown in the sketch did not show marked differences, and such differences as were found did not indicate any special point in the cross section where the water was better than elsewhere. Only a few such comparisons, however, were made.

Chemical analyses were made occasionally at other points on the river between Albany, with results which are summarized in Table 38. The figures of the different stations are not strictly comparable, however, as they represent different periods of time.

The bacteriological investigations were confined chiefly to the determination of the total number of bacteria in the water of the Hudson at Poughkeepsie and vicinity, and to the presumptive test for the presence of bacillus coli. The series of observations was interrupted in June by the sad death of the assistant (Mr. Myers) who attended to that part of the work.

The results of the daily counts for the Hudson River are summarized in Table No. 35. The figures given are the averages of two determinations. It will be seen that the number of bacteria fluctuated greatly, but yet followed a general law, increasing and decreasing with the flow of the stream. Thus when the stream discharge fell during the latter part of April, the numbers of bacteria dropped. In May they were relatively low, but increased again in June after the rains. This can be seen best from the monthly averages. About 75 per cent. of the samples tested for bacillus coli gave positive results.

Other series of samples were taken across the stream at different places and at different depths. These samples gave no further result beyond showing that there was no regular law of distribution. The wind and the intermittent tidal flow apparently cause the water to become thoroughly mixed,

* Due to inflow of sea water in May and June.

TABLE 38.

Chemical and Biological Analyses of the Water of the Hudson River at Various Places Below the Troy Dam, 1903.

Sample.	Number of Samples.	Date, 1903.	Physical Examination. Turbidity (Parts per Million of Silica).	Physical Examination. Color (Parts per Million of Platinum).	Physical Examination. Odor.	Chemical Analysis (Parts per Million). Nitrogen as Albuminoid Ammonia. In Solution.	Nitrogen as Albuminoid Ammonia. In Suspension.	Nitrogen as Albuminoid Ammonia. Total.	Nitrogen as Free Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Total Solids.	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopic Examination. Microscopic Organisms Standard Units per c.c.
Albany	2	April 6 to Aug. 17	40	38	3 v	.124	.029	.153	.062	.012	.18	156.0	2.2	69.7	58.5	11.2	1.22	30
Castleton	6	Feb. 10 to Sept. 2	12	31	2 v+1 d	.120	.036	.156	.053	.003	.18	103.0	1.6	49.3	40.0	9.3	.45	139
Saugerties	1	March 29	50	30	3 v	.164	.052	.216	.060	.002	.15	105.0	2.6	31.0	23.0	8.0	1.20	90
Hudson	4	Feb. 12 to June 22	9	28	2 v	.114	.019	.133	.037	.003	.18	87.0	1.5	43.5	38.0	5.5	.18	146
Kingston	24	May 12 to Aug. 5	16	30	3 v+2 m	.114	.010	.124	.018	.014	.10	109.0	2.0	55.4	46.6	8.8	.38	144
Hyde Park	26	April 21 to Aug. 19	24	29	2 v+1 m	.115	.027	.143	.029	.009	.12	108.8	1.4	45.7	42.3	3.4	.46	135
Poughkeepsie	28	Jan. 23 to Aug. 19	16	29	2 v+1 m	.107	.029	.137	.021	.006	.15	102.0	1.5	49.6	42.4	7.2	.36	116
Newburg	20	April 28 to July 21	23	27	2 v+1 d	.098	.035	.131	.022	.004	.20	108.5	5.0	45.6	42.8	3.8	.51	174
Garrison	1	April 1	90	35	3 d	.232	.104	.336	.024	.002	.10	274.0	0.6	36.5	32.0	4.5	4.50	....
Peekskill	2	Jan. 27 to Aug. 25	17	27	2 v+2 m	.109	.017	.126	.131	.004	.13	293.5	102.8	85.8	42.5	43.3	.30	....
Tarrytown	1	August 25	20	25	2 v+1 m	.128	.024	.152	.050	.005	.05	1697.0	780.0	327.5	49.0	278.5	.40	60

and not even in the deep pockets were great differences in the quality of the water observed between top and bottom. The temperatures of the water at different depths taken with the thermophone also showed but slight fluctuations.

Success of Filtration.

In view of the practical demonstrations of what can be done in the way of purifying the water of the Hudson, it was not considered necessary to conduct any special experiments. The old style sand filters at Hudson and Poughkeepsie and the more modern covered sand filter at Albany were given careful consideration. The first mentioned plant at Hudson was one of the first filters used in this country. It is not adequate either in size or efficiency to the needs of the community, and is not to be considered as a criterion of what can be accomplished by filtration. On June 22 samples of water before and after filtration were collected with the kind permission of Mr. H. K. Bishop, City Engineer. The results of the analysis are given in Table 39.

TABLE 39.

Analyses of Samples of Water Collected at the Hudson City Filter on June 22, 1903.

	Raw Water.	Filtered Water (New Filter).
Physical Examination—		
Turbidity	10	2
Color	35	30
Odor	3v	2v
Chemical Analysis (parts per million).		
Nitrogen as Albuminoid Ammonia—		
In solution	.134	.094
In suspension	.030	.006
Total	.164	.100
Nitrogen as free ammonia	.028	.038
Nitrogen as nitrites	.006	.004
Nitrogen as nitrates	.20	.20
Total solids	104.0	126.0
Chlorine	2.4	2.0
Hardness	48.5	75.0
Alkalinity	43.0	65.0
Iron	0.20	0.00
Microscopical Examination—		
Microscopic organisms (per cubic centimeter)	235	5
Amorphous matter	5	10
Bacteriological Examination—		
Number of bacteria per c. c	1200	72*
Test for B. coli: 0.1 c. c	0	0
1.0 c. c	+	0
10.0 c. c	+	0

* This sample was taken from Clear Water Basin No. 2. A sample collected from the effluent gate-house of the "new" filter contained 197 per c. c., and a sample collected from the effluent of the "old" filter contained 100 per c. c.

The inefficiency of the filter is only too well told by the typhoid death rate of the city, which during the past five years has been as high as 55 per 100,000.

The quality of the water furnished by the Poughkeepsie filter was studied in considerable detail. The bacterial efficiency can be found in a general way by comparing the number of bacteria in the tap water each day with the number in the unfiltered river water. The average number of bacteria thus found were as follows:

Month.	Average Number of Bacteria per c.c.		Percentage Removal.
	Raw Water.	Filtered Water. (Tap on Main St.)	
April	24,683	785	96.8
May	9,067	64	99.3
June	20,243	185	99.1
July	3,106	165	94.7
August	3,494	125	96.4
Average	....	....	97.3

These figures are not a strict measure of the efficiency of the filtration, inasmuch as they do not differentiate the effect of the storage of the filtered water in an open reservoir, or the effect of the distribution pipes. It is quite possible that the apparently reduced efficiency during July and August may have been due to bacterial growths in the reservoir, accompanying the presence of microscopic organisms.

TABLE

Results of the Microscopical Examination of the Hudson

Sample Number	17824	17825	17826	18303	19435	19598	20063	20064
Date of Collection	Jan. 28	Jan. 28	Jan 28	Feb. 17	Apr. 23	May 11	May 26	May 26
Diatomaceæ—								
Asterionella	....	....	....	....	10	....	....	5
Cyclotella	....	....	....	....	....	....	5	....
Fragilaria	....	....	....	....	....	....	....	....
Melosira	....	....	....	....	....	30	....	90
Navicula	4	6	4	5	25	....	....	15
Stephanodiscus	....	....	4	25	....	....	10	65
Surirella	....	....	....	50	....	35	....	10
Synedra	6	....	10	5	20	5	....	....
Tabellaria	....	....	....	....	....	....	....	....
Diatoma	....	....	....	....	....	....	....	50
Chlorophyceæ—								
Scenedesmus	....	....	....	....	5	....	....	....
Cyanophyceæ—								
Anabaena	....	....	....	....	....	....	....	....
Schizomycetes and Fungi—								
Crenothrix	4	....	....	60	....	....	....	....
Protozoa—								
Euglena	....	....	....	....	....	....	....	....
Peridinium	....	....	....	....	....	....	....	....
Trachelomonas	....	....	....	....	....	....	....	5
Cryptomonas	....	....	....	....	....	....	....	....
Codonella	....	....	....	....	....	....	....	....
Rotifera—								
Polyarthra	....	....	....	...	....	....	....	....
Notholca	....	....	....	....	....	....	....	....
Total Organisms	14	6	18	145	60	70	15	255
Amorphous Matter	74	2	88	375	35	185	230	215

41A.

River Water Before Filtration, Poughkeepsie, N. Y.

20320	20321	20391	20415	20542	20543	20592	20593	20771	21033	21082	21083	21288	21289
June 8	June 8	June 12	June 12	June 20	June 20	June 25	June 25	July 2	July 17	July 23	July 23	Aug. 6	Aug. 6
5	20	10	15	....	....	10	....	....	....	....	....	15	....
....	...	15	15	....	....	....	50	....	....	....	....	....	....
....	....	....	....	....	....	15	....	....	....	....	....	....	....
50	....	....	30	....	....	....	90	25	....	15	....	....	....
10	10	5	5	5	10	5	....	....	10	....	10	30	15
60	90	135	80	30	20	30	45	50	....	60	25	60	10
....	20	....	25	75	45	50	40	50	25	36	....	25	....
5	....	....	20	5	....	....	10	....	....	....	10	....	5
5	....	....	....	....	10	....	....	....	....	....	....	....	65
...	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	10	....	....	....	....	....	....
....	....	....	....	....	....	20	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	25	....	15	....	....	....	....	....	...	25	....
....	....	....	....	....	....	....	....	....	....	....	25	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	10	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	40	....	....	....	....	....	....	....
....	....	....	....	50	....	....	....	....	....	....	....	....	....
....	....	....	40	....	....	....	....	....	....	....	....	....	....
135	140	175	255	165	100	170	245	125	35	111	70	155	95
95	180	190	105	65	60	195	200	205	260	225	230	185	85

TABLE

Results of the Microscopical Examination of the Filtered

Sample Number	19152	19223	19457	19593	19719	19970
Date of Collection	April 6.	April 9.	April 24.	May 1.	May 11.	May 22.
Diatomaceæ—						
Asterionella	....	60	625	150	105	60
Cyclotella	....	....	....	5	....	....
Melosira	....	....	350	25	....	60
Navicula	5	....	....	....	....	....
Synedra	200	10	325	10	25	170
Tabellaria	....	375	....	....	5	20
Diatoma	....	15	15	....	....	....
Stephanodiscus	....	....	....	....	....	10
Chlorophyceæ—						
Closterium	....	....	....	....	....	....
Gonium	....	....	....	....	....	15
Pediastrum	....	40	....	....	....	....
Protococcus	....	....	....	....	....	....
Raphidium	....	....	....	....	....	10
Scenedesmus	....	....	....	....	....	....
Spirogyra	....	....	....	....	....	....
Staurastrum	....	....	....	....	....	15
Cyanophyceæ—						
Anabaena	....	....	....	....	....	....
Aphanizomenon	....	....	....	....	....	10
Chroococcus	....	....	10	....	....	....
Clathrocystis	....	....	....	....	....	....
Cœlosphærium	....	....	....	....	....	....
Microcystis	....	25	....	....	....	....
Schizomycetes and Fungi—						
Crenothrix	....	....	5	....	....	....
Mold Hyphæ	....	....	....	....	....	....
Protozoa—						
Anthophysa	....	....	....	....	....	....
Dinobryon	....	....	25	....	....	10
Glenodinium	....	....	....	....	....	....
Mallomonas	....	....	....	....	....	....
Peridinium	....	15	....	....	....	....
Trachelomonas	....	....	....	....	....	5
Vorticella	....	15	....	....	....	50
Codonella	....	25	....	....	....	....
Rotifera—						
Anuraea	....	....	....	....	....	....
Synchæta	....	....	100	....	....	....
Crustacea—Cyclops	....	....	....	....	....	....
Total Organisms	205	580	1,455	190	135	465
Amorphous Matter	45	30	20	15	35	50

41C.

Water Collected from the Poughkeepsie Reservoir, 1903.

20080	20317	20400	20544	20611	20832	20938	21057	21158	21178	21287	21414	21512	21754
June 1.	June 8.	June 11.	June 20.	June 25.	July 8.	July 14.	July 21.	July 28.	July 31.	Aug. 6.	Aug. 17.	Aug. 24.	Sept. 9.
....	30	5	....	20	150	40	5	50	600	650	250	120	20
....	....	5	25	55	50	....	....	....	30	110	15	10	....
....	....	....	....	....	....	....	....	5	....	....	....	....	....
....	....	....	....	....	....	5	....	....	5	....	....	....	....
....	....	5	....	....	....	6	475	100	825	850	1,175	250	15
....	....	10	....	....	175	....	....	....	....	....	....	....	....
....	10	....	....	....	....	....	....	....	....	....	....	....	....
....	10	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	5	....	....	....	....	....	....	....	20
....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	145	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	450	....	650	100	25	....	....
....	....	....	25	....	....	....	....	....	....	....	....	10	10
....	5	....	....	20	....	....	....	....	15	20	15	....	....
....	....	....	10	....	....	....	....	....	....	....	500	....	....
....	....	....	....	....	20	10	....	....	....	....	....	....	....
....	....	....	45	....	....	....	....	....	240	460	....	....	550
....	....	....	....	....	....	....	....	....	....	25	....	....	....
....	....	....	....	....	....	....	....	10	....	....	....	....	....
....	....	....	....	....	....	....	....	....	75	....	....	....	....
....	....	....	....	25	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	25	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	15	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	25	....	....	....	....	....
....	5	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	15	....	....	....	....	....	....	....
....	....	....	....	....	40	....	....	....	....	10	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	5	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	40	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	25
....	....	....	25	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	200	....	....	....	....	....	....	....	....
....	65	25	130	255	655	101	930	190	2,140	2,265	1,980	390	640
25	25	60	35	40	55	50	55	10	55	85	30	55	45

Table 42 gives a summary of the important facts which relate to the efficiency of the Albany filter, recently computed and kindly furnished by Mr. Allen Hazen, who designed and built the plant:

TABLE 42.

ALBANY FILTER.

Some Data for Four Years' Service. *

Month.	Average for 4 Years.			Year ending September 30, 1900.		Year ending September 30, 1901.		Year ending September 30, 1902.		Year ending September 30, 1903.	
	Raw Water.	Effluent.	Per Cent. Removed.	Raw Water.	Effluent.	Raw Water.	Effluent.	Raw Water.	Effluent.	Raw Water.	Effluent.
October	11,400	62	99.46	10,700	102	16,500	25	4,350	49	12,072	32
November	22,300	84	99.62	9,200	71	47,600	93	21,735	290	10,868	43
December	65,700	352	99.46	45,800	213	63,700	233	74,100	680	79,404	264
January	67,300	514	99.16	66,300	1,232	71,400	300	51,700	225	56,608	299
February	600	860	98.93	119,090	938	105,100	2,117	58,600	265	40,043	117
March	71,600	660	99.08	44,700	426	123,700	1,601	64,900	505	52,960	127
April	48,700	113	99.77	26,000	80	107,600	276	34,300	49	26,903	49
May	9,500	49	99.48	2,600	35	26,500	92	4,700	36	5,020	33
June	7,400	58	99.21	3,100	45	15,600	106	2,440	42	8,353	41
July	5,300	31	99.41	3,500	32	7,700	39	6,235	26	5,800	25
August	5,200	30	99.42	3,400	23	8,300	42	3,215	26	5,753	28
September	5,700	54	99.05	5,000	24	7,600	46	4,250	27	5,860	26
Year	32,906	239	99.27	28,300	272	50,300	414	27,500	177	25,600	92
Per cent. removed	99.27			59.05		99.18		99.36		99.64	
Turbidity, U. S. G. S. scale (daily determinations)				30	0	34	1	39	0		
Color, platinum standard (weekly determinations)				34	27	34	30	30	24		
Solids, parts per million				124	95	145	124	144	120		
Suspended matter				17	0	33	0	24	0		
Albuminoid ammonia				0.341	0.165	0.231	0.112	0.266	0.124		
Free ammonia				0.121	0.030	0.115	0.024	0.096	0.012		
Nitrogen as nitrites				0.007	0.006	0.008	0.008	0.006	0.004		
Nitrogen as nitrates				0.065	0.184	0.157	0.283	0.372	0.451		
Hardness				69	65	71	71	67	67		
Oxygen consumed				5.	328	6.08	4.67	5.51	3.94		

* Kindly furnished by Mr. Allen Hazen, C. E.

While the investigations of this department have been sufficiently comprehensive to show that the use of the filtered Hudson water is a practical possibility, and that a slow sand filter would be the most desirable type of filter to be used, no attempt has been made to investigate such matters of detail as the time required for sedimentation, the advisability of using some form of preliminary filtration, the necessity of using a coagulant at times when the river is turbid, the best rate of filtration, the character of available sand, etc., as the other investigations indicated plainly that water of a more satisfactory quality could be obtained elsewhere. The equipment of the department was such, however, that these questions could have received proper attention had occasion required.

V.—GROUND WATER STUDIES.

The present supplies of the boroughs of Queens and Richmond are derived almost entirely from driven wells, and between 40 per cent. and 50 per cent. of the water supply of the Borough of Brooklyn is also ground water. It has been stated elsewhere in this report, moreover, that sooner or later all of the present surface supplies of Brooklyn must be either filtered or abandoned, and this means that additional ground water supplies must be sought.

The ground water studies which have been made for many years in connection with the present Brooklyn supply furnished the best information available in regard to the probable quality of any future supply which can be derived from Long Island, but inasmuch as these observations were limited geographically, other samples were collected at various places on Long Island, chiefly in Suffolk County. The results of analyses of some of these samples are given in Table 43. As might be expected, the results of analyses differ greatly according to local conditions.

The samples taken from the regions where the population is dense gave less satisfactory analyses than those taken from regions where the population is sparse, but from the sanitary standpoint the differences were less than might have been expected. The effect of the increasing population on Long Island upon the quality of the ground water is a matter of vital importance in connection with the ultimate future supply of Brooklyn, and when one views the results of the chemical analyses of samples of well water collected at various places in the Borough of Brooklyn and in the region just east of this, his apprehension is likely to be aroused. These samples show, for example, very high chlorines, high nitrates and hardnesses, and in some cases even high nitrites and free ammonia. A few years ago, when chemical analysis was the only means at hand for ascertaining the sanitary quality of water, some of these samples would have been condemned as unfit for drinking. Recent investigations, however, have shown that a ground water may give an unsatisfactory chemical analysis and yet pass all the prescribed bacteriological tests as to its sanitary quality. For instance, a driven well water may have a high chlorine and high nitrate and yet contain very few bacteria and invariably give a negative test for bacillus coli.

Such a combination of analytical results would indicate that the sources of supply had once received pollution of some sort, but that the passage of the water through the ground had effectually removed all the active dangerous elements. Such a water, although undesirable for certain purposes, from the mere presence of the large amounts of chlorine, hardness, etc., cannot be considered as necessarily unsafe from a sanitary standpoint. Observations have shown that these conditions obtain to a very large extent in the western

TABLE

Chemical and Microscopical Analyses of Samples of

	Sample.	Date. 1903.	Physical Examination. Turbidity (parts per Million of Silica).	Color (Parts per Million of Platinum).	Odor.
1..	Sumpawampus Creek	Jan. 15	3	23	2 v
2..	Babylon Stream	" 15	4	23	3 v
3..	Stellenwerf Stream, Islip	" 16	2	15	3 v
4..	Orowoc Creek, Islip, L. I.	" 16	3	30	3 v
5..	Doxies Stream, Islip, L. I.	" 16	2	38	3 v
6..	Connetquot Stream, Great River	" 16	4	22	2 v
7..	Edwards Creek, Sayville, L. I.	" 16	1	15	3 v
8..	Tuttle Creek, Patchogue, L. I.	" 17	3	13	3 v
9..	Patchogue River, L. I.	" 17	2	14	3 v
10..	Swan Creek, Patchogue, L. I.	" 17	1	12	3 v
11..	Ronkonkoma Lake	" 23	3	10	2 v + 1 m

43A

Water from Various Surface Waters on Long Island.

Chemical Analysis (parts per million).												Microscopic Examination.
Nitrogen as						Total Solids.	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopic Organisms Standard Units per c.c.
Albuminoid Ammonia in Solution.	Albuminoid Ammonia in Suspension.	Total.	Free Ammonia.	Nitrites.	Nitrates.							
....	....	.052	.010	.002	.15	37.0	4.6	30.0	5.0	25.0	.20	30
....	....	.098	.004	.002	.10	41.0	4.0	24.5	5.0	24.5	.60	36
....	....	.026	.002	.000	.020	30.0	4.0	19.5	5.0	14.5	.00	2
....	....	.066	.004	.000	.05	32.0	4.4	12.5	4.0	8.5	.10	4
....	....	.102	.040	.000	.05	35.0	4.4	22.0	3.0	19.0	.05	24
....	....	.028	.022	.000	.05	37.0	4.0	24.5	9.0	15.5	.05	8
....	....	.028	.006	.002	.000	38.0	6.8	23.5	5.0	23.5	.20	52
....	....	.030	.012	.003	.000	47.0	5.2	23.5	5.0	18.5	.10	0
....	....	.028	.008	.003	.000	58.0	4.0	23.5	19.0	4.5	.20	0
....	....	.024	.008	.003	.000	45.0	4.4	23.5	10.0	13.5	.20	0
....	....	.122	.003	.001	.000	28.0	4.4	11.0	8.0	3.0	.10	0

TABLE

Chemical and Microscopical Analyses of Samples of

	Sample.	Date, 1903.	Physical Examination. Turbidity (Parts Per Million of Silica.)	Physical Examination. Color (Parts Per Million of Platinum.)	Physical Examination. Odor.
1	Babylon, L. I. R. R. W. S., two 10-inch wells, 22 and 27 feet deep	Jan. 15	0	0	2v
2	Babylon Water Works, four 8-inch wells, 80 feet deep	" 15	2	7	0
3	Bayshore Supply, Islip, L. I	" 16	0	6	0
4	Patchogue Water Supply, Sayville, L. I	" 16	+	7	0
5	Patchogue Water Supply, L. I	" 17	1	5	2v
6	Conn. River, East Brookhaven, L. I	" 20	..	..	..
7	Rockville Centre Water Works	Feb. 3	2	4	0
8	Hempstead Water Works	Mar. 27	1	0	0
9	Barren Island, Well No. 2	Jan. 27	18	110	0
10	Greenwood Cemetery, Well	" 30	2	4	2d
11	Brooklyn Turkish Baths, Driven Well	" 30	2	3	0
12	Nassau Mills, Driven Wells	" 30	1	0	0
13	Brooklyn Hygiene Ice, Driven Wells	" 30	2	8	2d
14	Lutheran Cemetery Water Supply, Driven Wells	" 31	6	12	0
15	Calvary Cemetery, Driven Wells	" 31	8	24	0
16	F. Munch Brewery, Driven Well	Feb. 4	0	0	0
17	Nassau Brewery, Driven Well	" 5	0	4	0
18	Railroad Supply, Oyster Bay, L. I., Driven Well, 35 feet deep	Jan. 23	1	0	0
19	Pratts Supply, Glencove, L. I., Driven Wells	" 24	1	0	2d
20	Nassau Light & Power Co., Roslyn, L. I., two 8-inch wells, 250 feet deep.	" 24	3	0	0
21	Town Water Supply, Huntington, L. I., two 8-inch wells, 46 and 56 feet deep	" 23	2	0	0
22	Town Water Supply, Northport, L. I	" 23	1	0	0
23	Masters, L. I., ½ mile East	" 20	2	13	2v
24	Town Water Supply, Port Jefferson, L. I., Wells 53 feet deep	" 23	0	1	0

43B.

Water from Various Ground Waters on Long Island.

Chemical Analysis (Parts per Million).												Microscopic Examination.	Bacteriological Examination.	
Nitrogen as						Total Solids.	Chlorine.	Total Hardness.	Alkalinity.	Permanent Hardness.	Iron.	Microscopic Organisms. Standard Units per C.C.	Number of Bacteria per C.C. 48 hours at 20° C.	Per cent. of Positive Tests for B. coli in 1 C.C.
Albuminoid Ammonia.			Free Ammonia.	Nitrites.	Nitrates									
In Solution.	In Suspension.	Total												
....	....	.01[illegible]	.072	.003	.90	92.0	9.4	42.0	13.0	29.0	.20	0	....	0
....	....	.005	.000	.012	.50	43.0	4.8	30.0	7.0	23.0	.40	34	....	0
....	....	.014	.006	.006	.10	35.0	4.4	26.0	7.0	19.0	.20	2	....	0
....	....	.006	.000	.002	.15	42.0	5.0	21.0	10.0	11.0	.20	2	....	0
....	....	.012	.000	.004	.00	50.0	4.4	23.5	10.0	13.5	.30	0	....	0
....	....	....	....	....	....	....	....	....	....	....	....	....	....	..
....	....	.020	.014	.001	.60	71.0	7.4	12.5	6.0	6.5	.90	0	....	0
....	....	.024	.004	.002	1.15	29.0	5.0	9.5	8.0	1.5	.0	0	....	0
....	....	.006	.032	.002	.05	85.0	6.0	3[illegible].0	....	30.0	5.00	0	....	0
....	....	.014	.000	.005	9.60	490.	32.0	265.	185.0	80.	.15	0	....	0
....	....	.026	.014	.004	10.00	1113.0	224.	712.5	216.0	496.	.05	0	.10	0
....	....	.003	.008	.001	10.00	435.0	34.0	207.5	81.0	126.5	.10	0	.10	0
....	....	.038	.048	.300	10.00	453.0	40.0	272.5	148.0	124.5	.05	0	2650	0
....	....	.010	.013	.020	16.00	466.0	42.0	250.0	133.0	117.0	.80	0	....	0
....	....	.016	.028	.004	16.00	313.0	12.4	166.0	58.0	[illegible]8.0	1.40	0	....	0
....	....	.010	.000	.000	12.40	502.0	66.0	227.5	94.	133.5	.05	0	13500	0
....	....	.012	.000	.024	11.00	520.0	54.0	307.5	155.0	152.5	.05	0	50	0
.012	.002	.014	.000	.008	23.5	100.0	7.8	37.5	17.0	20.5	.05	0	....	0
....	....	.010	.020	.002	1.15	80.0	7.0	3[illegible].5	22.0	10.5	.05	0	....	0
....	....	.006	.000	.008	.65	50.0	4.6	11.0	8.0	3.0	.05	0	....	0
....	....	.014	.004	.000	1.35	55.0	6.2	27.5	7.0	20.5	.05	0	....	0
....	....	....	.010	.000	.40	60.0	6.0	18.0	13.0	5.0	.00	0	....	0
....	....	.040	.000	.003	.02	27.0	5.0	11.0	10.0	1.0	.05	0	....	0
....	....	.004	.000	.008	.00	47.0	4.4	21.0	18.0	3.0	.05	0	....	0

part of Long Island, and as pollution increases they are likely to extend eastward.

In a sandy soil like that which exists on Long Island it seems probably that nearly all of the ground water found under natural conditions at a depth of more than about 10 feet is perfectly safe for drinking, provided that it does not receive any immediate sub-surface pollution, and provided that it is collected in such a way as not to be contaminated from above. Any tubular well on Long Island driven to a depth of more than 10 or 15 feet, and not located near a sub-surface source of pollution, will probably yield water safe for drinking, even though the well be located in a comparatively densely populated region. An open or dug well, however, presents a different condition, as the water in such a well may be easily polluted from above. Such wells may be very dangerous, as was shown by the Department of Health of the City of Brooklyn a number of years ago, and their use in a crowded community should be absolutely prohibited. Wells of this class, however, are not likely to be used for sources of public water supply.

In order to determine the effect which the population has upon ground water under Long Island conditions, estimates have been made of the population per square mile found in regions above and surrounding the driven well stations of the Brooklyn Water Supply and the various water supplies in the Borough of Queens, as well as a number of driven wells located in the heart of the Borough of Brooklyn. For the purpose of making these estimates, it would have been desirable to have considered the actual watershed tributary to the different wells, but as no data in regard to this subject were obtainable, a certain definite region was taken in each case. This consisted of a rectangle one mile wide and four miles long (unless limited by the boundary of the watershed as shown by surface contours) extending upwards from the well in the probable direction of the lines of flow of ground water, terminating below in a circle one mile in diameter around the well. The results obtained by such a method lack in precision, but they serve as an approximate guide, and their relative value may be considered as fairly reliable.

The results of these estimates of population are as follows:

Station.	Population per Square Mile.	Station.	Population per Square Mile.
Massapequa	25	Jameco	860
Wantagh	100	Lutheran Cemetery	900
Matowa	100	Oconee	940
Northport	100	Citizen's Water Company, No. II.	1,130
Citizen's Water Company, No. III.	125	Whitestone, No. II	1,260
" No. V.	125	Baiseley's	1,330
Merrick	150	Whitestone, No. I	1,330
Hempstead	150	Shetucket	1,800
Forest Stream	150	Long Island City, No. I	1,800
Clear Stream	150	Calvary Cemetery	2,000
Citizen's Water Company, No. IV.	170	Montauk	2,200
Flushing	180	Long Island City, No. II	2,400
Oyster Bay	200	Spring Creek	2,600
Huntington	200	Long Island City. No. III.	2,800
Glen Cove	200	Blythebourne	3,000
Roslyn	200	New Utrecht	3,300
Rockville Centre	200	Woodhaven	3,600
Agawam	250	Gravesend	4,000
Springfield	250	Flatbush Water Company	7,000
Queens County	250	New Lots	10,000
Babylon (Railroad)	250	Greenwood Cemetery	13.000
" Town	250	German-American W. S. Company	14,000
Patchogue	300	Nassau Brewery	35,000
Bayshore	300	Malcolm Brewery	50,000
Port Jefferson	300	Brooklyn Turkish Baths	53,000
Bayside	320	F. Munch Brewery	55,000
Citizen's Water Company, No. I	710	Nassau Mills	60,000

These figures, when compared with the analyses of the water from the various wells, showed a general increase of dissolved mineral matter corresponding to the increase in population. This was most marked in the case of the nitrogen present as nitrates, but it was also noticeable in the case of the chlorine, hardness, etc. The influence of sea water in a number of cases, however, tended to obscure the latter relations. Except in a few cases, there was no marked increase of organic matter or of nitrogen in the form of free ammonia or nitrites. Nor did the number of bacteria increase directly with the population, although the highest numbers found were in samples from populous districts. In all cases the samples gave negative tests for bacillus coli, even in the case of the samples collected in the cemeteries and in the heart of the city. It should be observed here that all the samples were collected from driven wells and not from dug-wells. The relation between population on the watershed and the amount of nitrates present in the water is illustrated by Diagram 38. It must not be inferred from these investigations that the driven well water found in the heart of Brooklyn is desirable for general use. It is not. But from the sanitary standpoint there is no direct evidence that the water represented by the samples mentioned is injurious to health. It is quite apparent, however, that water on Long Island from a comparatively thickly settled territory, if properly collected at a point not subject to immediate pollution, can be safely used for drinking. The chemical character of such a water may make it an undesirable supply for household and industrial uses.

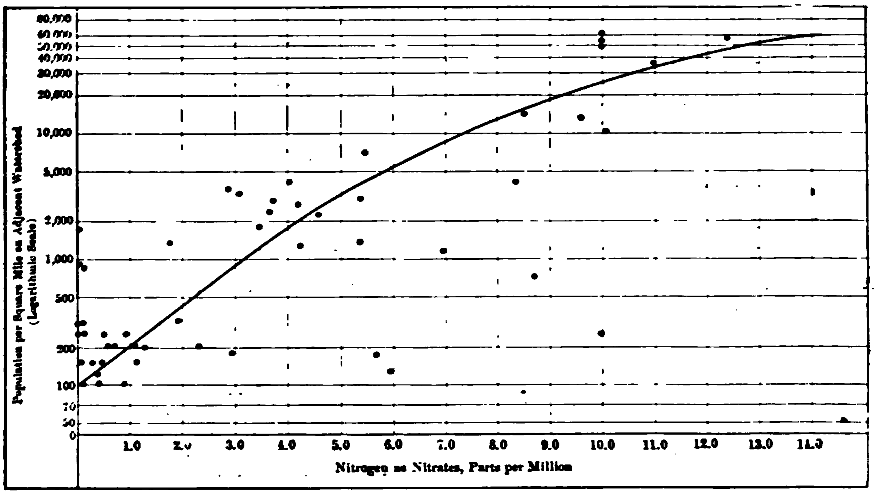


DIAGRAM 38. APP. VI.

CITY OF NEW YORK.

COMMISSION ON ADDITIONAL WATER SUPPLY.

DEPARTMENT OF CHEMISTRY AND BIOLOGY.

Diagram Showing the Relation Between the Amount of Nitrogen as Nitrates in Well Waters on Long Island, and the Density of Population on the Watershed.

The question has been often asked: " How long will the Flatbush water remain safe for drinking, considering the increasing population in that section?" As this is a question which applies to many of the other isolated plants, it may be answered by stating that there has been no evident deterioration shown by analysis during the past five years, and the results of our ground water studies would not lead one to expect any important deterioration for many years to come, if the method of taking the water remains the same, and if sources of pollution are kept at sufficient distance.

During the past years the subject of ground water pollution has been given considerable attention, and on July 14 a report upon the subject was made to Mr. I. M. de Varona, Chief Engineer for Brooklyn of the Department of Water Supply, Gas and Electricity, in connection with his system of infiltration galleries.

The subject of ground water pollution is appropriately divided into two parts:

1. Surface Pollution.
2. Sub-surface Pollution.

The first refers to pollution caused by matter placed on the surface; the second to pollution caused by material placed beneath the surface.

Danger from Surface Pollution.

It has been said that the soil of Long Island is very sandy. It is, indeed, an immense natural filter bed, and to this fact more than to any other, perhaps, the safety of the present water supply of the Borough of Brooklyn is due.

When water passes downwards naturally through the soil, it leaves in the strata near the surface the polluting material with which it may have been originally contaminated, and water leaching through polluting material on the surface of the ground gradually becomes purified as it descends into the soil. This has been repeatedly shown to be true by determinations of the number of bacteria in the soil at various depths. A number of such determinations were made in connection with the proposed infiltration galleries at Wantagh and Valley Stream. Some of these results are given in the Table 44.

These results indicated that at the point of collection the soil below a depth of five feet contained very small numbers of bacteria and was, in fact, almost sterile. The tests also indicated that below a depth of three or four feet bacillus coli was invariably absent. Similar series of observations were made at other places on the line with almost invariably the same results. In one case the samples were taken at a spot where manure is being continually unloaded from the cars of the Long Island Railroad. Here the following results were obtained:

Depth in Feet.	Number of Bacteria Per C.C.
Surface	360,000
5 feet	2,040
8 feet	4,500
15 feet	0
20 feet	120

All of these examples gave negative tests for B. coli.

These results corroborate the more extensive investigations which have been made in England, and indicate that the superficial layers of the soil exert a great influence in purifying the water which passes into the ground. The so-called soil bacteria which are so abundant near the surface of the ground no doubt play an important part in the destruction of contagia. (See " The Earth in Relation to the Preservation and Destruction of contagia," by Geo. Vivian Poore. Longmans, Green & Co., 1902. Also various papers in the last four annual reports of the Medical Officer of the Local Government Board of Great Britain.)

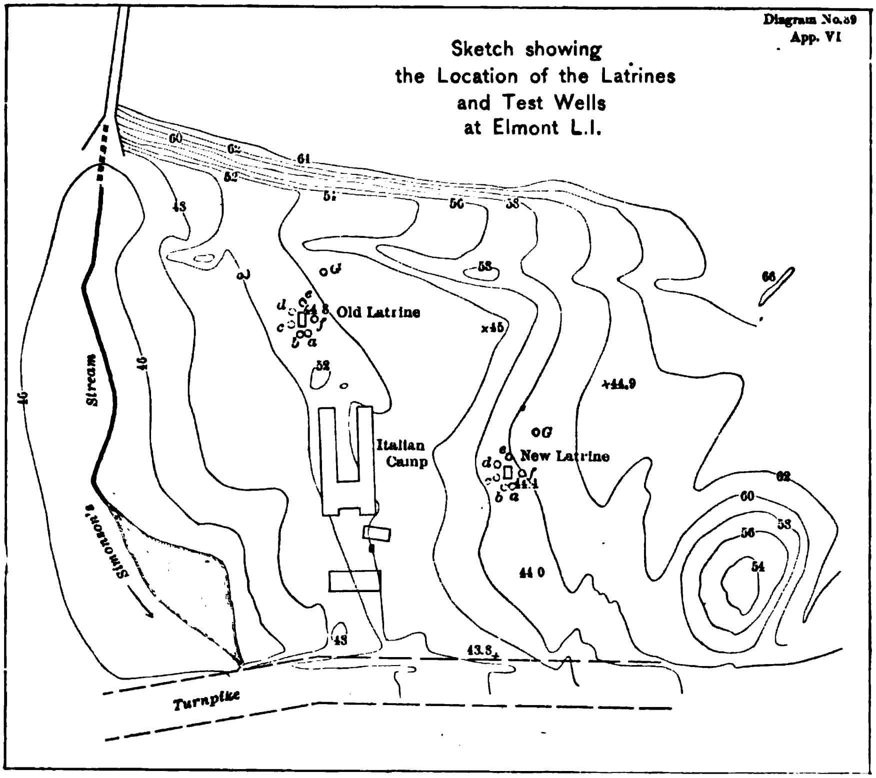
TABLE 44.

Table Showing the Number of Bacteria in the Soil at Different Depths, at a Point on the Conduit Line Nearly Opposite the Valley Stream Station of the Long Island Railroad.

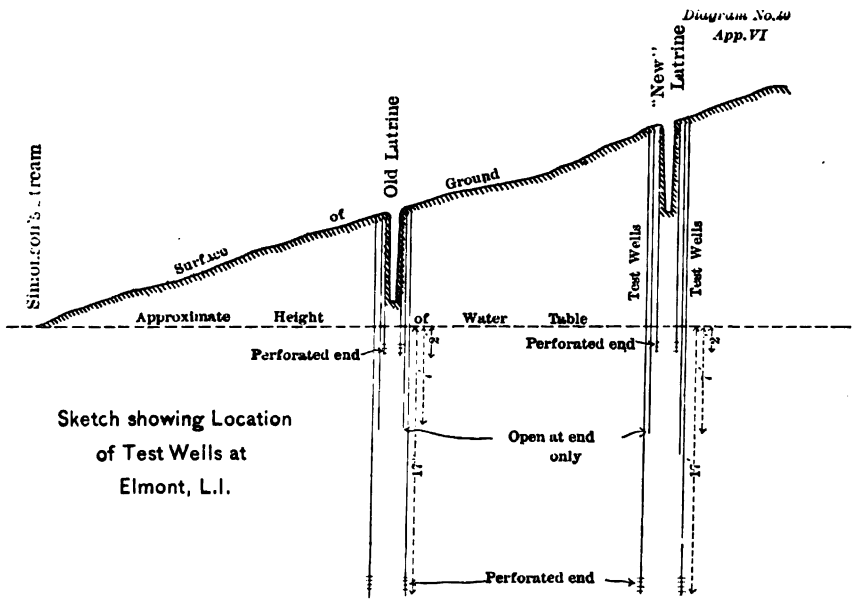
Depth in Feet.	Number of Bacteria per Gram of Dry Material.						
	April 24, 1903.	April 25, 1903.	April 27, 1903.	April 28, 1903.	April 29, 1903.	May 4, 1903.	May 5, 1903.
0	136,130	353,700	200,000	173,700	164,400	156,300	142,400
0.5	115,790	175,600	182,000	81,580	77,500	19,700	40,600
1	6,800	111,700	17,400	28,700	5,750	4,900	3,300
2	2,850	35,870	5,800	8,950	1,150	2,200	2,000
3	855	6,780	3,160	3,040	1,600	100	880
4	380	1,900	2,240	2,100	260	50	520
5	60	730	160	210	160	0	0
6	0	830	110	160	Broken	0	0
7	0	170	......	......	......	......	......

Danger from Sub-surface Pollution.

When fecal matter is deposited in the ground below the upper strata, where the soil bacteria are most abundant, the antagonistic influence of these bacteria is lost, and the destruction of any pathogenic bacteria that may be present is less rapid and less complete than if the fecal matter had been deposited upon the surface of the ground. Water leaching through such material may abstract and carry dangerous germs for a distance that will depend in great measure upon the character of the soil and the velocity of flow. With low velocities polluted water passing through the finer sands that exist on Long Island for a distance of twenty-five feet may be considered as practically safe for use, and it is probable that in most cases a distance less than this would serve as an efficient safeguard. That under severe conditions, however, sewage bacteria, such as bacillus coli, may pass through the soil for a considerable distance, was shown by experiments made at Elmont, Long Island, during June and July, 1903.



Sketch showing the Location of the Latrines and Test Wells at Elmont L.I.



Sketch showing Location of Test Wells at Elmont, L.I.

A camp of Italian laborers was located at Elmont, near the headwaters of Simonson's Stream. The men—between two and three hundred in number—used a common latrine, located as shown in Diagram No. 39. This was a pit 6 feet deep, 2½ feet wide and 11 feet long. It was dug on May 27 and put into use two or three days later. While it was being dug samples of the soil were collected at different depths and mechanical and bacteriological examinations made. The sand at the bottom of the pit which was a fair representation of all the material observed, had an effective size of 0.26 m. m., and a uniformity coefficient of 2.71. The results of the bacteriological examinations were as follows:

Date.	Depth of Sample in Inches.	Number of Bacteria per Gram of Dry Soil.	Test for B. Coli.
May 27, 1903	4	615,000	Negative.
" "	15	1,750	"
" "	27	800	"
" "	33	0	"
" "	46	0	"
" "	55	0	"
" "	61	0	"
" "	72	0	"

During the early part of June, 15 2-inch wells were driven around this latrine (which to distinguish it from one previously used is called the "New Latrine") at the points shown on the diagram. The depths and distances from the pit were as follows:

Well.	Distance in Feet from Nearest Part of Pit.	*Approximate Depth in Feet Below Water Table.	Character of Bottom of Well.
A1	10	2	Lowest 2 feet perforated.
2	10	7	Open only at bottom.
3	10	17	Lowest 2 feet perforated.
B1	10	2	"
2	10	7	Open only at bottom.
3	10	17	Lowest 2 feet perforated.
C1	10	2	"
2	10	7	Open only at bottom.
3	10	17	Lowest 2 feet perforated.
D1	10	2	"
2	10	7	Open only at bottom.
3	10	17	Lowest 2 feet perforated.
E2	10	7	"
F2	10	7	"
G2	50	7	"

* The depth of the water table below the surface of the ground was about 13½ feet.

About one week after the latrine was put into use samples were collected from some of the wells at A and B, and other samples were collected at different times between June 4 and July 3. The results of analyses of these samples are given in Table 45. They showed that all of the water was heavily polluted; that the nitrogens were high—and especially that part of the nitrogen in the form of free ammonia and nitrates, which indicates active decomposition. The bacteria were also exceedingly high, some of the samples containing numbers comparable with those found in sewage. The great fluctuations in the numbers of bacteria found at different times were apparently due to the rainfall. This may be seen by the figures given in Table 46.

TABLE 45.

Analyses of Samples of Water from Wells at Elmont Surrounding the "New" Latrine.

Date 1903.	Well.	Depth Below Water Table, in Feet.	Nitrogen as				Chlorine.	Number of Bacteria per C.C.	Test for B. Coli.		
			Albuminoid Ammonia.	Free Ammonia.	Nitrites.	Nitrates			0.1 C.C.	1 C.C.	10 C.C.
June 12..	A 1	2	.122	.056	.192	.85	7.4	44,750	0	0	0
" 26..	A 1	2	.182	.380	.224	1.10	11.0	85,000	0	0	+
" 27..	A 1	2	.088	.136	.480	.50	13.0	27,800	0	0	0
" 30..	A 1	2	....	.840	.400	....	....	420,000	0	0	0
July 3..	A 1	2	....	....	....	....	....	190,000	0	+	+
June 30..	A 2	7	....	.360	.040	....	....	180,000	0	0	0
July 3..	A 2	7	....	....	....	....	....	150,000	0	0	0
June 4..	A 3	17	.124	.068	.104	1.05	23.8	24,000	0	0	0
" 12..	A 3	17	.066	.004	.208	.80	12.8	40,500	0	0	0
" 26..	A 3	17	.112	.248	.018	.05	12.2	10,000	0	0	0
" 30..	A 3	17	....	.260	.280	....	....	283,000	0	0	0
July 3..	A 3	17	....	....	....	....	....	60,000	0	0	0
June 12..	B 1	2	.062	.014	.176	.80	11.4	255,000	0	0	0
" 26..	B 1	2	.084	.066	.120	.55	13.0	32,500	0	0	0
" 27..	B 1	2	.084	.024	.060	.10	12.0	36,400	0	0	0
" 30..	B 1	2	....	.440	.260	....	....	274,000	0	+	+
July 1..	B 1	..	....	1.160	....	....	...	368,000	0	0	+
June 4..	B 2	7	.184	.120	.018	1.50	13.7	540,000	0	0	+
" 12..	....	..	....	....	....	....	....	137,000	0	+	+
" 26..	....	..	....	...	....	....	....	21,000	0	0	0
" 27..	....	..	.096	.044	.280	1.40	17.0	26,000	0	0	0
" 30..	....	..	....	.180	.880	....	....	450,000	0	0	0
July 1..	....	..	....	.280	....	....	....	194,000	0	0	+
June 4..	B 3	17	.082	.042	.028	3.00	13.2	12,000	0	0	+
" 12..	....	..	.046	.020	.240	.60	7.2	67,500	0	0	0
" 26..	....	..	....	....	....	....	....	70,000	0	0	0
" 27..	....	..	.120	.252	.300	.35	16.0	38,000	0	0	0
" 30..	....	..	....	.280	.080	....	....	310,000	0	0	0
July 1..	....	..	....	.320	....	....	....	360,000	0	0	0
June 12..	C 1	2	.148	.048	.272	.65	13.2	39,150	0	0	0

TABLE 45—*Continued.*

Date 1903.	Well.	Depth Below Water Table, in Feet.	Nitrogen as Albuminoid Ammonia.	Free Ammonia.	Nitrites.	Nitrates	Chlorine.	Number of Bacteria per C. C.	Test for B. Coli. 0.1 C. C.	1 C. C.	10 C. C.
July 2..	....	..	....	....	....	....	....	800,000	o	o	+
June 12..	C 2	7	.146	.300	.003	.00	13.4	81,750	o	o	o
" 26..	....	..	.114	.160	.019	.05	12.6	41,000	o	o	o
" 27..	....	..	.112	.044	.480	1.80	15.0	55,000	o	o	o
July 2..	....	..	....	....	....	....	....	940,000	o	o	o
" 12..	C 3	17	.106	.082	.224	.185	12.2	87,500	o	o	o
" 30..	....	..	....	.320	.040	....	....	......	..	..	..
" 2..	...	..	....	....	....	....	....	360,000	o	o	o
June 27..	D 2	7	.108	.332	.120	.10	15.0	29,500	o	o	+
" 26..	D 3	17	.138	.472	1.600	.05	13.8	65,000	o	o	+
" 27..	....	..	.116	.604	.440	.55	16.0	49.000	o	+	+
" 30..	....	..	....	.680	.960	....	....	202,000	o	o	o
" 26..	E 2	7	.100	.080	.036	.05	12.6	50,000	o	o	o
" 27..	....	..	.120	.056	.130	1.10	16.0	45,000	o	o	o
" 30..	....	..	....	.180	.480	....	....	204,000	o	o	+
July 1..	...	..	....	.280	....	....	....	178,000	o	o	+
" 2..	....	..	....	....	....	....	....	320,000	o	o	o
" 3..	....	..	....	....	....	....	....	70,000	o	o	o
June 26..	F 2	7	.116	.388	.080	.05	13.6	50,000	o	o	o
" 27..	....	..	.120	.156	.560	1.15	17.0	50,000	o	o	o
" 30..	....	..	....	.360	.560	....	....	240,000	o	o	+
July 1..	....	..	....	.660	....	....	....	496,000	o	o	o
" 2..	....	..	....	....	....	....	....	492,000	+	+	+
" 3..	....	..	....	....	....	....	....	140,000	o	o	o
June 26..	G 2	7	.166	.834	.480	.05	13.0	45,000	o	o	o
" 27..	....	..	.096	.456	1.200	2.10	18.0	82,000	o	o	o
" 30..	....	..	....	.212	.880	....	....	980,000	o	o	o
July 1..	....	..	....	1.640	....	....	....	332.000	o	o	o
" 2..	....	..	....	....	....	....	....	318,000	o	o	o
" 3..	....	..	....	....	....	....	....	140,000	o	+	+

Table 46.

Table Showing Relation Between Rainfall and Number of Bacteria in Test Wells at Elmont, L. I.

Date.	Rainfall at Floral Park, near Elmont.	Average Number of Bacteria Per c. c. at Depth Below Water Table of—					
		New Latrine.			Old Latrine.		
	Inches.	2 Feet.	7 Feet.	17 Feet.	2 Feet.	7 Feet.	17 Feet.
June 1	....	......	......	......	......	......	......
" 2	....	......	......	......	......	......	......
" 3	....	......	......	......	......	......	......
" 4	....	......	540,000	18,000	......	......	......
" 5	....	......	......	......	......	......	......
" 6	....	......	......	......	......	......	......
" 7	1.48	......	......	......	......	......	......
" 8	.28	......	......	......	......	......	......
" 9	.03	......	......	......	......	......	......
" 10	.08	......	......	......	......	......	......
" 11	....	......	......	......	......	......	......
" 12	2.05	113,000	109,000	66,000	......	......	......
" 13	.09	......	......	......	......	......	......
" 14	.64	......	......	......	......	......	......
" 15	.55	......	......	......	......	......	......
" 16	....	......	......	......	......	......	......
" 17	.01	......	......	......	......	......	......
" 18	.13	......	......	......	......	......	......
" 19	.29	......	......	......	......	......	......
" 20	.41	......	......	......	......	......	......
" 21	.31	......	......	......	......	......	......
" 22	.02	......	......	......	......	......	......
" 23	.71	......	......	......	......	......	......
" 24	.42	......	......	......	......	......	......
" 25	....	......	......	......	......	......	......
" 26	....	58,000	41,000	48,000	32,000	18,000	36,000
" 27	....	32,000	41,000	44,000	53,000	54,000	30,000
" 28	....	......	......	......	......	......	......
" 29	2.32	......	......	......	......	......	......
" 30	.19	347,000	269,000	265,000	647,000	405,000	296,000
July 1	....	368,000	289,000	360,000	278,000	304,000	158,000
" 2	1.10	800,000	591,000	360,000	423,000	293,000	240,000
" 3	.08	190,000	137,000	60,000	90,000	233,000	108,000

TABLE 47.

Analyses of Samples of Water from Wells at Elmont Surrounding the "Old" Latrine.

Date 1903.	Well.	Depth Below Water Table in Feet.	Bacteria per c. c.	Test for B coli.		
				0.1 c. c.	1 c. c.	10 c. c.
June 26	A 1	2	8,000	o	o	o
" 27	....	..	65,oco	o	o	o
" 30	....	..	560,000	o	o	o
July 2	....	..	435,000	o	o	o
" 3	....	..	90,000	o	o	o
June 30	A 2	7	540,oco	o	o	o
July 2	....	..	620,000	o	o	+
" 3	....	..	450,000	o	o	o
June 26	A 3	17	90,000	o	o	o
" 27	....	..	29,000	o	o	o
" 30	....	..	310,000	o	+	+
July 2	....	..	260,oco	o	o	o
" 3	....	..	107,500	o	o	o
June 26	B 1	2	5,000	o	o	o
" 27	....	..	11,000	o	o	o
" 30	....	..	900,000	o	o	o
June 26	B 2	7	23,600	o	o	+
" 27	...	..	41,000	o	o	o
" 30	....	..	308,000	o	o	+
June 26	B 3	17	12,000	o	o	o
" 27	....	..	45,500	o	o	o
" 30	....	..	182,co)	o	o	o
June 26	C 1	2	14,000	o	o	o
" 27	....	..	24,000	o	o	o
" 30	....	..	......	o	o	o
July 2	..	..	410,coo	o	o	o
June 30	C 2	7	370,000	o	o	o
July 2	....	..	190,000	o	o	o
June 26	C 3	17	17,200	o	o	o
" 27	....	..	9,500	o	o	o
" 30	....	..	......	o	o	o
July 2	....	..	220,oco	o	o	o
June 26	D 1	2	68,000	o	o	o
" 27	....	..	110,oco	o	+	+
" 30	....	..	480,000	o	o	+
July 1	....	..	278,000	o	o	o
June 26	D 2	7	15,600	o	o	o
" 27	....	..	65,500	o	o	o
July 1	....	..	304,000	o	o	o
June 26	D 3	17	18,000	o	o	o
" 27	....	..	32,600	o	o	o
July 1	....	..	158,000	o	o	o
" 3	E	7	100,000	o	o	o
" 2	F	7	380,000	o	o	o
" 3	....	..	150,000	+	+	+
June 26	G	7	4,500	o	o	o
" 27	....	..	33,000	o	o	o
" 30	....	..	300,coo	o	o	o
July 1	....	..	27,200	o	o	o
" 2	....	..	322,000	o	+	+
" 3	....	..	120,000	o	o	o

The 2 and 17 feet wells were perforated for two feet from the bottom; the 7 feet wells were open only at the bottom.

The high counts obtained from June 30 to July 3, were evidently due to the effects of the rain on June 29 and July 2. June was a rainy month, and the counts were probably higher than under ordinary conditions.

In connection with the very large numbers of bacteria found in the ground water at Elmont, it is instructive to note the comparative absence of B. coli. Out of 59 samples tested positive tests were obtained in only 1.7 per cent. with 0.1 c. c.; 10 per cent with 1 c. c., and 28.8 per cent with 10 c. c. (See Table 48.) These figures indeed indicate a polluted water, but the degree of pollution is vastly less than would naturally have been expected under the existing conditions. To some extent the small numbers of B. coli found may have been due to the fact that chloride of lime was used about the privy. The quantity used, however, was entirely insufficient to completely disinfect the mass—a fact which was substantiated by bacteriological examination of the contents of the latrine.

At Elmont there existed an old latrine which had been used for several months before the new one was built. Wells were driven around this in the same way as around the new one—depths, distances and method of nomenclature being precisely similar. The results of the analyses of samples from these test wells are given in Tables 46 and 47. In general the results have corresponded closely with those already referred to, and do not indicate any permanent concentration of organic matter in the ground.

It is important to notice that the samples from well G, 50 feet from the latrine, were only slightly better than the samples from the wells 10 feet away, indicating that the pollution may be carried for at least that distance. It was the intention to drive other series of wells at greater distances in order to ascertain the diameter of the circle influenced by this excessive source of pollution, but pressure of other work interfered with the plan.

Five wells were driven, however, at distances of 130 to 220 feet from the new latrine. Samples from these wells, collected on July 31, gave the following results:

No. of Well.	Distance from Latrine in Feet.	Chlorine.	Free Ammonia.	Nitrites.	B. Coli.		
					0.1	1	10
1	160	8.0	.280	.012	.0	0	0
2	160	8.0	.560	.018	.0	0	†
3	130	14.0	.720	.192	.0	0	†
4	220	14.0	.180	.448	.0	0	0
5	300	18.0	.136	.960	.0	0	0

These samples gave negative tests for Bacillus coli in three of the wells and positive tests in two wells, and then only with 10 c.c. of water. The nitrogens were, however, very high, and indicated that the organic matter was actively undergoing decomposition.

TABLE 48.

Table Showing the Per Cent. of Samples from the Wells Surrounding the Latrines at Elmont, Which Gave Positive Tests for Bacillus Coli.

"New" Latrine.

Distance from Latrine in Feet.	Depth of Well in Feet Below Water Table.	Number of Samples of Water Tested.	Per Cent. of Positive Tests With		
			0.1 c.c.	1 c.c.	10 c.c.
10	2	12	8.3	16.7	41.7
10	7	25	0.0	8.0	32.0
10	17	16	0.0	6.3	18.8
50	7	6	0.0	16.7	16.7
	Total.....	59	1.7	10.0	28.8

"Old" Latrine.

10	2	16	0.0	6.3	12.5
10	7	14	7.2	7.2	28.6
10	17	15	0.0	6.7	6.7
50	7	6	0.0	0.0	16.7
	Total.....	51	2.0	7.8	15.7
Total,	both series....	110	1.8	9.1	22.7

The subject is an important one in connection with the development of the underground water resources by means of the filter gallery method, and should be pursued further, under conditions where the soil is more open and where the velocities of flow are greater than at Elmont. There seems to be no reason to question the safety of the water obtained by means of filter galleries on Long Island if properly constructed, but the experiments at Elmont emphasize the necessity of taking means to prevent any danger of infection from sub-surface sources of pollution. The drain pipes in the infiltration systems now being constructed are made water tight when passing by possible sources of danger.

The fact that the water of certain infiltration galleries in Europe has at times become polluted, and that in one instance at least it has been supposed to have occasioned an epidemic of typhoid fever (Le Fievre Typhoide a Auxerre en 1902 per M. Max le Couppey de la Forest, " Revue d' Hygiene, Juin, 1902 "), shows that this method of developing ground water is not without its dangers.

VI.—SOIL PHYSICS.

Between the surface of the ground and the level of the underground water there is a zone where the pores of the soil under ordinary conditions are only partially filled with water. This soil moisture varies in amount, and its upward and downward movements are governed by laws of capillarity and percolation which are but very imperfectly understood. A knowledge of these laws is of great importance in connection with the development of a ground water supply, because the downward percolating rain must traverse the upper layers of the soil before it really becomes an integral part of the ground water. Agriculturists are even more interested in the subject, because it has an immediate bearing upon growing crops. And when, as on Long Island, the interest of the farmer and those of the water supply seeker are both concerned, the subject assumes an importance which demands extensive investigation, in order that in case of conflicting interests no injustice may be done to either party through ignorance of the facts.

The experiments which have been made in connection with slow sand filtration have added much to our information in regard to the capillary flow of water through coarse material, and have given us a convenient, although not entirely adequate method of grading soil materials. The results of such experiments are not strictly applicable to the soil as it exists in nature. The experiments of the agricultural chemists and physicists have been more directly related to the problem, inasmuch as they have been made largely under field conditions. In the published reports and scientific papers of Hilgard, King, Whitney, Slichter and others, we obtain our most reliable data. Most of the work which has been done in the United States, however, has been done at agricultural experiment stations in California, Wisconsin and elsewhere, where the character of the soil and the climatic conditions have been quite different from those which exist on Long Island, and the applicability of these data to Long Island conditions has been a matter of doubt. In order to partially supply these deficient data and to supplement the field investigations of the Long Island Department, certain lines of laboratory experiments on the physics of the soil were undertaken by the Department of Chemistry and Biology. These included:

1. Studies of Soil Texture.
2. Experiments on Percolation.
3. Experiments on Capillarity.
4. Field Observations of Soil Moisture.*

The results of these investigations have not been wholly completed, but the leading results obtained may be summarized as follows:

Soil Texture.

The texture of the soil depends chiefly upon the sizes of the constituent particles and the closeness with which they are packed under natural conditions. Other factors, such as the shape of the particles, the effect of soluble salts, the cementitious quality of some of the ingredients, their hygroscopic properties, etc., are of secondary importance, and have received no attention during the present investigation. The sizes of the Long Island sands have been determined in the laboratory, and their closeness of packing ascertained by determining the "pore-space" by field experiment. In this connection it was necessary to make many determinations of specific gravity.

Sand Analyses.

The sand analyses of the coarse materials have been made by sifting through graded sieves according to the method well known to filtration engineers. The finer materials have been separated by elutriation.

The sieves were made of brass wire cloth, mounted in brass frames 4½ inches in diameter and 1½ inches high, so constructed that they could be nested, the coarser above the finer, with a cover at the top of the pile and a pan at the bottom. The sieves thus nested were mounted in the rack of a mechanical shaker which had a lateral to and fro motion of 2 inches, and which was ordinarily operated so as to give 100 strokes per minute. The samples, which were collected by the Long Island Department and forwarded to the laboratory, were subdivided by successive quarterings and the needed amount thoroughly dried. One hundred grams were put in the top sieve of the nest, and the shaker operated for 5 minutes, at the end of which the constituent grains were found in the different sieves according to their size. The portion found in the various sieves were separately weighed, and the per cent. found on each one calculated. The sieves used had the following sizes of separation:

* Not here reported.

Sieve Number.	Approximate Number of Meshes to a Linear Inch.	Size of Separation* in Millimeters.	Sieve Number.	Approximate Number of Meshes to a Linear Inch.	Size of Separation* in Millimeters.
200	200	0.10	16	16	1.30
120	120	0.14	10	10	2.10
100	100	0.17	..	..	....
80	80	0.21	9	8	2.80
70	70	0.24	8	6	3.90
60	60	0.22	7	3	8.00
50	50	0.36	6	2	14.50
40	40	0.43	5	1¼	23.00
36	36	0.53	4	1	27.00
30	30	0.64	3	¾	41.00
24	24	0.83	2	½	57.00
20	20	1.00			

* By the size ot separation is meant the diameter of a sphere equivalent in volume to the grain which will just barely pass through the sieve.

Sieves No. 2 to No. 9 were 13 inches in diameter, and were operated by hand instead of by the mechanical shaker.

TABLE 49.

Table Showing the Physical Character of Certain Typical Long Island Sands.

Sample Number.	Date of Collection.	Effective Size.	Uniformity Coefficient.	Per Cent. by Weight of Grains Between Certain Limiting Diameters.														Boring Number.	Remarks.
				—0.10 mm.	0.10–0.14 mm.	0.14–0.17 mm.	0.17–0.21 mm.	0.21–0.24 mm.	0.24–0.32 mm.	0.32–0.36 mm.	0.36–0.43 mm.	0.43–0.53 mm.	0.53–0.64 mm.	0.64–0.83 mm.	0.83–1.00 mm.	1.00–1.30 mm.	1.30–2.10 mm.	2.10– mm.		
249	Apr. 10	..	..	16.4	2.4	1.4	1.8	0.8	2.4	2.4	4.4	2.6	8.6	4.2	3.8	3.2	7.0	38.6	422	1A. Sample No. 1, surface loam.
254	" 10	.47	5.53	0.6	0.2	0.8	0.2	0.2	1.6	1.8	4.4	2.2	8.4	4.6	4.8	5.6	12.8	52.4	422	1A. Sample No. 2, subsoil.
259	" 10	.25	4.10	0.8	1.8	1.0	3.6	2.0	7.0	7.4	7.8	4.0	10.4	5.0	4.8	4.6	11.4	28.4	422	1A. Sample No. 3, at 5.00 feet.
265	" 10	.29	4.31	..	0.4	0.6	2.6	1.8	6.4	5.6	7.4	4.2	13.4	6.8	6.0	6.2	12.0	26.6	422	1A. Sample No. 4, at 10.00 feet.
270	" 10	.24	2.83	0.4	0.8	1.0	4.2	3.2	10.4	8.2	10.2	5.4	16.2	6.8	6.6	5.4	9.6	11.6	422	1A. Sample No. 5, at 15.00 feet.
275	" 10	.36	1.72	0.2	0.4	0.4	1.0	0.8	2.8	4.4	11.0	7.8	37.6	19.0	10.4	3.8	0.4	..	422	1A. Sample No. 6, at 22.00 feet.
280	" 10	.22	2.36	1.0	1.6	1.8	4.6	3.2	10.2	11.6	14.8	8.6	11.6	5.8	5.0	4.4	7.0	1.8	422	1A. Sample No. 7, at 26.00 feet.
284	" 10	.16	2.50	4.6	3.0	3.6	4.8	3.0	14.2	15.8	19.4	11.0	14.8	2.4	1.6	1.2	0.6	..	422	1A. Sample No. 8, at 35.00 feet.
250	" 10	..	..	26.4	3.6	1.6	4.4	2.4	8.4	7.6	8.4	6.4	14.8	5.2	4.4	2.4	3.2	0.8	423	2A. Sample No. 1, surface loam.
255	" 10	.10	1.95	10.8	2.6	0.6	1.4	0.6	2.0	2.2	2.8	1.8	6.0	3.6	4.6	6.6	18.0	36.4	423	2A. Sample No. 2, subsoil.
261	" 10	.35	4.71	0.2	0.6	0.8	1.6	1.0	3.2	4.6	5.8	3.8	12.6	6.6	6.2	6.8	13.0	33.2	423	2A. Sample No. 3, at 5.00 feet.
266	" 10	.26	1.62	0.2	0.4	0.6	3.0	2.8	14.6	19.4	24.2	8.6	18.0	4.2	2.2	1.0	0.8	..	423	2A. Sample No. 4, at 8.00 feet.
271	" 10	.26	3.85	2.4	1.4	1.0	2.4	1.6	4.8	5.0	9.2	6.8	16.8	4.8	3.4	2.8	7.0	30.6	423	2A. Sample No. 5, at 11.00 to 13.00 feet.
276	" 10	.10	2.45	3.7	2.4	1.2	3.5	2.4	10.5	12.8	16.8	8.9	18.3	5.1	2.8	2.0	7.3	2.3	423	2A. Sample No. 6, at 19.00 to 21.00 feet.
285	" 10	.23	2.17	1.4	1.8	1.2	3.8	2.6	11.0	13.2	15.6	8.0	22.8	7.0	5.8	3.2	2.4	0.2	423	2A. Sample No. 8, at 35.00 feet.
251	" 10	..	..	12.4	2.0	1.4	2.4	1.4	4.0	6.2	6.8	4.4	13.6	5.8	5.0	4.2	6.4	24.2	424	3A. Sample No. 1, surface loam.
256	" 10	.53	5.85	0.4	0.1	0.1	0.1	0.1	1.2	2.4	3.2	1.8	7.6	3.8	4.2	4.6	16.6	53.8	424	3A. Sample No. 2, subsoil.
262	" 10	.21	3.00	3.4	2.2	1.0	3.0	3.4	5.0	6.2	10.6	6.8	22.4	8.8	8.2	7.0	8.2	3.8	424	3A. Sample No. 3, at 5.00 feet.
267	" 10	.23	3.74	3.6	1.6	1.0	2.6	1.8	7.0	6.4	9.8	5.0	13.4	6.2	6.4	6.8	12.6	15.8	424	3A. Sample No. 4, at 8.00 feet.
272	" 10	.17	3.59	3.6	2.8	3.6	5.4	3.0	8.4	8.8	7.8	5.4	14.8	6.8	6.0	5.0	10.2	8.4	424	3A. Sample No. 5, at 1.00 feet.
277	" 10	.23	9.50	0.4	3.6	1.8	2.8	2.4	3.8	5.0	3.2	3.8	6.8	3.6	5.0	5.2	10.8	41.8	424	3A. Sample No. 6, at 20.00 feet.
281	" 10	.17	1.65	2.8	2.8	4.0	18.4	14.6	30.6	15.4	8.4	1.6	1.2	0.2	..	..	..	..	424	3A. Sample No. 7, at 32.00 feet.
286	" 10	.15	1.73	5.0	4.0	4.4	21.4	14.8	32.0	10.6	5.0	1.0	0.6	0.4	0.4	0.2	0.2	..	424	3A Sample No. 8, at 25.00 feet.
252	" 10	..	..	48.4	5.0	4.8	4.4	1.8	5.2	4.4	4.4	3.0	7.4	2.4	2.4	1.8	2.4	2.2	425	4A. Sample No. 1, surface loam.
257	" 10	..	..	40.8	6.0	4.4	4.6	4.6	5.8	2.2	5.0	2.6	7.4	3.4	2.8	3.0	4.0	3.4	425	4A. Sample No. 2, subsoil.
263	" 10	.26	4.81	0.6	1.0	1.0	2.4	3.0	6.6	6.8	7.8	4.8	11.4	6.2	5.4	5.8	12.2	25.0	425	4A. Sample No. 3, at 5.00 feet.
268	" 10	.35	3.94	0.2	0.2	0.2	1.0	0.8	4.4	4.2	6.6	3.4	12.4	7.4	8.8	8.2	19.4	22.8	425	4A. Sample No. 4, at 11.00 feet.
273	" 10	.27	3.70	1.6	1.4	1.0	2.4	1.8	5.4	7.2	9.4	4.8	12.4	6.4	6.2	6.6	15.4	18.2	425	4A. Sample No. 5, at 18.00 feet.
278	" 10	.26	5.00	1.4	1.6	1.0	2.6	1.2	4.6	6.4	7.4	3.4	11.4	5.8	5.2	5.6	12.8	29.6	425	4A. Sample No. 6, at 23.00 feet.
282	" 10	.21	2.57	3.0	2.2	1.2	3.4	3.8	10.4	9.0	13.4	7.0	18.4	9.4	6.8	6.4	5.6	..	425	4A. Sample No. 7, at 30.00 feet.
287	" 10	.28	1.82	0.6	0.4	0.4	2.0	2.0	9.4	14.2	18.6	13.0	29.4	4.4	3.6	1.8	0.2	..	425	4A. Sample No. 8, at 36.00 feet.
290	" 10	.28	1.46	..	0.2	0.4	1.6	2.6	14.8	19.0	25.4	10.8	19.8	3.2	1.0	0.2	..	..	425	4A. Sample No. 9, at 43.00 feet.
253	" 10	.13	6.00	8.8	1.8	1.6	2.8	2.0	6.4	4.2	8.4	5.0	12.6	8.2	6.6	6.2	8.8	16.6	407	2B. Sample No. 1, surface loam.

controls the rate of filtration through it. The diameter of the grain at the point where the 60 per cent. line crosses the curve, divided by the effective size gives the uniformity coefficient. The higher the value of the uniformity coefficient the less uniform in size are the grains. If the grains were all alike the uniformity coefficient would be unity. Very few natural sands have a uniformity coefficient below 1.5.

The results of some of the mechanical analyses of Long Island sands are given in Table 49. These results are discussed in the report of the Long Island Department.

When the sample contained much material finer than 0.1 mm. the finer portions were separated by elutriation, according to the method described by Hazen*, but with slight modifications.

The method of elutriation by beakers checked by microscopical examination of the sediment was found to be more convenient and quite as accurate as the method involving the use of elutriators. All forms of separation by water are very inaccurate, and the whole subject of elutriation is much in need of careful study. Experiments made to combine some of the methods of turbidimetry with those of elutriation give promise of important results. Many experiments were made to determine the effect of temperature upon elutriation. They showed that it had a slightly greater effect on the separation of the coarse material than the finer material. In the first separation a difference of 20 degrees C. in the temperature of the water made a difference of 100 per cent. in the quantity of material which settled, while in subsequent separations it was much less.

Experiments on Percolation.

The experiments on percolation were made according to the method used by King (" Principles and Conditions of the Movements of Ground Water," by F. H. King. 19th Annual Report, U. S. Geol. Survey, Part II. 1897-8), but with different materials and with slight modifications in the apparatus. Galvanized iron tubes three inches in diameter and ten feet long were placed on end and filled with various kinds of sands, both natural and artificially graded. They were capped at the top to prevent evaporation, but a capillary opening was left. At the bottom the sand column was supported on a wire mesh screen (30 meshes to the inch) covered with silk bolting cloth. The lower end of the tube entered a chamber which had an outlet connected with a measuring flask. The general arrangement is shown in Diagram No. 42.

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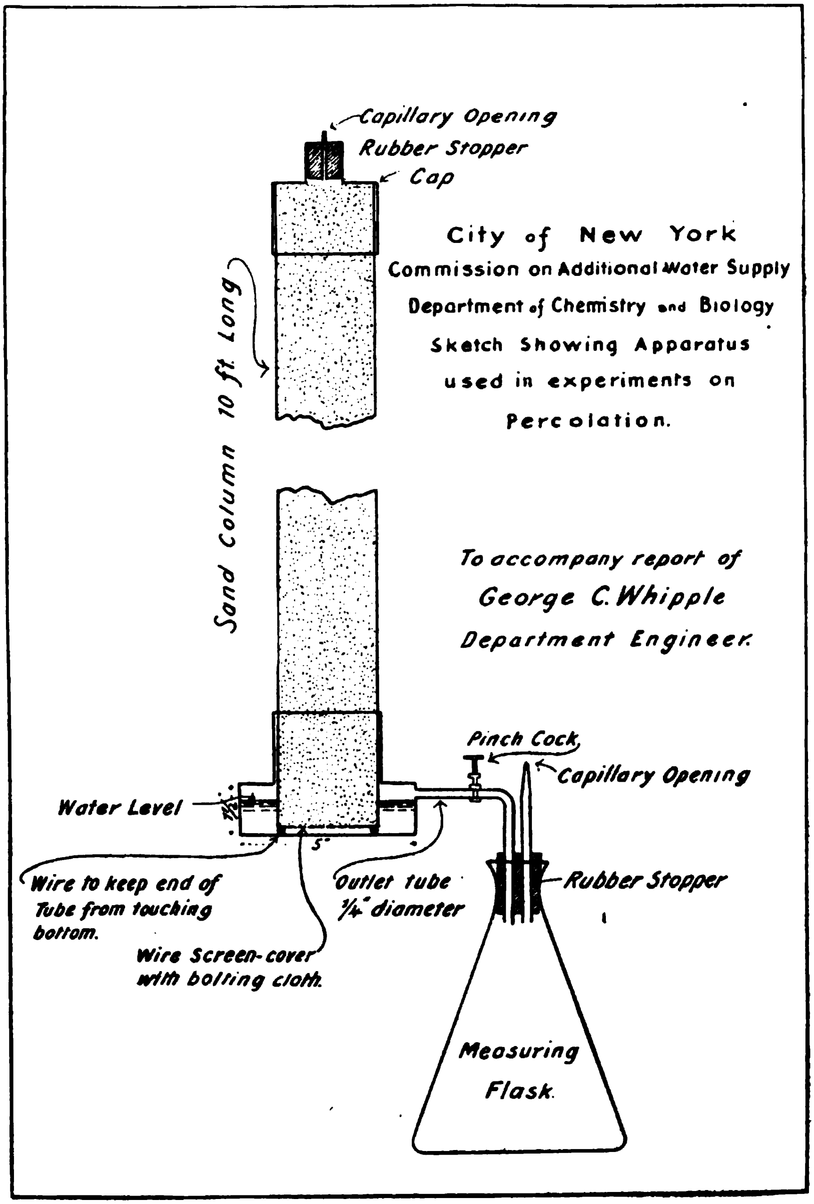
* Physical Properties of Sand, by Allen Hazen. Report Massachusetts State Board of Health, 1892, p. 541.

Diagram 42 App VI.



The tubes, 14 in number, were placed side by side in the basement of the gate-house at Mt. Prospect Reservoir, where the temperature was comparatively low and the fluctuations small.

The tubes were first filled with dry material in as compact a condition as could be obtained by rolling and shaking, and water introduced from below (applying an aspirator meanwhile at the top) until the whole column was saturated. They were allowed to settle for three weeks, and the amount of water adjusted so that the surface was just flushed. The outlet was then opened and the amount of water which came out measured at intervals. For a few minutes the flow was rapid and it was necessary to measure the volume every few minutes. Gradually the flow decreased and the observations were reduced to once an hour and then to once a day. After the first twelve hours the percolation was determined by weighing the catchment flask instead of measuring the water in a graduate. These observations were continued for several weeks, or until the percolation had very greatly decreased. In no case did it finally stop, and Prof. King (loc. cit.) has found that it may even continue for several years. In view of his results the experiments were shortened in time, and the tube refilled and the experiments repeated. In some cases this was done three or four times. In the first experiment tap water was used; in the second, distilled water, and in the third, tap water filtered and boiled.

The materials used were in part natural Long Island sands, and in part graded sands. The latter were carefully dried, ignited and sifted (but not washed), and it was the intention to have these uniformly graded from the finest sand commonly found on Long Island to sand which represented the coarser deposits. Mechanical analyses made after sifting, however, showed the presence of more or less fine material in nearly all of the sands, as may be seen from the following figures. (Table 50.)

TABLE 50.

Table Showing Character of Natural and Graded Sands Used in Percolation Experiments.

Grade.	Nominal Grading (Sieve Numbers)	Effective Size in mm.	Uniformity Co-efficient.	Per Cent. by Weight between															Specific Gravity of Material.
				—.10 0.10 mm.	.10—.14 mm.	.14—.17 mm.	.17—.21 mm.	.21—.24 mm.	.24—.32 mm.	.32—.36 mm.	.36—.43 mm.	.43—.53 mm.	.53—.64 mm.	.64—.83 mm.	.83—1.00 mm.	1.00—1.30 mm.	1.30—2.10 mm.	2.10— mm.	
Graded Sands—																			
A	—60	....	....	63.8	....	4.6	8.3	2.3	2.1	0.6	0.5	0.2	0.6	0.2	0.1	0.2	....	....	2.66
B	60—40	.27	1.35	0.7	0.1	0.2	1.7	2.7	24.6	26 2	42.3	1.1	0.4	....	....	....	....	....	2.68
C	40—36	.22	1.77	2.2	1.1	1.1	5.3	4.4	15.5	17.8	31.7	16.2	3.9	0.8	....	....	....	....	2.68
D	36—30	.28	1.96	1.2	0.4	0.7	2.8	2.2	8.4	6.9	14.9	13.5	47.8	0.9	0.3	....	....	....	2.68
E	30—24	.31	1.87	0.1	0.2	0.3	2.1	1.6	6.6	7.2	11.1	8.3	36.7	19.1	6.6	0.1	....	....	2.685
F	30—20	.57	1. 8	....	....	....	....	0.1	0.1	0.5	1.3	1.9	46.9	37.6	11.3	0.2	0.1	....	2.68
G	20—10	.94	1 49	....	....	....	....	....	....	....	....	0.1	0.3	1.8	20.2	33.8	43.7	....	2.70
Natural Sands—																			
1	......	2.9	1.32	0.1	0.1	0.1	1.1	2.1	18.3	25.5	31.9	10.0	9.4	0.9	0.3	0.1	0.1	....	2.65
2	......	....	....	....	....	....	....	....	....	....	....	....	....	...	....	....	....	....	....
3	......	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4	......	....	....	....	6.5	2.9	2.2	1.1	2.8	1.9	2.4	1 1	3.6	1.1	1.6	1.3	2.1	2.0	2.65
5	.....	.32	3.75	0.1	0.1	0.1	0 7	0.7	6.7	8.4	11.2	3.7	11.8	6.7	6.5	6 4	10.7	26 2	2.68
6	......	.59	9.33	0.1	0.1	0.1	0.1	0.1	0.9	1.6	2 7	1.3	6.2	4.2	4.0	4.1	10 3	64.5	2.66

Tube No. 1 was filled with a rather fine sand from Jameco, L. I.

Tube No. 2 was filled with a reproduction of a vertical section of the soil in a garden at Rockville Centre, L. I., near the shore of Hempstead Storage Reservoir. It was composed of the following strata:

Depth Below Surface. Inches.	Thickness of Material. Inches.	Kind of Material.
0– 9	9	Black Loam
9–23	14	Gravelly Loam
23–35	12	Gravel
35–55	20	Sandy Gravel
55–68	13	Sand
68–120	52	Sand.

Tube No. 3 was filled with alternate layers of sands B and E described above, one foot in thickness, with the coarser sand E forming the bottom layer.

Tube No. 4 was filled with a clayey loam from a bank at the corner of Underhill avenue and Eastern Parkway, Brooklyn. The character of the material is shown by the analysis in Table 50.

Tube No. 5 was filled with a natural sandy gravel, also from Rockville Centre, L. I. (See Table 50.)

Tube No. 6 was filled with a natural sandy gravel, also from Rockville Centre, L. I. (See Table 50.)

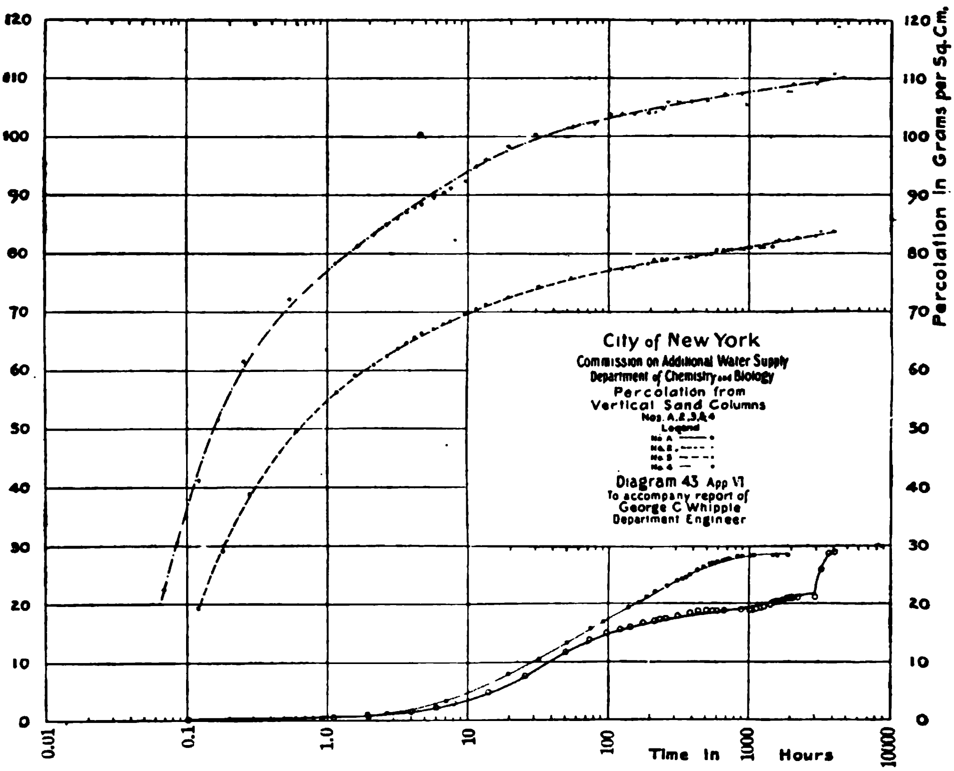
Tube No. 7 was filled with assorted materials which represented an actual section of the soil at Floral Park, L. I., and made up as follows:

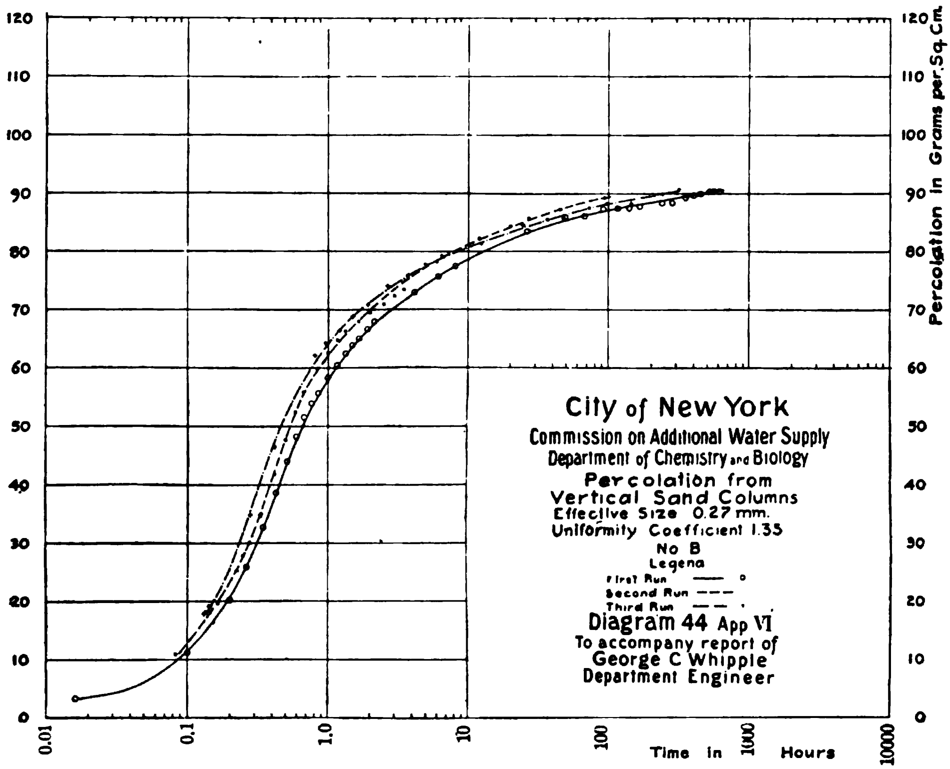
Depth Below Surface. Inches.	Depth of Layer. Inches.	Kind of Material.	Per Cent Finer than 0.10 m.m.	Eff. Size.	Uniformity Coefficiently.
0– 6	6	Dark Loam	37.3	....	....
6– 24	18	Brown Clayey Loam	19.3	...	....
24– 54	30	Sand	0.7	.30	3.02
54– 81	27	Gravelly Sand	0.3	.26	2.38
81–120	39	" "	0.6	.23	3.04

The following figures show the volume of the tubes, sands, etc., after the sand had become well settled.

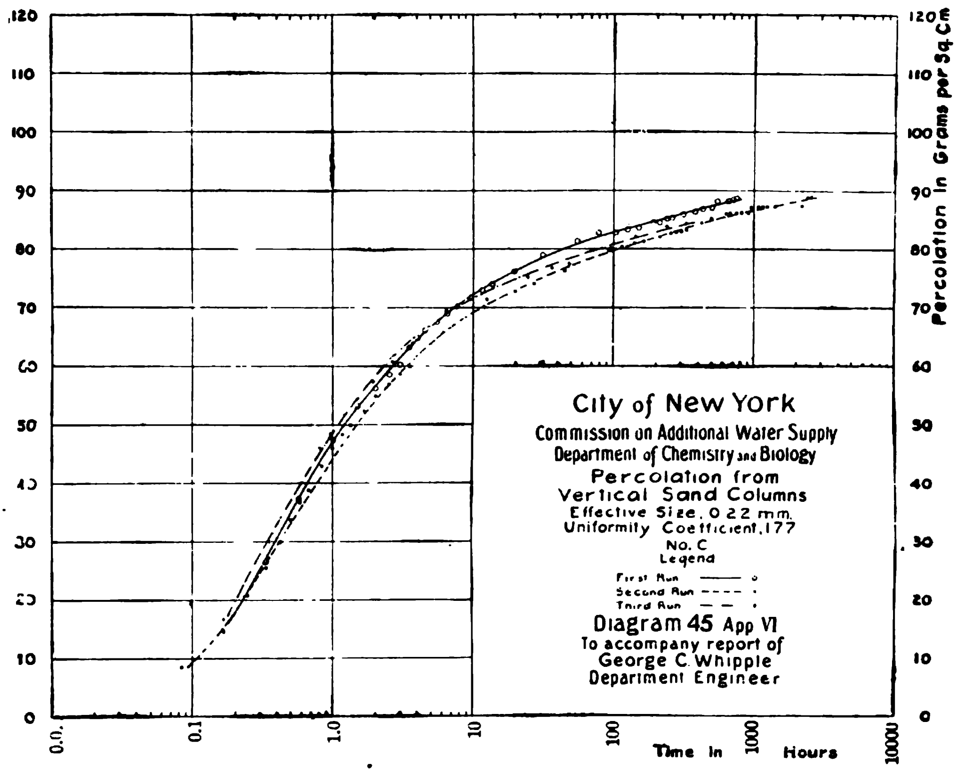
Tube Number.	Volume of Tube to top of Sand Layer. C. C.	Weight of Sand in Grams.	Volume of Sand. C. C.	Void Space. C. C.	Per Cent of Void Space.
A	13,485	17,630	6,628	6,857	51.0
B	13,354	19,838	7 403	5,951	44.6
C	13,645	20,307	7,577	6,068	44.5
D	13,601	20,563	7,673	5,928	43.6
E	13,601	20,565	7,674	5,927	43.6
F	13,768	20,673	7,714	6,054	44.0
G	13,747	20,706	7,669	6,078	44.2
I	13,558	20,300	7,632	5,926	43.7
4	13,747	20,200	7,623	6,124	44.5
5	13.819	21,261	7,937	5,882	42.6
6	13,812	23,490	8,831	4.981	36.1

The results of the experiments so far as they relate to percolation are shown in Diagrams 43 to 50, where the time intervals are plotted as abscissas (logarithmic scale) and the total amount of percolation as ordinates (natural scale).

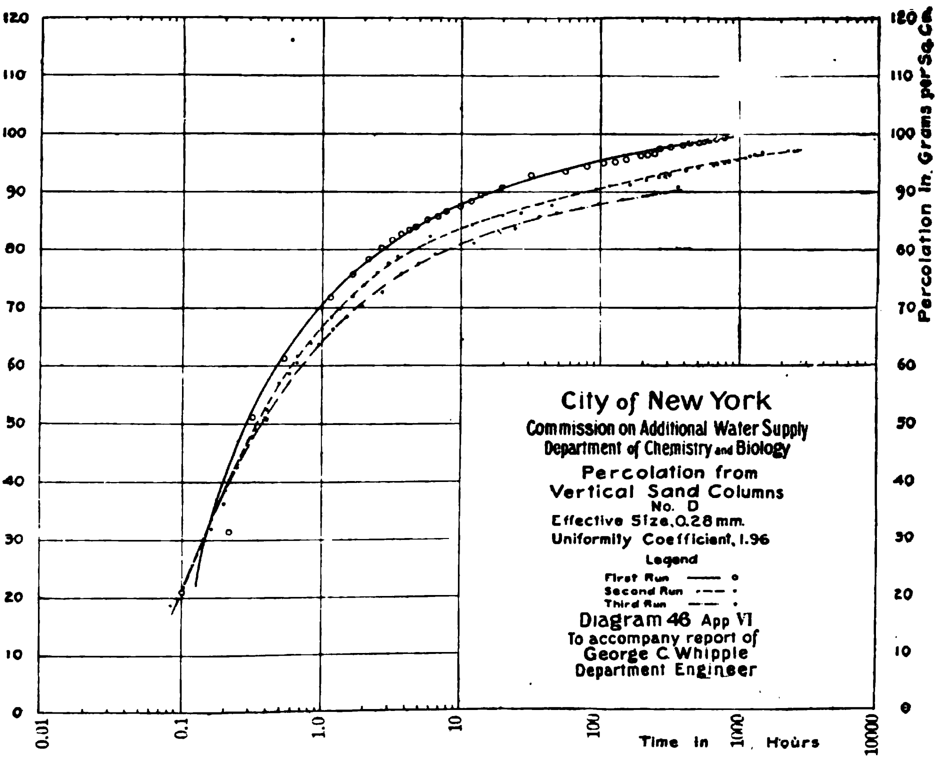

City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
Nos. A, 2, 3, & 4
Legend
No. A
No. 2
No. 3
No. 4
Diagram 43 App VI
To accompany report of
George C Whipple
Department Engineer
Percolation in Grams per Sq. Cm.
Time in Hours
0
10
20
30
40
50
60
70
80
90
100
110
120
0.01
0.1
1.0
10
100
1000
10000



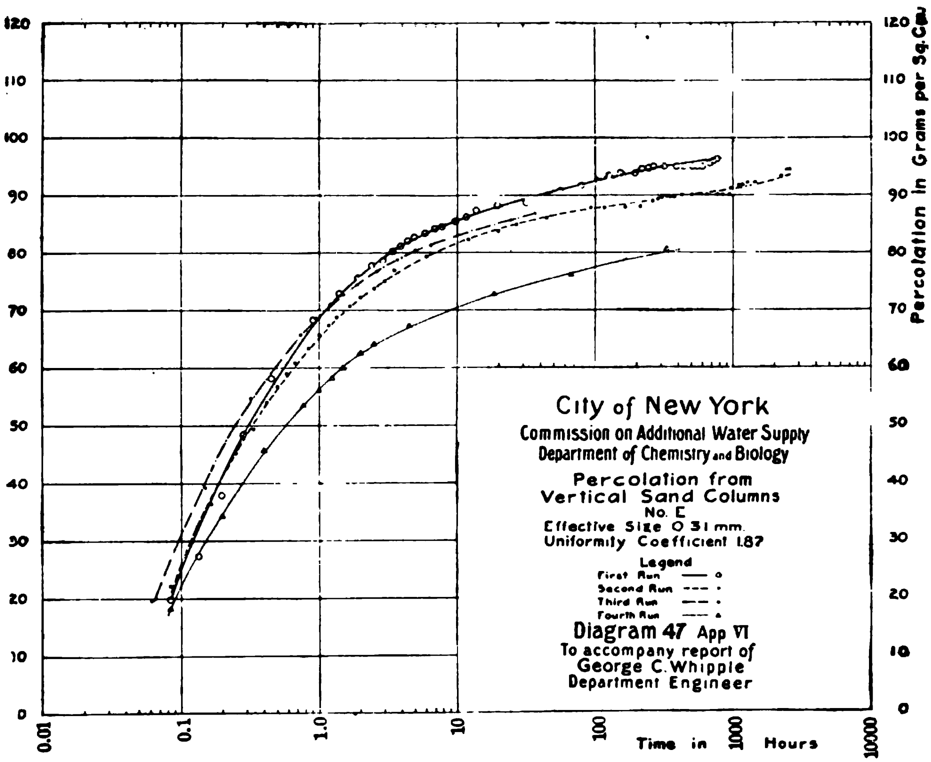
City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
Effective Size 0.27 mm.
Uniformity Coefficient 1.35
No B
Legend
First Run
Second Run
Third Run
Diagram 44 App VI
To accompany report of
George C Whipple
Department Engineer
Percolation in Grams per Sq. Cm.
Time in Hours
0.01
0.1
1.0
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100
110
120

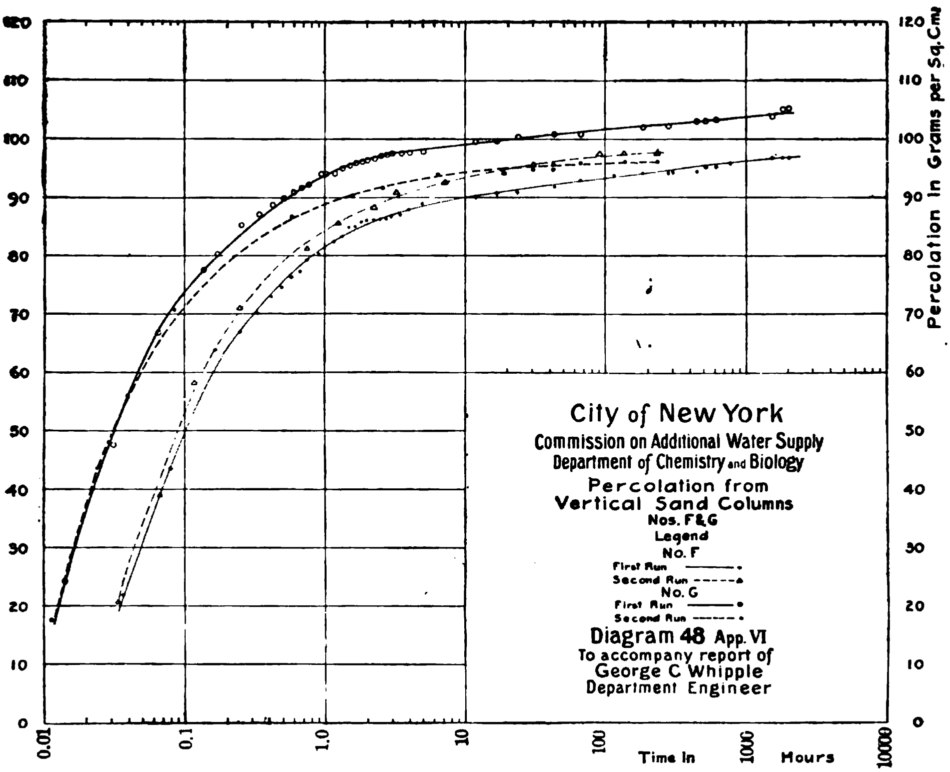


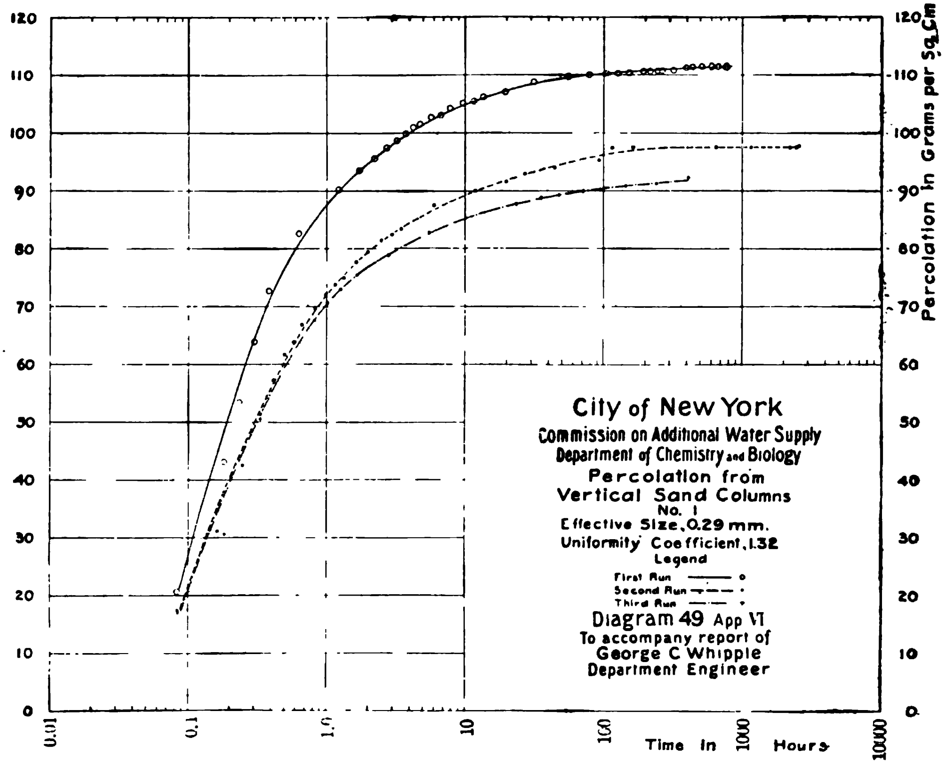
City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
Effective Size, 0.22 mm.
Uniformity Coefficient, 1.77
No. C
Legend
First Run
Second Run
Third Run
Diagram 45 App VI
To accompany report of
George C. Whipple
Department Engineer
Percolation in Grams per Sq. Cm.
Time in Hours
0.01
0.1
1.0
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100
110
120

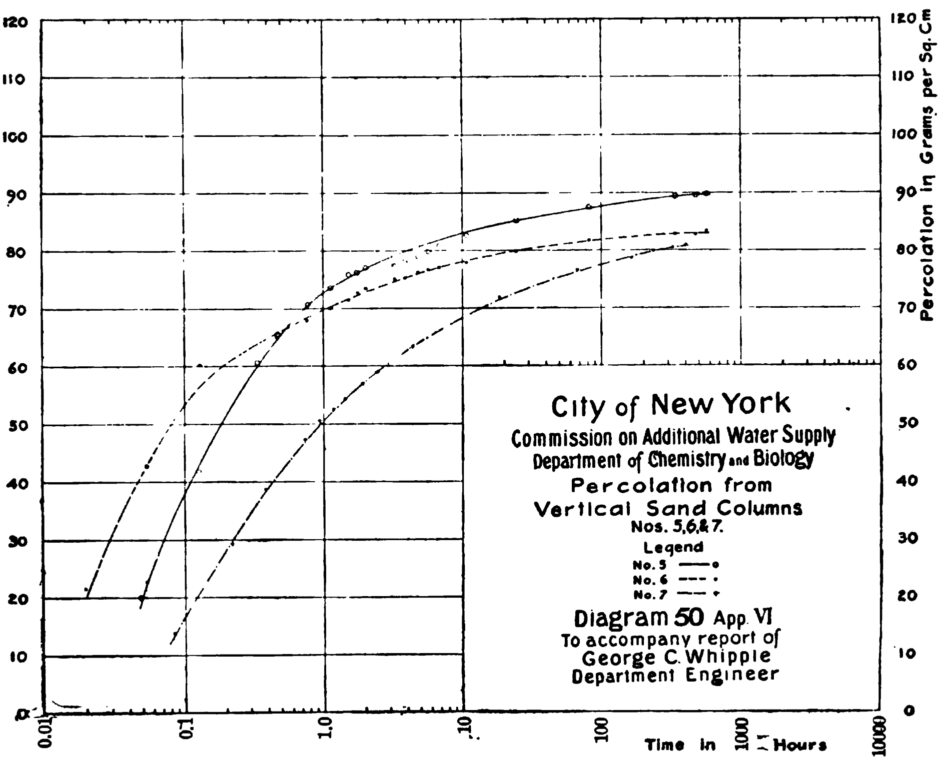


City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
No. D
Effective Size, 0.28 mm.
Uniformity Coefficient, 1.96
Legend
First Run
Second Run
Third Run
Diagram 46 App VI
To accompany report of
George C. Whipple
Department Engineer
Percolation in Grams per Sq. Cm.
Time in Hours
0.01
0.1
1.0
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100
110
120


City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
No. E
Effective Size 0.31 mm.
Uniformity Coefficient 1.87
Legend
First Run
Second Run
Third Run
Fourth Run
Diagram 47 App VI
To accompany report of
George C. Whipple
Department Engineer
Percolation in Grams per Sq.Cm.
Time in Hours
0.01
0.1
1.0
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100
110
120


City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
Nos. F & G
Legend
No. F
First Run
Second Run
No. G
First Run
Second Run
Diagram 48 App. VI
To accompany report of
George C Whipple
Department Engineer
Percolation in Grams per Sq. Cm.
Time in Hours
0.01
0.1
1.0
10
100
1000
10000


City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Percolation from
Vertical Sand Columns
No. 1
Effective Size, 0.29 mm.
Uniformity Coefficient, 1.32
Legend
First Run
Second Run
Third Run
Diagram 49 App VI
To accompany report of
George C Whipple
Department Engineer
Percolation in Grams per Sq. Cm
Time in Hours
0.01
0.1
1.0
10
100
1000
10000
0
10
20
30
40
50
60
70
80
90
100
110
120



The results obtained with the graded sands showed that the coarser materials drained most rapidly and came first to a point where percolation became small, while the finer materials drained less rapidly at first but gave a more constant percolation. The total percolation at the end of any given time was greater with the coarser sands. This is indicated by Diagram 51, where the average percolations shown by the three different runs are given for various periods of time, the effective size of the material being used as the basis for classification. The rates of percolation at different times are given in Table 51.

TABLE 51.

Sand Number.	Test Number.	Effective size in Mm.	Uniformity Coefficient.	Rate of Percolation in Grams per Square Centimetre per Minute at or near the End of the Interval from the Start of											
				Minutes.					Hours.				Days.		
				Initial.	5	10	20	30	1	12	24	48	15	30
A	1	....	....	....	0.0073	....	....	....	0.00694	0.00679	0.00389	0.00279	0.0001187	0.0000117
B	1	0.27	1.35	2.285	1.60	1.50	1.354	1.058	0.281	0.01553	0.00533	0.001737	0.0002145	0.00000685
	2	....	....	....	2.23	1.72	1.436	1.156	0.265	0.0112	0.00303	0.00148	0.0000198	0.00000965
	3	....	....	....	....	2.23	1.84	....	0.237	0.0059	0.00437	0.000508	0.000185	....
C	1	0.22	1.77	....	....	1.439	0.444	0.768	0.396	0.00859	0.004043	0.001643	0.0001071	0.0000506
	2	....	....	....	1.688	1.216	0.954	0.760	0.307	0.01156	0.003133	0.00206	0.0002245	0.000005075
	3	....	....	....	....	1.655	1.223	....	0.284	0.0078	0.00538	0.000953	0.0001055	....
D	1	0.275	1.96	....	3.488	1.481	3.320	0.829	0.2855	0.0987	0.00279	0.000407	0.000107	0.0000416
	2	....	....	....	3.728	2.632	1.302	0.908	0.2455	0.00567	0.000836	0.00129	0.0000907	0.0000396
	3	....	....	....	3.48	2.56	1.627	....	0.1837	0.0512	0.00356	0.000993	0.000154	....
E	1	0.31	1.87	....	3.99	2.516	1.054	0.963	0.3780	0.00768	0.00207	0.000814	0.0000005	0.00038213
	2	....	....	....	4.45	2.848	0.848	0.557	0.2235	0.00823	0.00272	0.000457	0.000174	0.000008
	3	....	....	5.41	....	3.66	1.535	....	0.2185	0.00329	0.00421	....	....	....
	4	....	....	....	3.652	2.291	0.952	....	0.209	0.00308	....	....	0.000148	....
F	1	0.57	1.175	10.11	....	3.795	0.649	0.316	0.1008	0.00308	0.000338	0.000768	0.000056	0.0000477
	2	....	....	10.33	9.16	6.40	....	....	0.145	0.00677	0.00194	0.000009	....	....
G	1	0.94	1.49	29.31	9.625	1.275	0.3863	0.2193	0.00219	0.00418	0.00168	0.000463	0.0000198	0.00000343
	2	....	....	26.33	5.60	....	....	0.532	0.0593	0.00095	....	0.0000061	....	....
I	1	0.285	1.315	....	4.43	3.75	2.613	1.98	0.2114	0.00366	0.00235	0.000641	0.0000802	....
	2	....	....	....	3.486	2.736	1.79	0.896	0.2325	0.00670	0.00324	0.00103	....	....
	3	....	....	....	3.40	2.61	1.993	0.874	0.2690	0.00525	0.00433	0.000764	0.0000885	....
2	..	....	....	....	2.772	2.422	1.61	0.558	0.1935	0.01168	0.00257	....	0.0000284	0.0000098
3	..	....	....	5.64	8.23	3.433	1.863	0.644	0.1708	0.0168	0.00251	0.00110	0.00000152	....
4	..	....	....	....	....	....	....	....	0.0092	....	0.00328	0.00264	0.000198	0.0000533
5	..	0.32	3.75	6.88	4.55	....	1.537	0.633	0.1436	0.00743	0.00325	....	0.0001119	....
6	..	0.59	9.33	19.01	....	3.95	....	2.44	0.0965	0.00362	0.00267	....	0.0000709	....
7	..	....	....	....	2.796	1.905	....	....	0.1936	....	0.09979	....	0.000157	....

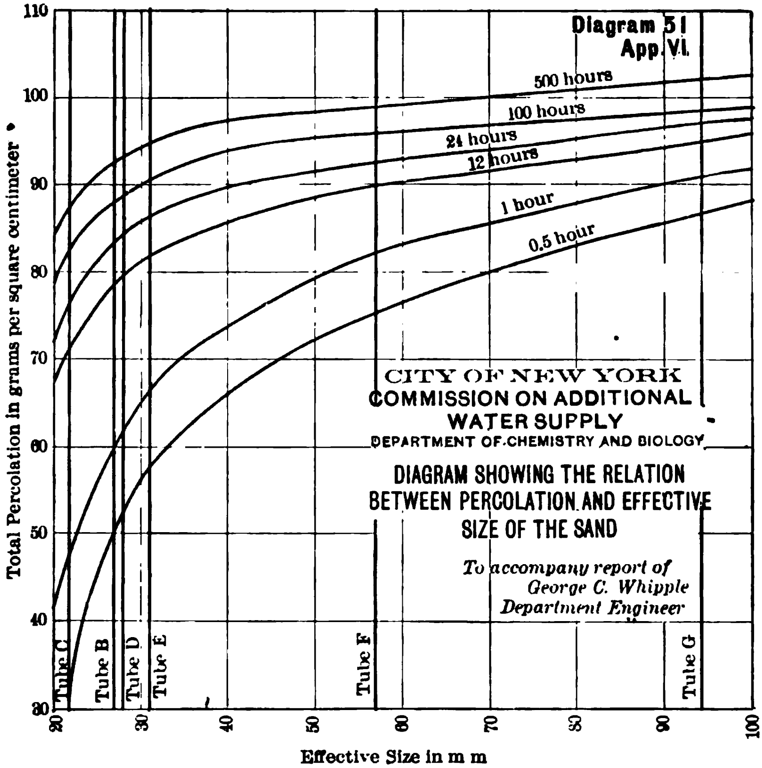


Diagram 51
App. VI.
500 hours
100 hours
24 hours
12 hours
1 hour
0.5 hour
Tube C
Tube B
Tube D
Tube E
Tube F
Tube G
Total Percolation in grams per square centimeter
Effective Size in m m
CITY OF NEW YORK
COMMISSION ON ADDITIONAL WATER SUPPLY
DEPARTMENT OF CHEMISTRY AND BIOLOGY
DIAGRAM SHOWING THE RELATION BETWEEN PERCOLATION AND EFFECTIVE SIZE OF THE SAND
To accompany report of
George C. Whipple
Department Engineer

Comparison of the different runs showed that in most cases the first run gave the greatest percolation, but this was not always the case. The differences were not constant, however, and no explanation based on compacting of the material, the character of the water used, the growth of bacteria in the water, the temperature of the water, or the meteorological conditions served to explain them, although all of these factors may have influenced the results.

In this connection it may be stated that at the end of the runs, samples of the sands at different depths were examined bacteriologically, and the following numbers of bacteria were found:

Depth in Feet Below Top of Sand.	Number of Bacteria per C. C.					
	Tube B	Tube C.	Tube D.	Tube E.	Tube F.	Tube I.
2	48,000	100,000	167,000	69,000	250	2,400
4	23,000	9,000	44,000	81,000	4,500	2,200
6	49,000	50,000	18,000	102,000	4,500	1,400
8	38,000	79,000	11,000	85,000	3,000	1,300
10	8 000	7,000	8,000	23,000	11,000	250

The natural distribution of moisture in the tubes at the conclusion of the experiments is shown by Table 52. It will be seen that in the case of the graded sands the total moisture remaining was inversely proportional to the fineness of the material.

Diagram 52 shows the vertical distribution of moisture in the tubes which contained the coarse sand, a fine sand and a very fine material which contained silt.

CITY OF NEW YORK

COMMISSION ON ADDITIONAL WATER SUPPLY

DEPARTMENT OF CHEMISTRY AND BIOLOGY

Diagram 52
App. VI

DIAGRAM SHOWING THE DISTRIBUTION OF MOISTURE AFTER 20 DAYS PERCOLATION IN TUBES G AND C FILLED WITH COARSE AND FINE SAND RESPECTIVELY

To accompany report of
George C. Whipple
Department Engineer

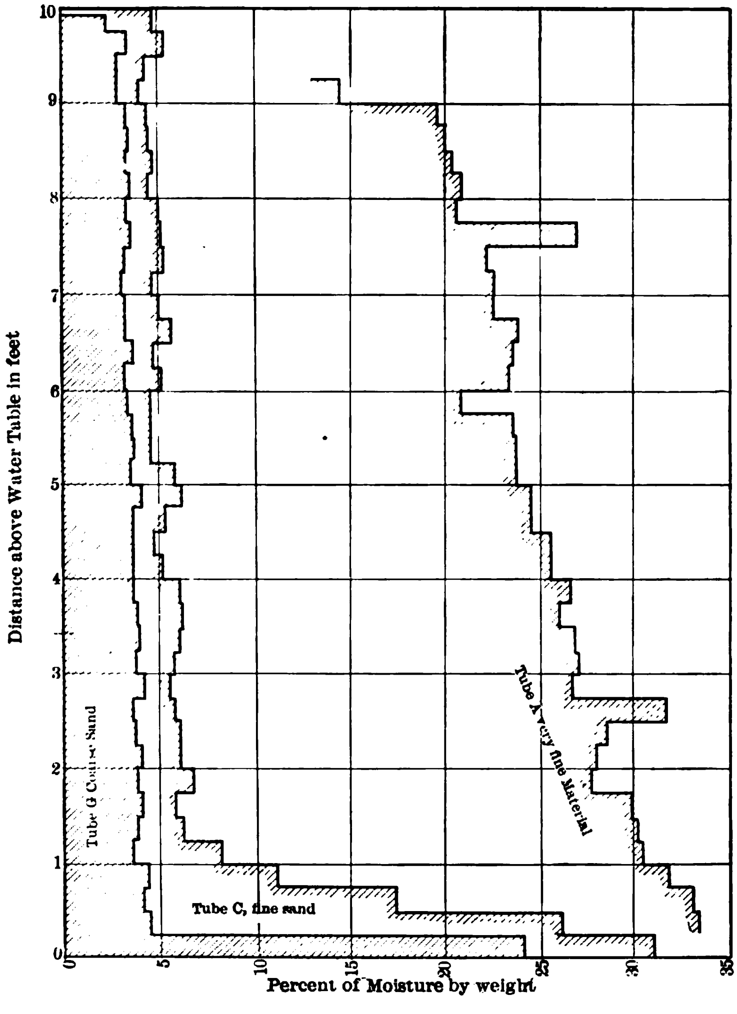


Diagram 53 shows the distribution of moisture in a column composed of alternate layers of coarse and fine sands, compared with the results obtained with the two sands used separately. The effect of the arrangement of sands in raising the total moisture retained is very marked.

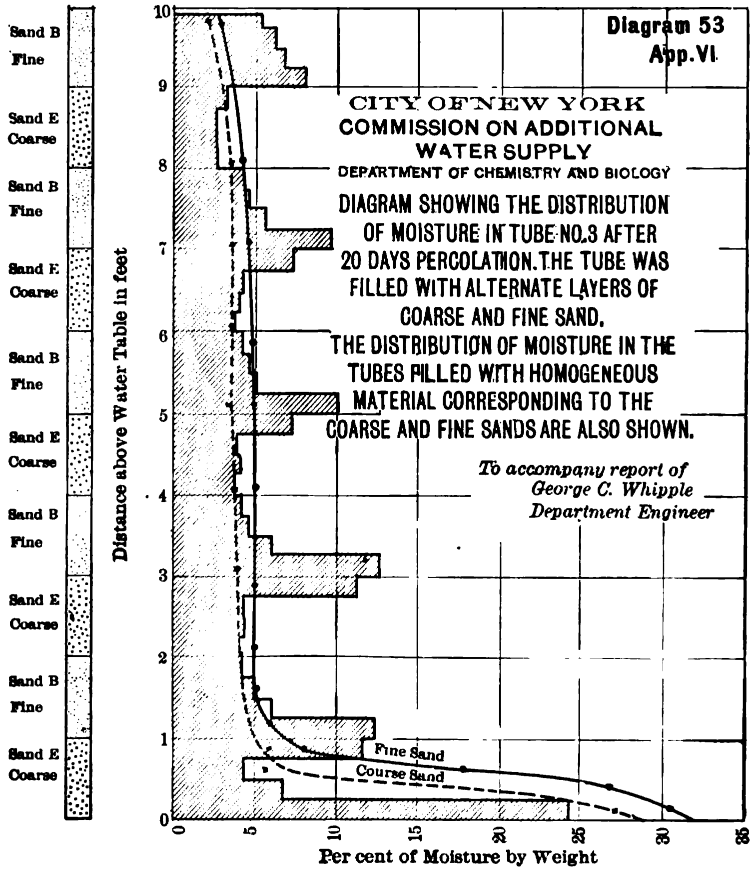
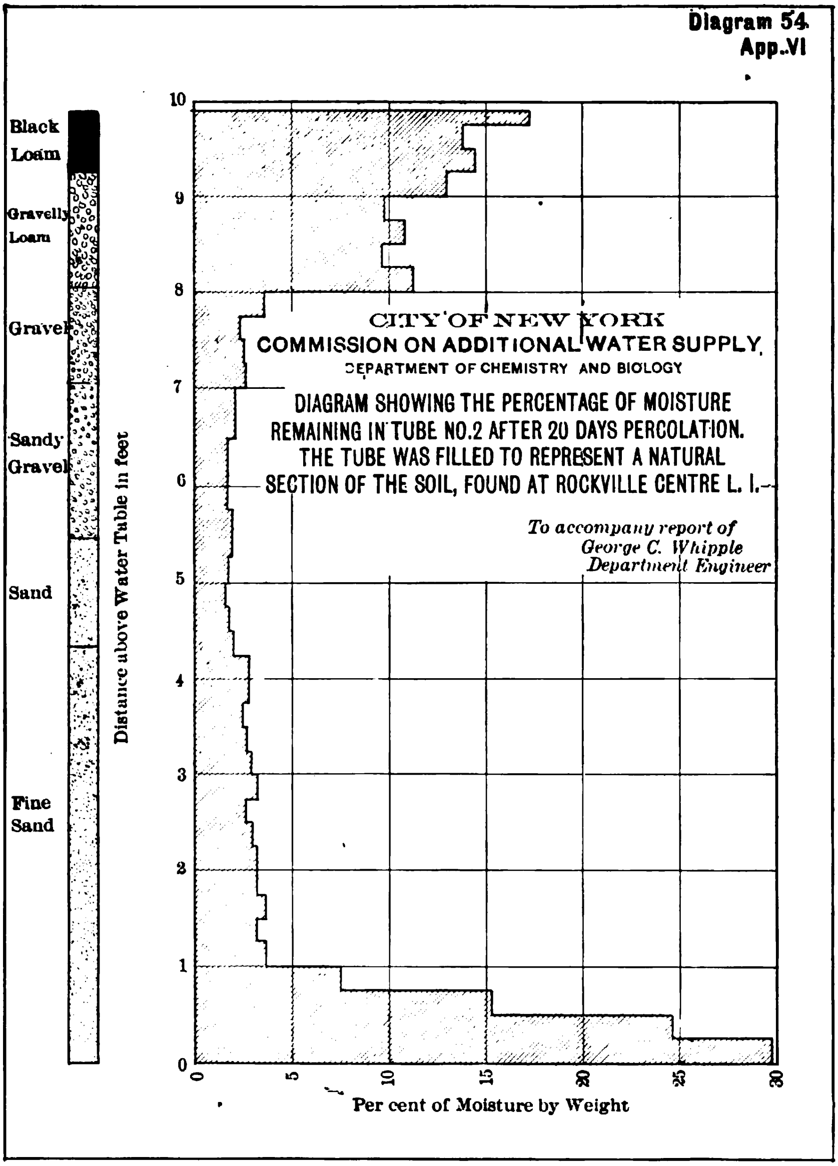


Diagram 54 shows the effect of the fine material at the surface of the ground upon the vertical distribution of moisture.



Capillarity.

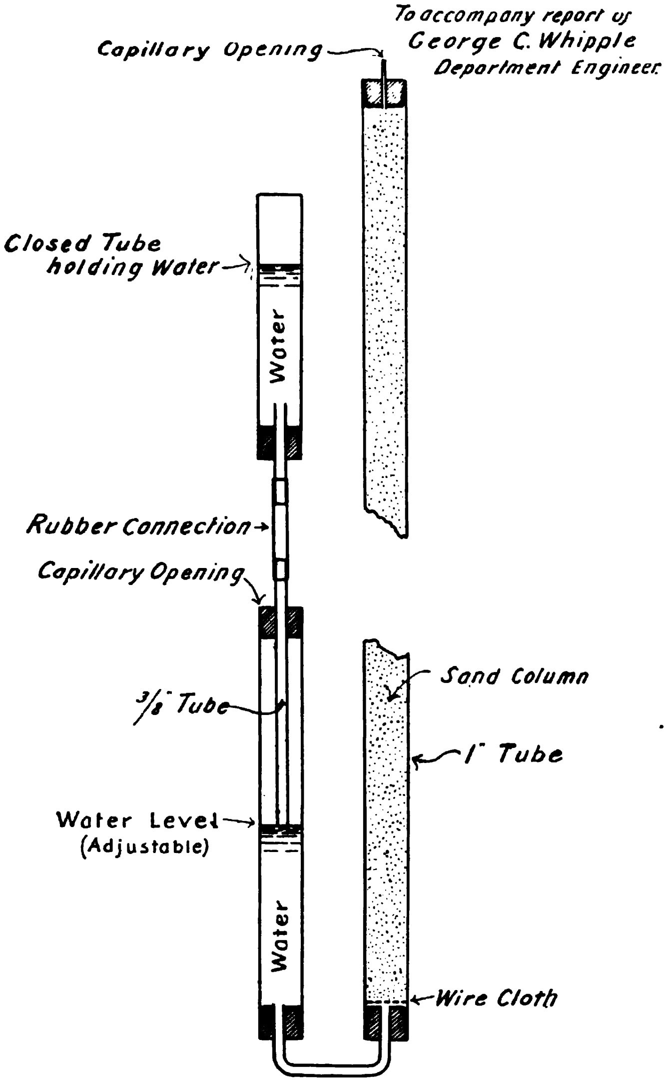
The experiments on capillarity were made to determine the maximum vertical distance through which water could be raised by the action of surface tension in soils of different texture under different conditions. Sands graded by sifting and natural deposits from Long Island were used. From the series of graded sands it was hoped that a relation might be established between the capillary limit and the "effective size" of the sand, and from the natural Long Island sands it was desired to ascertain if the limits thus established were applicable to natural materials. The experiments were made with both wet and dry sands, by methods which will be separately described.

Experiments on Dry Sands.

Thirty glass tubes one inch in diameter and six feet long were set in an upright position and filled with the materials to be tested. The general arrangement of each tube is shown in Diagram 55. The tubes were arranged in groups of three, each group having a different material. The first tube of each group was used with distilled water, the second with Brooklyn tap water, and the third with sea water. The following materials were used:

Numbers of Tubes.	Kind of Material.	Effective Size.	Uniformity Co-efficient.
1, 2, 3	Clay	....	....
4, 5, 6	Sand (containing silt)	.03 (estimated.)	....
7, 8, 9	Sand	.27	1.36
10, 11, 12	"	.36	1.26
13, 14, 15	"	.46	1.24
16, 17, 18	"	.49	1.47
19, 20, 21	"	.29	1.33
22, 23, 24	"	.29	1.26
25, 26, 27	"	.59	1.17
28, 29, 30	"	.92	1.52

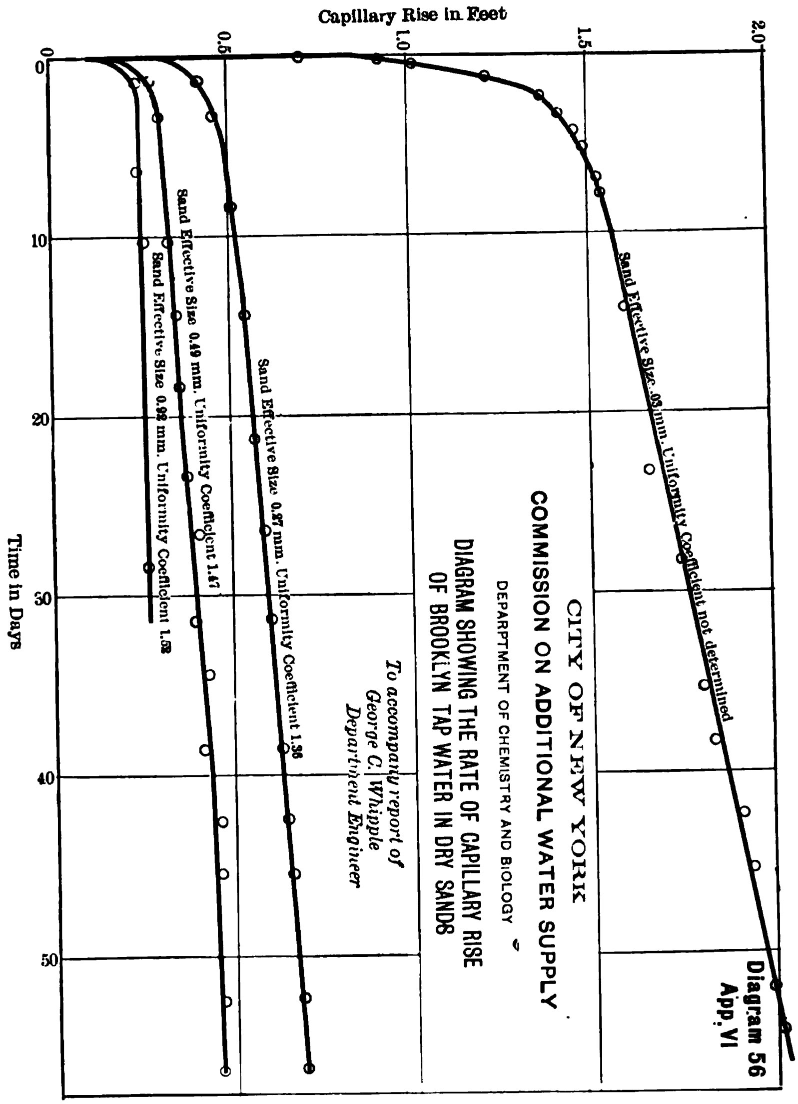
Diagram 55 App. VI



City of New York
Commission on Additional Water Supply
Department of Chemistry and Biology
Diagram Showing Apparatus used in Capillary Experiments with Dry Sands.
(Not drawn to Scale)

The sands were thoroughly dried in an oven, and put into the tubes, being stirred with a spiral wire and shaken during the process of filling in order to make the mass homogeneous and compact. After the tubes had been put in place, water was poured into the reservoir arms in such a way as to avoid any air traps. Observations upon the height of the capillary rise were made at frequent intervals during the first twenty-four hours, after which they were made daily for about two months. The point where the sand ceased to be visibly moist was not always well defined, so that the observations could not be made with great accuracy. Taken as a whole, however, they are substantially correct.

In all of the tubes there was a rapid initial rise of water in the sand columns, which was most marked in the case of the materials of finer grade. The rate of rise then gradually decreased until after a few days it ceased altogether in the coarser materials, as may be seen from Diagram 56. In the tubes filled with the fine sand it continued at a slow but constant rate for two months, in spite of the fact that the tubes were closed at the top save for a capillary vent. How much longer the water would have continued to rise in the fine sand is not known. The elevation of the top of the moist column of sand above that of the water in the reservoir at the end of the sixty days' experiment was taken as the capillary limit, although in the case of the fine sands this is not strictly correct, as Diagram 56 shows.


Capillary Rise in Feet
0
0.5
1.0
1.5
2.0
Time in Days
0
10
20
30
40
50
CITY OF NEW YORK
COMMISSION ON ADDITIONAL WATER SUPPLY
DEPARTMENT OF CHEMISTRY AND BIOLOGY
DIAGRAM SHOWING THE RATE OF CAPILLARY RISE
OF BROOKLYN TAP WATER IN DRY SANDS
To accompany report of
George C. Whipple
Department Engineer
Diagram 56
App. VI
Uniformity Coefficient not determined
Sand Effective Size 0.37 mm. Uniformity Coefficient 1.38
Sand Effective Size 0.49 mm. Uniformity Coefficient 1.47

The difference observed between the sea water, tap water and distilled water were not as great as had been expected. In the case of the finer sands the capillary limits with the three waters stood in the order just mentioned, approximately in the ratio of 1:1.15:1.25. In the case of the coarser sands the differences were quite irregular.

At the end of about two months the caps were removed from the tubes and the tops left open for evaporation. This did not appear to have any marked effect on the capillary rise of water as shown by the top of the moist columns. In a few of the tubes there was a slight lowering of the moisture level, which may have been due to evaporation.

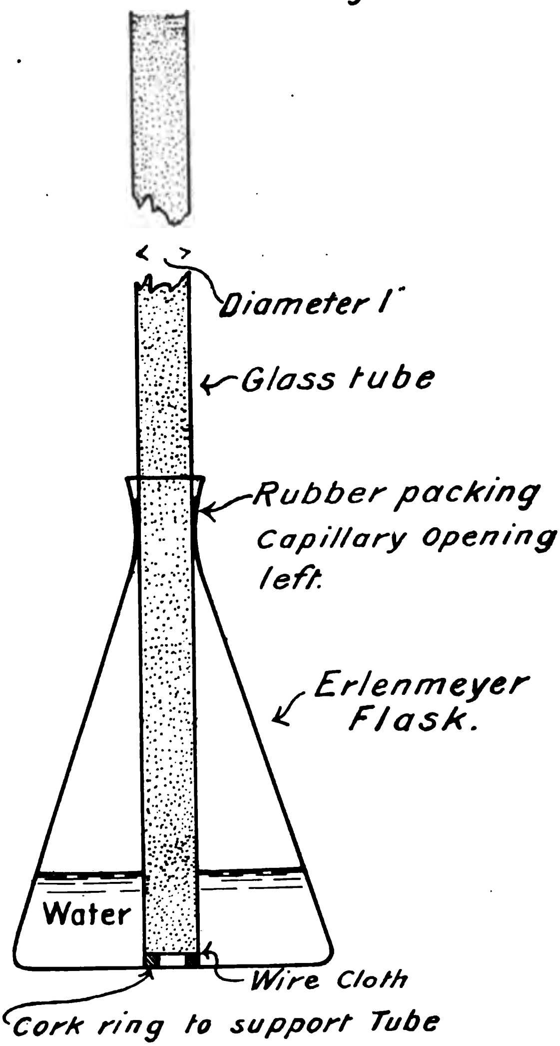
The capillary limits on the maximum vertical distance through which the water will move upward under the influence of surface tension for sands of different degrees of fineness is shown in Diagram 56.

Experiments on Wet Sands.

The capillary limit for wet sands obviously could not be determined by the same method that was used for dr ysands. The following method was, therefore, used instead.

Glass tubes, one inch in diameter and of variable lengths, were filled with the materials to be tested and placed vertically with their lower ends in Erlenmeyer flasks containing water. The detailed arrangement is shown in Diagram 57. The amount of water drawn up each day was obtained by removing and weighing the flasks. The tubes were carefully filled with dry material, compacted by stirring with a spiral wire, shaking and tapping the bottom. They were then filled from below with boiled tap water, and allowed to settle several hours. They were then set in a pan of water and allowed to drain for a week or more, the tops meanwhile being capped, with only a capillary opening left. After percolation had practically ceased the tubes were placed in the Erlenmeyer flasks, the caps removed, and the observations begun. In filling those tubes which were to contain loam, the material was put in in six-inch layers, and successively filled with water from below. Only in this way was it found possible to secure a compact column. The tubes were placed in a rack in the basement of the laboratory and the air over the tops of the tubes kept in motion by means of a fan. From time to time the flasks were removed and weighed and the loss of water by capillary abstraction determined. While the flasks were being weighed a second flask was substituted and a correction applied for the drip. These observations were carried on for a period of about three months.

Diagram 57 App. VI

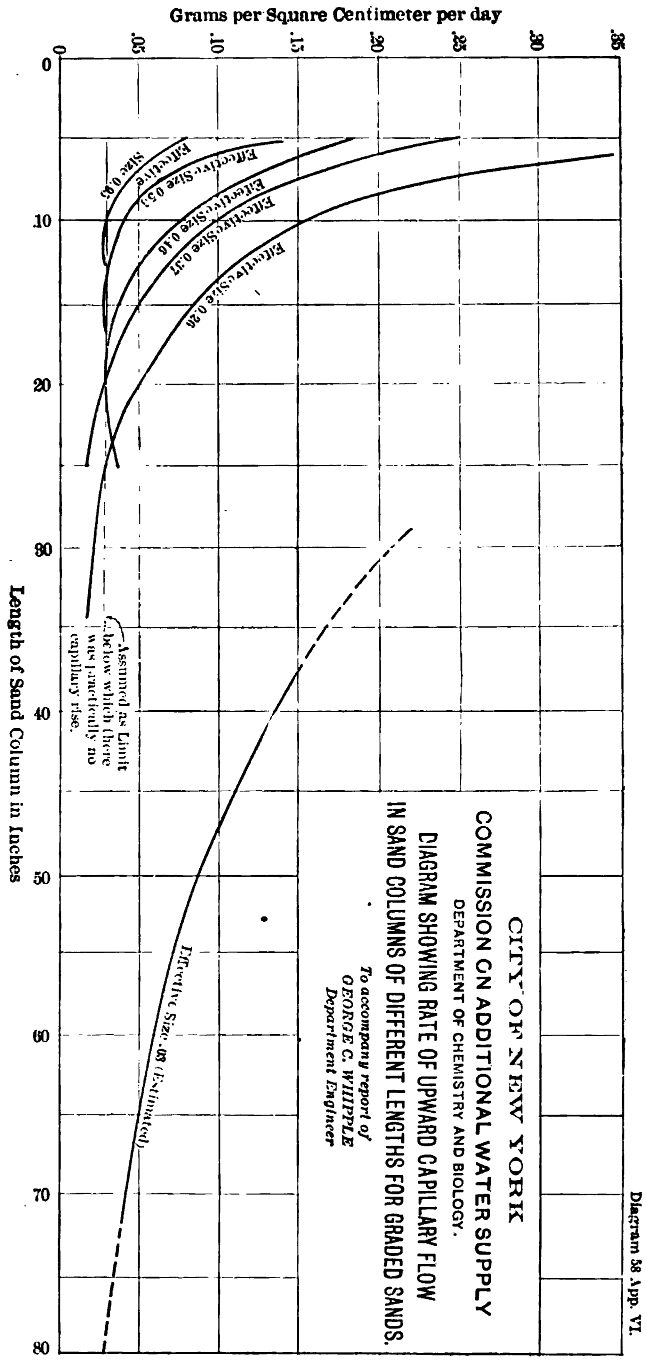


City of New York

Commission on Additional Water Supply
Department of Chemistry and Biology.

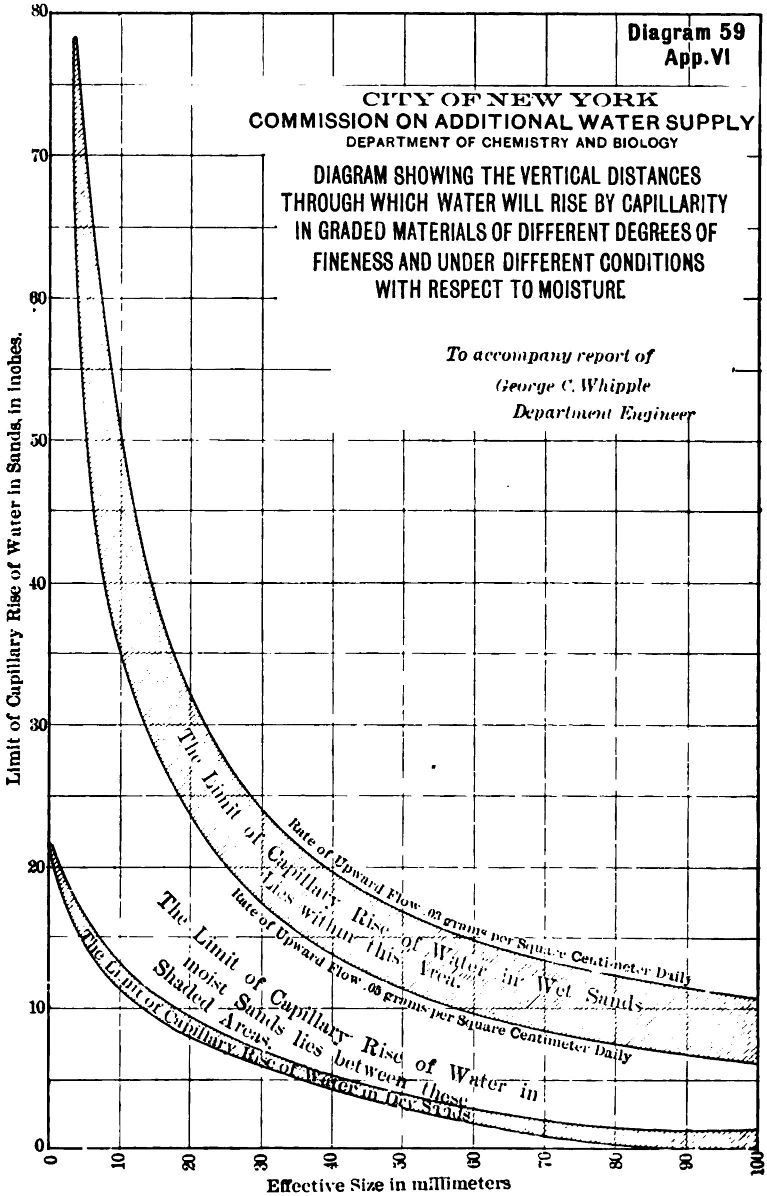
Apparatus Used for Capillary Experiments with Wet Sands.

To accompany report of
George C. Whipple.
Department Engineer.



Grams per Square Centimeter per day
0
.05
.10
.15
.20
.25
.30
.35
0
10
20
30
40
50
60
70
80
Length of Sand Column in Inches
Effective Size 0.63
Effective Size 0.53
Effective Size 0.46
Effective Size 0.37
Effective Size 0.26
Effective Size .08 (Estimated)
Assumed as Limit below which there was practically no capillary rise.
CITY OF NEW YORK
COMMISSION ON ADDITIONAL WATER SUPPLY
DEPARTMENT OF CHEMISTRY AND BIOLOGY.
DIAGRAM SHOWING RATE OF UPWARD CAPILLARY FLOW
IN SAND COLUMNS OF DIFFERENT LENGTHS FOR GRADED SANDS.
To accompany report of
GEORGE C. WHIPPLE
Department Engineer
Diagram 58 App. VI.

greater than about four feet, when the sand grains are wet. When such sands are dry, the capillary limit may be as low as one foot, and when they are moist, the limit is between one and four feet. These facts are illustrated in Diagram 59.



The coarser the sands, the lower the vertical capillary limit, and the finer the sands, the higher the limit. In case of silt-bearing sands the limit is probably not less than six or seven feet, and may be even greater than this.

The maximum rate at which an upward capillary flow will occur in sands of different texture is of great importance to agriculture, but pressure of other work did not permit the necessary experiments to be made.

VII.—Organization of the Department and Summary of Work Done.

The original instructions of the Commission to the Department Engineer were to make such chemical and biological analyses of water and such other investigations and inspections as were necessary to determine the sanitary quality of all the sources of water supply available for the City of New York, and their general fitness for purposes of a public supply; and to compare the qualities of the various waters proposed as sources of supply with that of the present water supply of the City of New York. Instructions were also received from Hon. Robert Grier Monroe, Commissioner of the Department of Water Supply, Gas and Electricity, to utilize the existing facilities and organization of the department laboratory in this work. At the same time Commissioner Monroe directed the regular operations of the laboratory to be extended so as to cover the water supplies of the entire City, the work up to that time having embraced practically only the Boroughs of Brooklyn and Queens. Moreover, as the work for the Commission progressed, its scope was extended to include numerous incidental investigations, the most important of which were those relating to soil physics; that is, to the phenomena of capillarity, percolation, etc., in columns of soil. All this work simultaneously undertaken made it necessary to enlarge the laboratory headquarters at Mt. Prospect, Brooklyn; to establish a branch laboratory for biological work at Katonah, on the Croton Watershed, and to equip a temporary laboratory at Poughkeepsie, N. Y., and a field station at Floral Park, on Long Island. It was also necessary to very materially increase the working staff.

The work was organized early in January of the present year, and the first party was sent into the field on January 5. For the first two months the field work was directed from Mt. Prospect Laboratory, but the Poughkeepsie Laboratory was occupied on March 3, and made the base of field operations until September 10. The building for the Katonah Laboratory was begun early in the year, but it was some time in June before the equipment was complete. The laboratory experiments on soil physics were begun on February 13, at Mt. Prospect Laboratory, and continued until October 31. The field station at Floral Park for the determination of soil-moisture was established about the middle of June. Most of the field work on stream investigations was suspended on September 1, but the tidal observations and the soil-moisture experiments were continued until October 31. On September 10 the field force was transferred to the Commission headquarters in the Park Row Buildindg, and relieved from duty as fast as the results of the observations were compiled. By October 31 the entire force had been discharged.

To mention those who deserve commendation for faithful service would require to name the entire force, but especial credit is due to Mr. George A. Johnson, director of field work, and to Mr. Langdon Pearse, who had charge of the experiments on soil physics. Mention should be made also of the four volunteer inspectors, students of the Massachusetts Institute of Technology, who, working without salary beyond their expenses, devoted their summer vacation to the sanitary inspection of the various watersheds.

The headquarters of the Department of Chemistry and Biology has been at Mt. Prospect Laboratory, the regular laboratory of the department. This laboratory was established while Brooklyn was an independent municipality by I. M. de Varona, C. E., then Engineer of Water Supply and now Chief Engineer of the Department of Water Supply, Gas and Electricity for the Borough of Brooklyn. It is located in the gate-house of Mt. Prospect Reservoir near the entrance to Prospect Park. It contains on the main floor two large chemical rooms, a biological room and the office, and in the basement a cement-testing room, which during the past summer, has been used chiefly for the sand analyses. There is also a deep basement, where the water mains leave the reservoir, and this has been utilized in connection with the experiments on soil physics. There is also in the basement a small photometer room which was used for the sand experiments. In all its departments the laboratory is well equipped with the most modern forms of apparatus, designed to facilitate the rapid execution of work as well as to insure accurate results. Practically all of the chemical analysis of water was carried on in Mt. Prospect Laboratory, and all solutions used in the branch laboratories and in the field were there prepared and tested.

The biological laboratory at Katonah was made necessary by the inability of the express companies to get samples of water from the Croton Watershed to Mt. Prospect Laboratory in time for satisfactory examination.

This laboratory is located near the centre of the watershed, and is in the same building with the office of the Assistant Engineer who has charge of the sanitary patrol, thus putting these two departments into close touch. The laboratory consists of a single room, and in its equipment and scope of work it resembles the old Chestnut Hill Laboratory of the Boston Water Works. Samples which require only microscopical or bacteriological examinations were sent there, but all samples for chemical analysis were sent to Mt. Prospect Laboratory, Brooklyn.

The laboratory at Poughkeepsie was established primarily for carrying on investigations to determine the character of the water of the Hudson River with reference to its filtration, and a complete equipment for bacteriological work was provided; but later it was found convenient to make this place the headquarters for most of the field work carried on in the Hudson valley. For this purpose a short lease was taken of three rooms on the second floor at No. 302 Main street. One of these served as the office of the field director and the other two were used for laboratory purposes. A valuable adjunct to the Poughkeepsie office was a 30-foot naphtha launch, which was in almost constant use on the Hudson in the collection of samples, observations of tides, currents, etc., and which on occasions was turned into a floating laboratory for making determinations of chlorine, etc.

The field station at Floral Park required no special equipment beyond the necessary tools and apparatus for collecting sand samples, etc. In addition to the collection of these samples the observer took charge of the meteorological instruments of the Long Island Division, which were also located at Floral Park.

The volume of work which has been done is shown in part by the following table of statistics:

Number of Samples of Water Examined, January 1, 1903 to November 1, 1903.

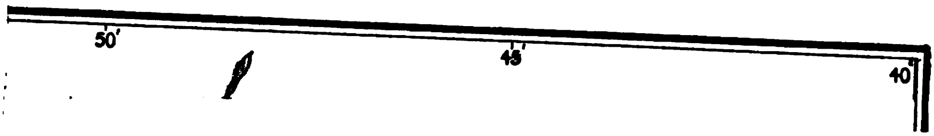
Mt. Prospect Laboratory—	
For Borough of Manhattan	1,494
For Borough of The Bronx	117
For Borough of Brooklyn	2,853
For Borough of Queens	164
For Borough of Richmond	99
For Commission on Additional Water Supply	994
Total	5,721
Katonah Laboratory—	
For Borough of Manhattan	1,010
Poughkeepsie Laboratory—	
For Commission on Additional Water Supply	9,520
Total	16,251

Character of Water Analyses Made between January 1 and November 1, 1903.

Analyses.	Mt. Prospect Laboratory.	Katonah Laboratory.	Poughkeepsie Laboratory.	Total.
Physical examinations	4,363	1,000	6,938	12,301
Complete chemical analyses	1,220	....	....	1,220
Partial " "	1,397	....	5,876	7,273
Microscopical examinations	2,122	670	....	2,792
Bacteriological examinations, quantitative	3,602	213	451	4,266
" tests for B. coli	3,573	209	200	3,982

Work of Department of Soil Physics.

Number of samples of sand analyzed mechanically	475
Number of samples of puddle tested for clay	200
Number of field determinations of soil moisture	1,400
Number of tubes used in percolation experiments	14
Number of tubes used in capillarity experiments	110


50'
45'
40'

APPENDIX VII.

Long Island Sources.

Appendix VII.

LONG ISLAND SOURCES.

WALTER E. SPEAR, *Department Engineer.*

To estimate the ground water resources of Long Island available for an additional supply for the Boroughs of Brooklyn and Queens, the general relations between the rainfall, evaporation, surface run-off and underground flow must be known.

The following facts must then be determined:

I.—The amount of rain that falls on Long Island.

II.—The amount of the evaporation or that portion of the rainfall which is evaporated from the soil and water surfaces and absorbed by vegetation.

III.—The surface run-off or that portion of the rainfall which flows directly into the surface streams without entering the soil.

IV.—The percolation or that portion of the rainfall which sinks into the ground and flows away through the pore spaces of the substrata.

V.—The percentage of this percolation that makes up a part of the flow of the surface streams and the remainder of the percolation, or the underflow, that reaches the sea without entering the streams; and

VI.—After the amount of ground water available for a water supply is known, the best and most economical means of developing the required supply must be found.

New Investigations.

The existing data on the general subject of ground water and on the specific problems of water supply and the geology of Long Island were inadequate for the solution of the questions that have been stated. Investigations of the problems of water supply and geology were begun early in March and continued until November 1, 1903.

Division of Work—The United States Geological Survey undertook the study of the geology of Long Island and of such of the water supply problems as were of general public interest, while this Commission investigated the particular questions that had a special bearing upon the additional ground water supply which it was proposed to obtain.

Investigations by the Commission on Additional Water Supply—The work originally assigned to the forces of the Commission comprised the rainfall studies, the driving of test wells, the measurements and levels required for the study of the fluctuations of the ground water and the contouring of its surface, the sanitary examinations of surface and ground waters and the studies of soil physics. To this work several other problems were afterward added, which had been taken up by the Geological Survey, but which had been left unfinished, including the stream gaugings, the under-flow measurements and the studies of the effect of pumping on the levels of the ground water.

The sanitary examinations of the Long Island streams, the studies of ground water pollution and the studies in the laboratory and in the field on soil physics were made by the Chemical and Biological Department.

Work of the Long Island Department.

The field work of the Long Island investigations, aside from that required for the studies of the Chemical and Biological Department, will be considered under the following subdivisions:

(*A*) *Meteorology*—Observations on temperature, wind, rainfall and relative humidity.

(*B*) *Evaporation and Percolation*—Studies on the evaporation from soil and the amount and rate of percolation through soils and substrata.

(*C*) *Location of Existing Dug and Driven Wells*—The location of wells over the area to be investigated, to obtain, as far as possible, the necessary ground water data without driving test wells.

(*D*) *Test Boring*—The sinking of test wells to supplement the existing wells and to determine the character of the substrata.

(*E*) *Ground Water Statistics*—The gathering of ground water statistics in order to learn the rate and amount of percolation from the surface of the ground to the surface of saturation, and to study the consequent fluctuations in the elevation of the water table.

(*F*) *Levels*—The connection, by a system of levels, of all the wells on which ground water observations were made with the surfaces of ponds and streams, in order to contour the upper surface of the ground water.

(*G*) *Stream Gauging*—Measurements of the surface flow of a group of Long Island streams to determine the relation of run-off to rainfall.

(*H*) *Underflow Measurements*—Measurements of underflow to secure an estimate of the amount of underground run-off or underflow from the Long Island watersheds.

(*I*) *Studies of the Effect of Pumping*—Examinations of the driven well stations of the Brooklyn Water Department and studies of the existing methods of obtaining ground water.

Extent of Investigations.

The investigations were at first confined to Nassau County and the Borough of Queens; later, the westerly portion of Suffolk County as far east as Patchogue and Port Jefferson was investigated with quite as much care as the original territory assigned; and, afterwards, less complete observations were made in the remainder of Suffolk County as far as Riverhead.

(*A*) *Meteorology.*

Seven rainfall stations were found on the Island in March, 1903, of which three were maintained by the United States Weather Bureau and four by the Brooklyn Water Department.

During the month of April, five meteorological stations were established by this Commission on Long Island, at Floral Park, Oyster Bay, Farmingdale, Brentwood and Manor, in order to supplement the rainfall measurements that were being made by the United States Weather Bureau and the Brooklyn Water Department, and to secure, in addition, such other information as the studies of evaporation, percolation, stream flow and ground water required.

Each of these stations was placed in an area not occupied by any existing station, in order that the distribution of the rainfall might be determined over the whole territory that was to be investigated. (See Plate V., page 672.) Two stations, those at Floral Park and Brentwood, were equipped with recording instruments to secure continuous observations of temperature, wind, relative humidity, atmospheric pressure and rainfall. The other three stations were each provided with the standard equipment of the voluntary stations of the United States Weather Bureau.

(a) *Stations Equipped with Recording Instruments.*

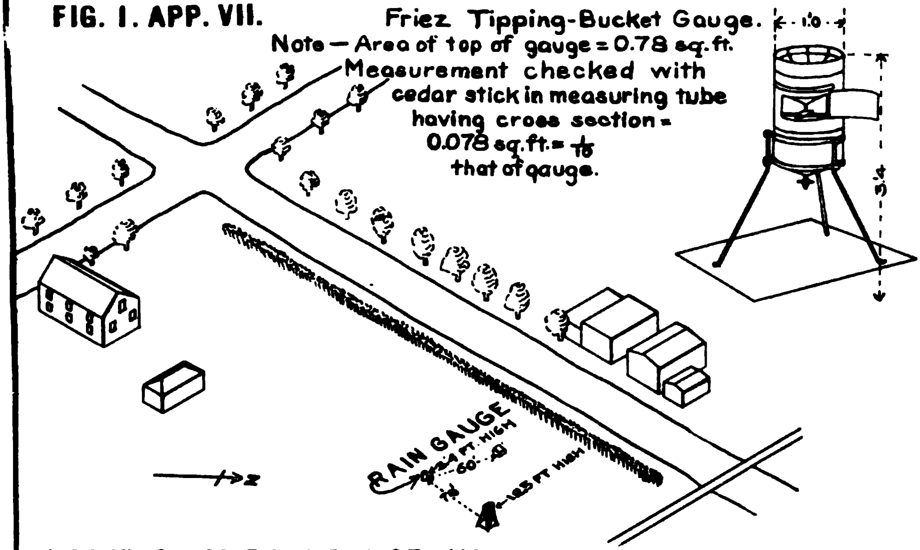
The location of the Floral Park station afforded continuous meteorological records which were representative of the conditions in the present Brooklyn Watershed; that of the Brentwood station, in Suffolk County, permitted a comparison of the meteorology of Suffolk County with that of Nassau County.

Floral Park Meteorological Station—At the Floral Park Station, the equipment consisted of a Friez tipping bucket rain-gauge, an anemograph, and a sunshine recorder, which registered on a single diagram (Friez " Triple Register "), a Richard thermograph, a Richard hygrograph, an accurate mercurial thermometer (H. J. Green), and a wet and dry bulb thermometer.

This station was located about one thousand feet east of the Floral Park railroad depot, on a lot of land about one acre in area, that was kindly placed at the disposal of the Commission by the owner, Mr. J. L. Childs, " The Seedman." Fig. 1, on page 623, shows the exposure of the rain-gauge and the position of the large standard Weather Bureau shelter, in which the thermograph, the hygrograph, the mercurial thermometer and the triple register were placed.

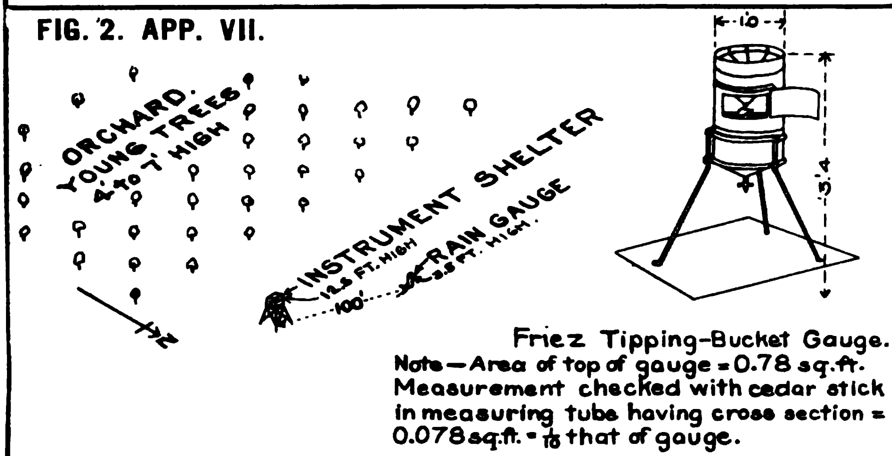
Brentwood Meteorological Station—The Brentwood Station was similarly equipped, excepting that a barograph was substituted for the hygrograph. The location of this station, two thousand feet east of the Long Island Railroad depot, was particularly favorable, as the instruments had a free exposure on all sides. (See Fig. 2, page 623.) Dr. W. H. Ross, on whose property the station was located, was formerly a voluntary observer of the United States Weather Bureau and kindly permitted the occupancy of the land without expense.

FIG. 1. APP. VII.



LOCATION OF RAIN GAUGE AT
FLORAL PARK METEOROLOGICAL STATION.
FLORAL PARK, NASSAU CO. N.Y.
MEASUREMENTS BEGUN APRIL 21, 1903.

FIG. 2. APP. VII.



LOCATION OF RAIN GAUGE AT
BRENTWOOD METEOROLOGICAL STATION.
BRENTWOOD, SUFFOLK CO. N.Y.
MEASUREMENTS BEGUN APRIL 8, 1903.

W.L.W. DEL.

At both stations, at Floral Park and at Brentwood, the instruments were compared by an engineering assistant.

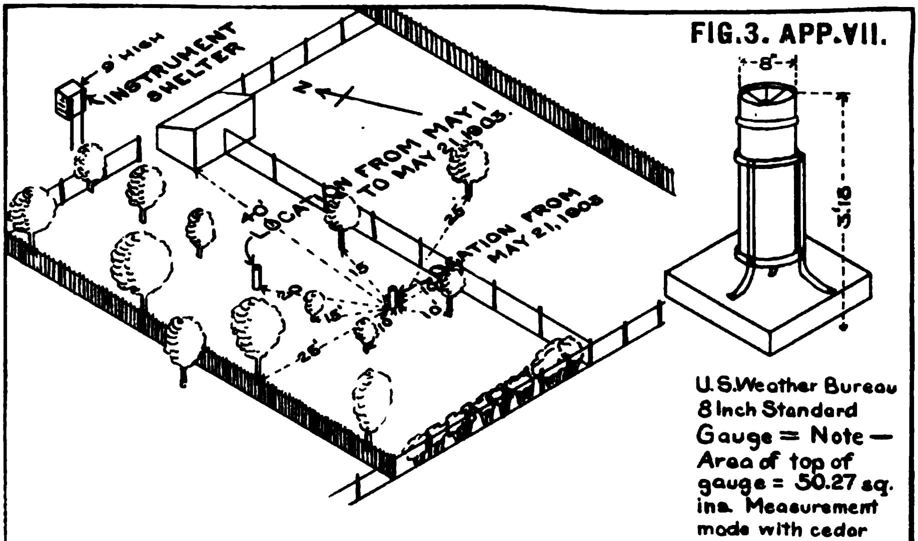
(*b*) *Stations Equipped with Standard Instruments.*

The Oyster Bay, Farmingdale and Manor Stations were equipped with standard rain-gauges and maximum-minimum thermometers, which were looked after by special observers. The thermometers were exposed in a small shelter, placed four feet above the ground, as shown in the sketches of these stations in Figures 3, 4 and 5.

Farmingdale Station—The instruments at this station were placed in the rear of the residence of the observer, Mr. Edward Bausch, three-quarters of a mile south of the Long Island Railroad depot at Farmingdale.

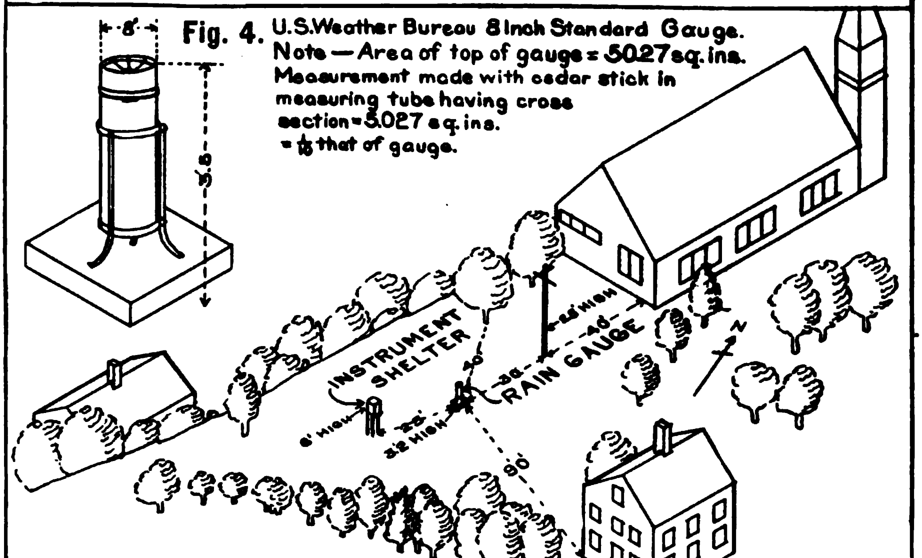
Oyster Bay Station—The Oyster Bay Station was located at the parsonage of the Presbyterian Church at Oyster Bay, where the observations were made by the Rev. A. G. Russell. The instruments were placed on the westerly side of the summit of a low hill, at a sufficient distance from the surrounding buildings and trees not to be affected by these obstructions.

FIG. 3. APP. VII.



LOCATION OF RAIN GAUGE AT FARMINGDALE RAINFALL STATION, FARMINGDALE, NASSAU CO. N.Y.
MEASUREMENTS BEGUN MAY 1, 1903.

Fig. 4. U.S. Weather Bureau 8 Inch Standard Gauge. Note — Area of top of gauge = 50.27 sq. ins. Measurement made with cedar stick in measuring tube having cross section = 5.027 sq. ins. = 1/10 that of gauge.



LOCATION OF RAIN GAUGE AT OYSTER BAY RAINFALL STATION, OYSTER BAY, NASSAU CO. N.Y.
MEASUREMENTS BEGUN MAY 1, 1903.

W.L.W. DEL.

Manor Station—The Manor Station was located on the farm of Mr. J. Norton Raynor, about a mile southwest of the Manor railroad depot; the observations were made by Miss E. A. Raynor. The rain-gauge was in an excellent position in an open field, and the thermometer shelter was attached to the north side of a wooden barn, about five feet above the ground.

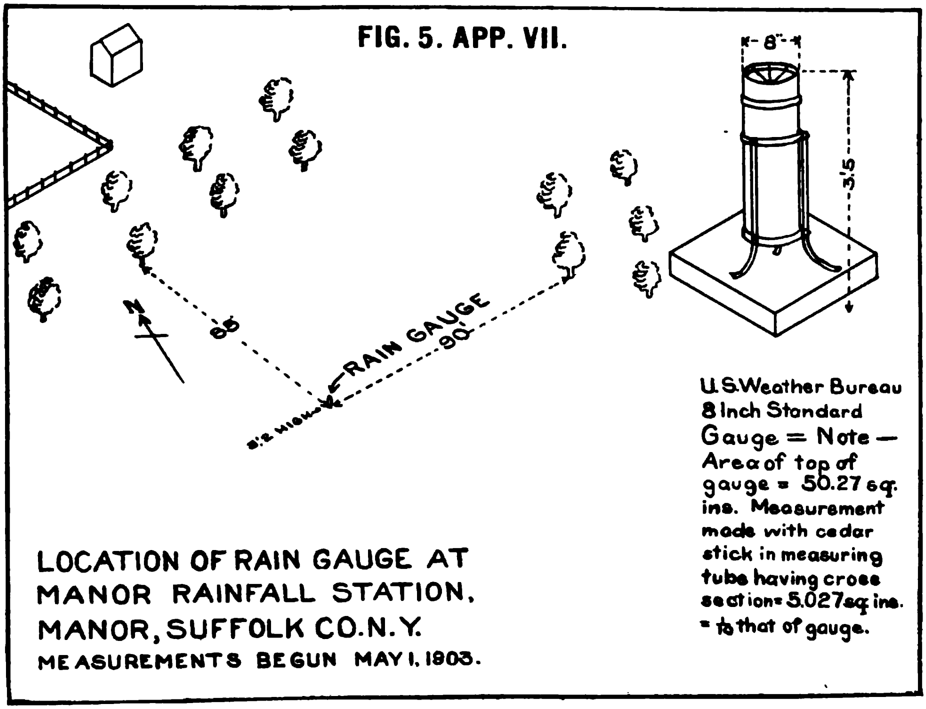


FIG. 5. APP. VII.

LOCATION OF RAIN GAUGE AT MANOR RAINFALL STATION, MANOR, SUFFOLK CO. N.Y.
MEASUREMENTS BEGUN MAY 1, 1903.

(*B*) *Evaporation and Percolation.*

(*a*) *Soil Evaporation.*

Observations on the evaporation from soil 2 feet above the surface of saturation were carried on from July to October at the Floral Park meteorological station, and in October from soil 4½ feet above surface of saturation.

In the first experiments the evaporation took place from a bare surface of sandy loam; this loam, with the subsoil and sand found at Floral Park, was placed in a galvanized iron tank 10 inches in diameter and 2½ feet in depth, in which the water was held, as closely as possible, at a height of 2 feet below the surface of the soil. This tank was maintained within another 12 inches in diameter, the top of which was flush with the surface of the ground. This arrangement permitted the inner tank, containing the soil, to be readily removed and weighed at frequent intervals and, since the space between the two tanks was filled with water, the soil in the inner tank was maintained at a temperature but little above the normal temperature of the earth outside. (See Figure 6).

The weighing was done with Fairbanks' platform scales, which read to one-quarter ounce, corresponding to less than one one-hundredth inch in

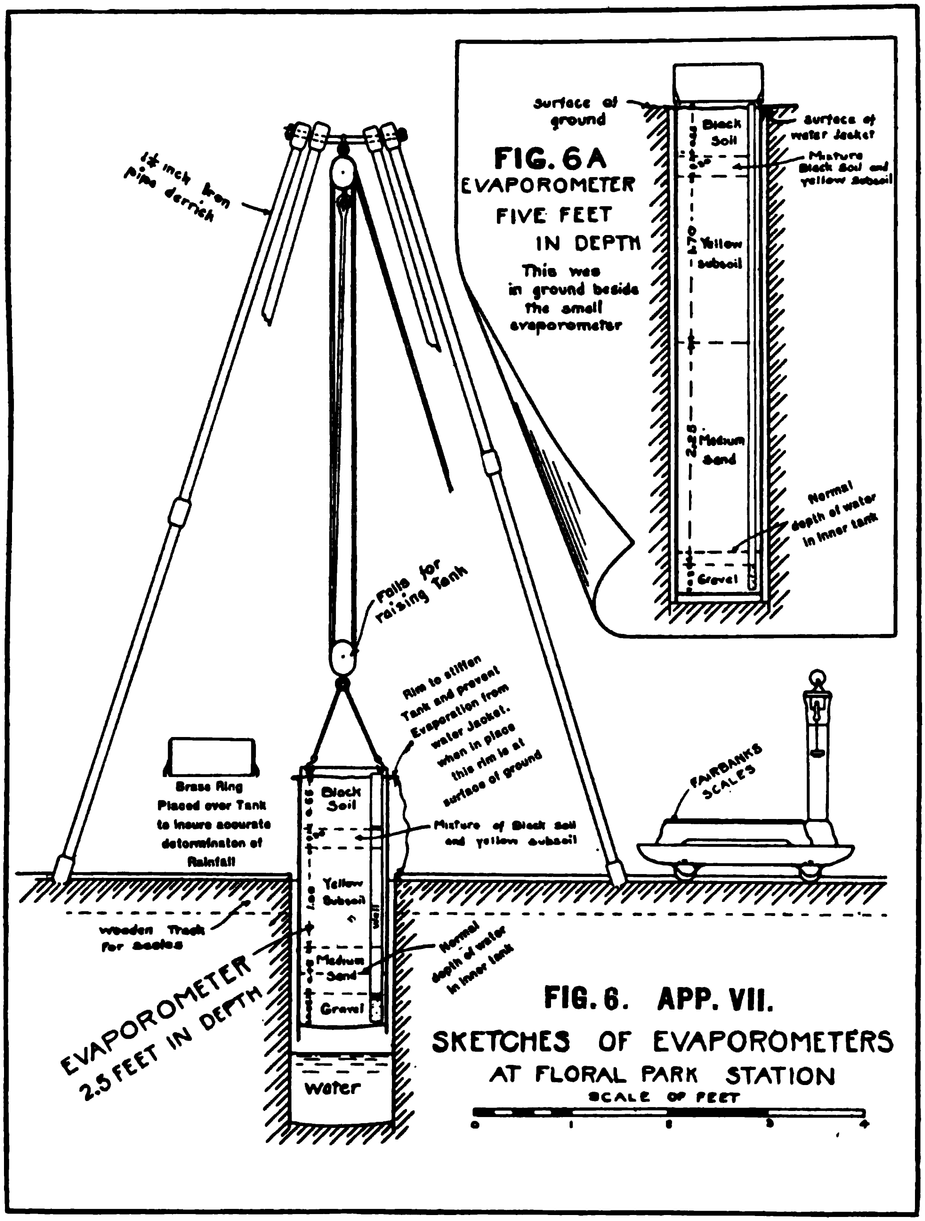


FIG. 6. APP. VII.
SKETCHES OF EVAPOROMETERS AT FLORAL PARK STATION

depth of water on the surface of the tank. The observations on this evaporometer were made every three hours from 6 A. M. to 9 P. M. daily during the greater part of the summer. At each observation, the weight of the tank was taken, the depth of water in the inner tank was measured, the temperature of the soil in the tank and in the ground outside to depths of 5 feet, and the temperature of the air at the ground and at an elevation of 10 feet were noted; and other observations on the recording instruments were made.

On October 1 another set of tanks, similar to the first, but 5 feet in depth, was put in beside the shallow set. This evaporometer permitted the water in the inner tank to be held 4½ feet below the surface of the soil, which is about the limiting distance through which any considerable amount of upward capillary flow of moisture can take place in the Long Island sands. The observations were similar to those on the shallower evaporometer, but the length of time of the observations was insufficient to afford more than a brief comparison between the two evaporometers. The results of these experiments are discussed under the subject of soil evaporation.

(*b*) *Percolation.*

The observations on soil evaporation at Floral Park also furnished data on percolation, but, like other tank experiments on a small scale which neglect the run-off factor, the results have not the same value as field experiments. The observations on the fluctuation of the ground water furnished, on the whole, more satisfactory information on which to estimate the amount of rainfall that enters the soil.

Cost of Meteorological Work and Experiments on Evaporation and Percolation.—The cost of the shelters, meteorological instruments and other apparatus, together with the cost of the observations and the office expenses, was $2,022.

(*C*) *Location of Existing Wells.*

The first work to engage the attention of this Department, when organized in March, was the location of existing wells in Nassau County, from the south shore to the foot of the moraine, in what is practically the present watershed of the Brooklyn Water Department. This area was enlarged by the successive additions of the remainder of Nassau County, of Queens Borough, of Suffolk County as far as Patchogue and Port Jefferson, and, later, by the further addition of the remainder of Suffolk County as far east as the Great Peconic Bay at Riverhead.

When the wells were located, much information was gathered regarding the character of the surface about each well; the number of people and cattle supplied, in order to approximately estimate the draft; the distance of the well from sources of pollution; the diameter, depth and construction of the well; when possible, the material penetrated in sinking the well; and the lowest and the highest stages of the ground water that the owner recalled.

Including 47 of the Brooklyn test wells and a few of the Long Island City service wells that were observed, 1,045 wells were located, of which 147 were in Queens Borough, 396 in Nassau County and 502 in Suffolk County.

The estimated cost of the location of these existing wells was $829.27, which makes the cost per well $0.786. The total depth of the 1,045 wells was about 26,200 feet. Had it been necessary to drive this number of feet of test wells at $1.096 per foot, which was the final cost of the test wells, the additional cost of securing the ground water observations would have amounted to $27,886.

(*D*) *Test Boring.*

The distribution of the existing wells was by no means uniform, and consequently large areas existed which it was necessary to explore in order to accurately contour the surface of the ground water. Test wells were also needed for the purpose of securing samples of the substrata for the studies on percolation and ground water flow and for the problems of the Geological Survey. The measurements of the velocity of the underflow also required that a number of wells be driven and that samples of the sands and gravels at the points of measurement below the surface of saturation be obtained.

(*a*) *Methods of Driving Test Wells.*

(1) *Dry Boring*—Although it was fully realized that the best means of securing correct samples was to drive the casings dry and remove with a sand bucket the material penetrated, the great number of test wells required and the greater cost of this method over that of washed boring, decided the method in favor of the latter.

(2) *Washed Boring*—The method used about New York, namely, that of alternately washing ahead and driving, was discarded, and the more satisfactory way adopted of washing and driving at the same time, without washing far ahead of the bottom of the casing. This method does not permit of as much progress as the "New York method," for when the wash pipe is advanced several feet below the bottom of the casing, a hole larger than the casing is usually made and the driving is, therefore, somewhat easier than when both the casing and the wash pipe advance together and the material is more tightly packed about the casing. As it was desired, however, to obtain samples as nearly correct as possible, it was considered that

washing ahead of the casing introduced errors, through the enlargement of the hole about the pipe and the caving of the material that would make the samples thus obtained of little value.

(3) *Size of Wells*—As these test wells were to be left in place for ground water observations, economy in material was necessary, and 2-inch wells were therefore considered to be sufficiently large for all purposes.

(*b*) *Outfit Required:*

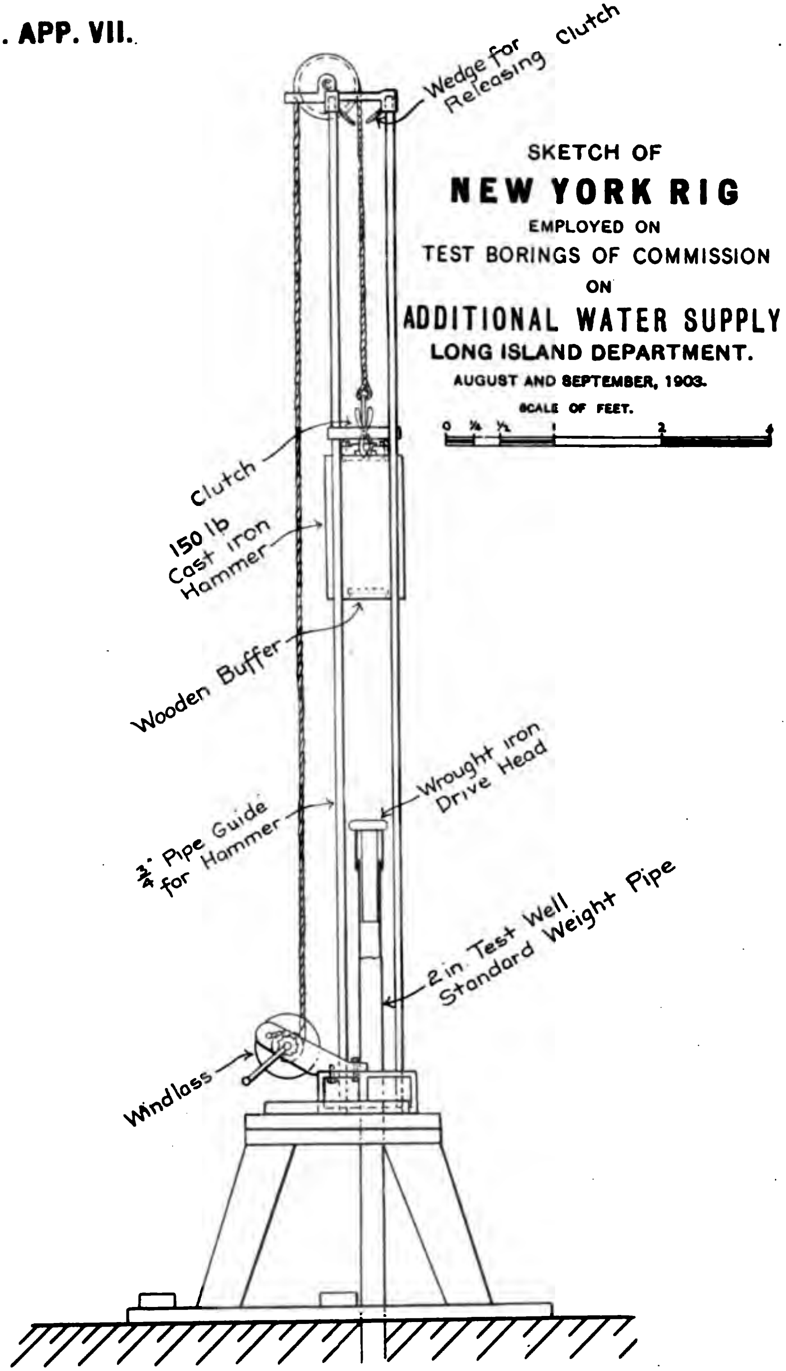
The washed borings were to be made at intervals of several miles in a country for the most part devoid of surface streams, and at points necessarily at some distance from existing wells. The problems, then, were to devise an outfit of great portability, that could be operated with the least possible labor, and to haul to each outfit all the water that was required to drive the wells and secure good samples. The most serious of these problems was that of securing sufficient water for good washed samples. Throughout the work the necessary water was hauled to each outfit in barrels on the wagons that also served for the transportation of the outfit.

There were four types of wash boring outfits used, each of which had certain merits; they may be designated as:

(1) New York Rig.
(2) Boston Rig.
(3) Providence Rig.
(4) Rig arranged by Commission on Additional Water Supply.

(1) *New York Rig*—The outfit commonly employed about New York, and adopted by the Brooklyn Water Department for driving their 2-inch service and test wells is shown on the opposite page.

FIG. 7. APP. VII.


Wedge for Releasing Clutch
SKETCH OF
NEW YORK RIG
EMPLOYED ON
TEST BORINGS OF COMMISSION
ON
ADDITIONAL WATER SUPPLY
LONG ISLAND DEPARTMENT.
AUGUST AND SEPTEMBER, 1903.
SCALE OF FEET.
0 ¼ ½ 1 2 4
Clutch
150 lb Cast iron Hammer
Wooden Buffer
Wrought iron Drive Head
¾" Pipe Guide for Hammer
2 in. Test Well Standard Weight Pipe
Windlass

This is the type of outfit used on the first test wells driven by P. H. & J. Conlan; its essential features are a heavy wooden base, or horse, about two feet high, four rods to guide the hammer, which are erected on this base, and a cast-iron head which holds the guide rods and the small gin wheel, over which the lead from the hammer passes to a small windlass with two cranks at the base of the guide rods.

The solid cast-iron hammer, which weighs about 150 pounds, is automatically tripped at the head of the machine, and drops on the top of the well, which is protected by a solid wrought-iron drive head; the weight of the clutch on the lead is sufficient to overhaul the windlass and again make itself fast to the hammer.

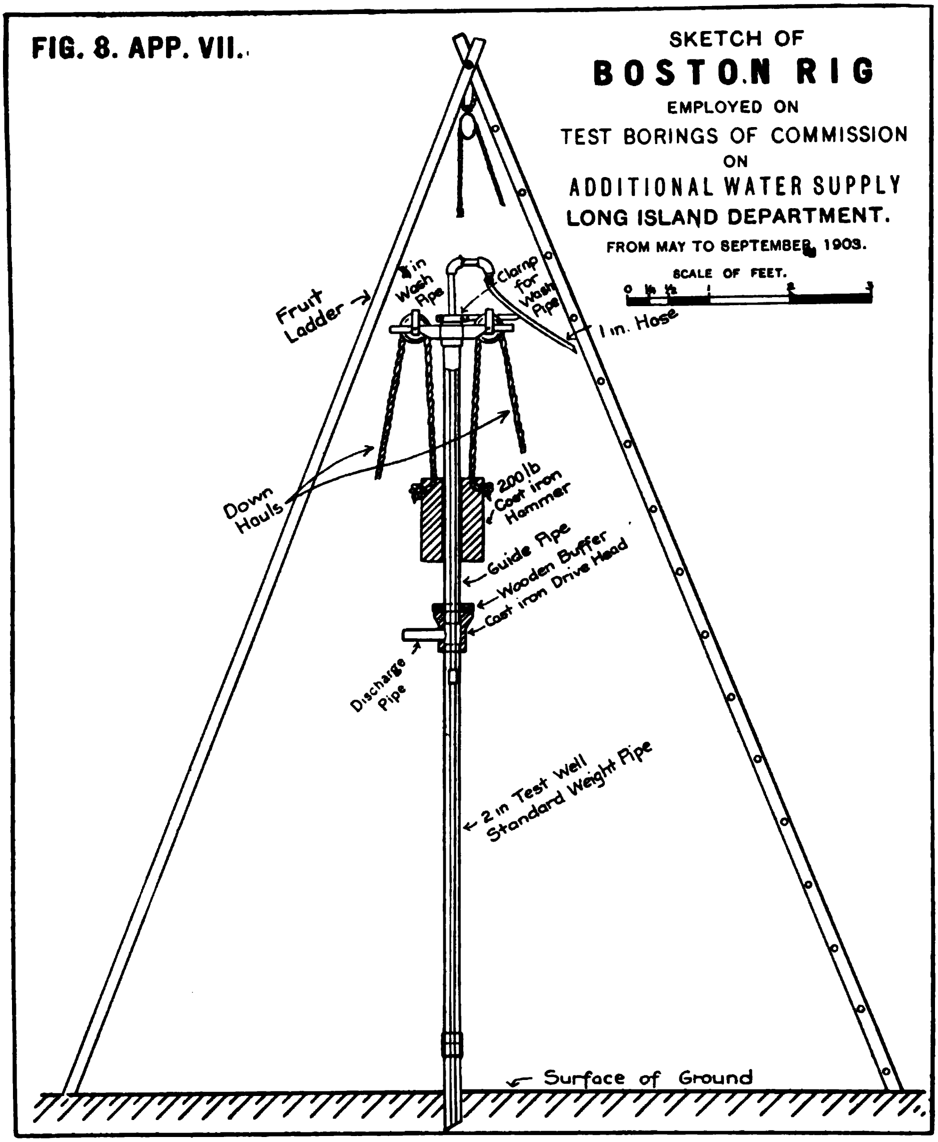
The length of the guide rods permits a maximum drop of the hammer of 8½ feet, which is sufficient to drive closed end points to depths of 30 to 40 feet, and, when jetting can be done, to penetrate to much greater depths.

Conlan used with this rig a ¾-inch wash pipe, a length of 1-inch hose, and an inexpensive 2½-inch "house force," or lift pump, which had a delivery of 8 to 10 gallons per minute. This is the type of pump generally adopted by well drivers in the East, but it is not adapted to wash boring work where good samples are required, for it will not deliver sufficient water nor create sufficient pressure to wash up gravel much larger than peas. The use of this pump in washing through strata containing coarse and fine material may lead to serious errors through the sorting action of the jet at the foot of the casing, which washes up the fine and leaves the coarse material.

As previously stated, the New York rig does not permit continuous washing and driving, and for that reason should not be used, even when equipped with a pump of sufficient capacity, when correct samples are desired. It has, however, a decided advantage over the other types of rigs which we have tried, in that only two men are required to operate it. For driving closed end points and sinking wells where it is not important to secure correct samples, this is perhaps the best rig used. On a large portion of the wells driven with closed end points for the purpose of making underflow measurements, one of these New York rigs kindly loaned by the Brooklyn Water Department was used.

(2) *Boston Rig*—The sketch of the rig shown in Figure 8 is, with slight changes, the wash boring outfit that was adopted, a few years ago, for driving 2½-inch wells during the investigations of the Metropolitan Water Board, at Clinton, Mass. (See page 634.)

FIG. 8. APP. VII.


SKETCH OF
BOSTON RIG
EMPLOYED ON
TEST BORINGS OF COMMISSION
ON
ADDITIONAL WATER SUPPLY
LONG ISLAND DEPARTMENT.
FROM MAY TO SEPTEMBER, 1903.
SCALE OF FEET.
Fruit Ladder
Wash Pipe
Clamp for Wash Pipe
1 in. Hose
Down Hauls
200 lb Cast iron Hammer
Guide Pipe
Wooden Buffer
Cast iron Drive Head
Discharge Pipe
2 in Test Well Standard Weight Pipe
Surface of Ground

The original outfit consisted of a hollow cast-steel driving head, annular in section, threaded top and bottom for a 2½-inch well casing and a 2½-inch guide pipe, and on the side for a 1½-inch discharge; two hammers, one 100 pounds in weight for shallow work, and one 200 pounds in weight for deep wells; and, attached to the top of the 2½-inch pipe that guided the hammer, a yoke and two small pulleys, over which lead the two ropes attached to the hammer, by which the latter was raised and dropped.

With 2½-inch wells, a wash pipe of 1-inch standard weight pipe was

BOSTON RIG.

As Used on the Metropolitan Water Works at Clinton, Mass.

used, and special wash drills to direct the water and loosen up the material.

At Clinton, 1-inch hose carried the water to the wash pipe from the town supply, which was piped to the work through a line of 2-inch pipe. Under those circumstances this outfit required, besides the foreman, four laborers, with the 100-pound hammer—two on the wash pipe and two on the hammer—and six with the 200-pound hammer.

The principal features of the Boston outfit, as used at Clinton, were retained, but several necessary changes were made to adapt it to the Long Island work. The steel drive-head was changed to fit 2-inch drive well pipe, the staging from which to handle the wash pipe was discarded for a light fruit ladder, a ¾-inch wash pipe was used instead of 1-inch, and the 200-pound hammer was adopted for both the deep and shallow wells. Since it was impossible to secure water under pressure from a municipal supply, as at Clinton, it was necessary to depend upon a small force

PROVIDENCE RIG.
USED ON LONG ISLAND INVESTIGATIONS.

pump, and a supply of water hauled in barrels from the nearest well or stream.

A "Challenge" double-acting force pump with a flexible rubber suction hose 1½ inches in diameter and 10 feet long was adopted, and a 1-inch discharge hose, 50 feet in length, was used as before.

After working with this rig several weeks, it was still further modified; several details proved to be faulty, and were discarded. The small width of the pulleys at the head of the machine did not permit of the use of a rope that was sufficiently large to be comfortably grasped by a man's hand and when a length of pipe was well down the head of the machine was so low that the men worked at great disadvantage.

A force of four men, a foreman and three laborers, was required on the Boston rig, besides the driver of the water wagon; two men worked on the hammer, one on the pump, and the wash pipe and the handling of the water required a fourth; the wagon was generally busy the greater part of the time hauling water to the outfit.

(3) *Providence Rig*—The Providence Rig, like that of the Metropolitan Water Board, is of the continuous wash type, but it differs essentially from the Boston rig in the method of operating the hammer. The drive-head and guide-pipe are similar to those of the Boston rig, but the hammer instead of being solid is made up of two or three annular sections, each about 50 pounds in weight; between these sections are bolted two horizontal handles by which the hammer is raised and dropped. This arrangement requires that the men on the "drop," as the hammer is called, work above the drive-head, and a light wooden platform is therefore attached to the casing, just below the drive-head, for them to stand on.

On the Long Island work, light fruit ladders were set up over the rig and served as a platform from which to handle the wash pipe and driving parts. The pumps first used with this type of rig were similar to that described with the New York rig—that is, "house lift" or force pumps, with 2½-inch cylinders. These small pumps were soon discarded and "Challenge" pumps, similar to those used with the Boston rig, were adopted.

The arguments in favor of working the drop from a platform attached to the casing, which is the distinguishing feature of this rig, are (1) that the weight of the men on the platform is of much assistance in lowering the casing, and (2) that it is much easier for the men to stand on the platform and lift than it is to stand on the ground and pull down on a rope.

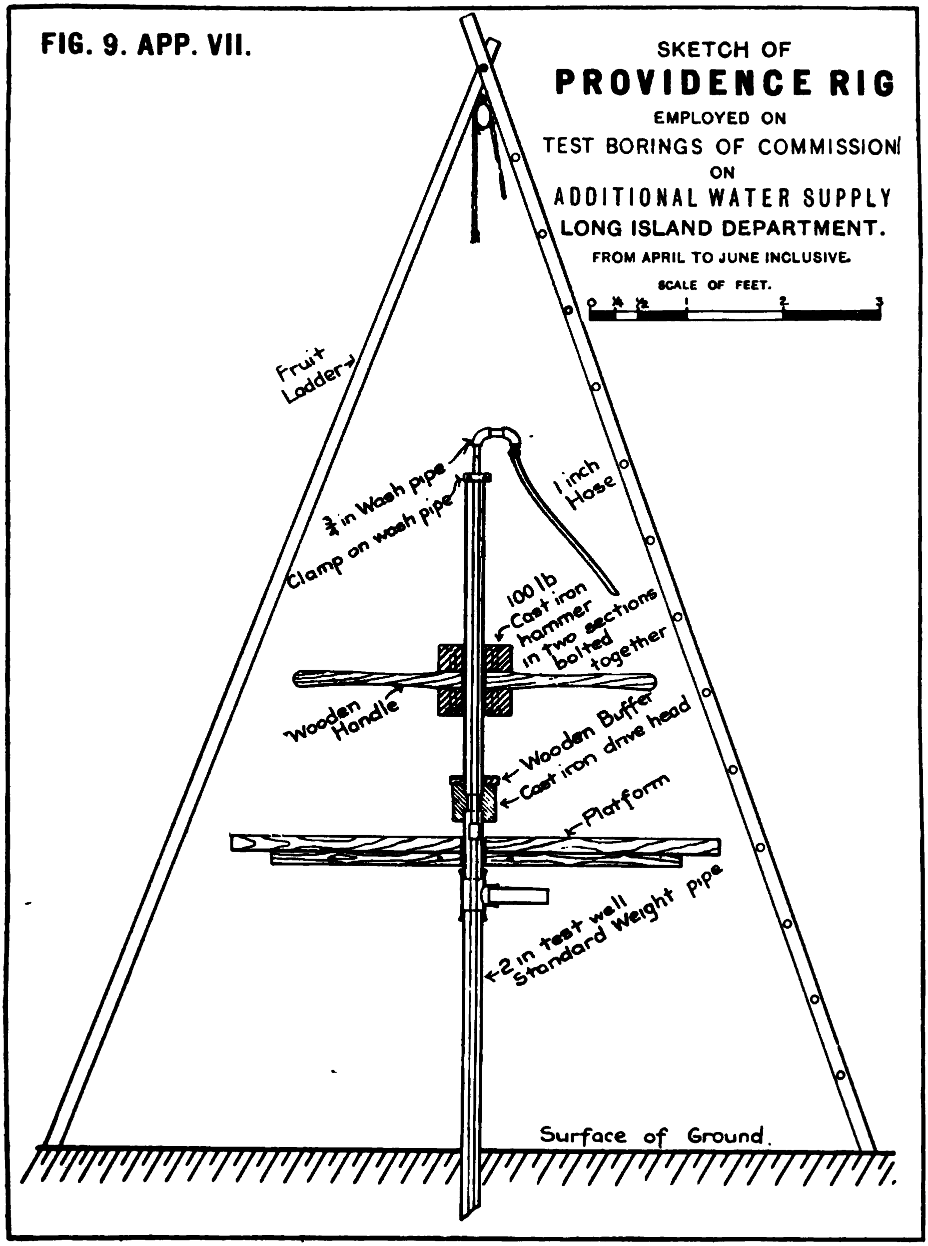
(1) Experience indicated that the additional weight of the men on the platform was of little value in lowering the casing, with the small amount of water and pressure available, and, indeed, was a positive disadvantage for the first three or four feet down on any length of pipe, for it was then found difficult to keep the casing in a vertical position and secure the full effect of the hammer blows, on account of placing so much weight so high above the ground.

(2) It is still a doubtful question whether a man can longer endure the lifting required on these drops than the pulling down necessary on the Boston rig.

The same force as that for the Boston rig, a foreman and three laborers, besides the driver of the wagon, was employed on the Providence rig.

(4) *Rig Arranged by the Commission*—The rig finally adopted for the test boring work of the Commission, which is shown on page 639,

FIG. 9. APP. VII.


SKETCH OF
PROVIDENCE RIG
EMPLOYED ON
TEST BORINGS OF COMMISSION
ON
ADDITIONAL WATER SUPPLY
LONG ISLAND DEPARTMENT.
FROM APRIL TO JUNE INCLUSIVE.
SCALE OF FEET.
0 ¼ ½ 1 2 3
Fruit Ladder
¾ in Wash pipe
Clamp on wash pipe
1 inch Hose
100 lb Cast iron hammer in two sections bolted together
Wooden Handle
Wooden Buffer
Cast iron drive head
Platform
2 in test well Standard Weight pipe
Surface of Ground.

in Figure 10, was patterned after the Boston rig already described. The yoke and the small pulleys were replaced by two large gin wheels, which are suspended at the peak of a 1¼-inch pipe derrick about 12 feet high, which serves at the same time to carry a staging for handling the wash pipe, drive head and hammer.

The great width of these gin wheels permits the use of 1-inch ropes and the greater diameter results in less frictional resistance; the height of the gin wheels allows the men on the hammer to sway out on the lines instead of obliging them to double up on the last few feet of a length of casing, as with the Boston rig. With the stiff pipe derrick, it is also possible to secure core samples by driving 1¼-inch pipe 3 or 4 feet into the material at the bottom of the casing.

The drive-head, hammer, pump, suction and discharge hose and the wash pipe that were used with the Boston rig were retained. A force of four men and driver were employed with this outfit as with the Boston and Providence rigs.

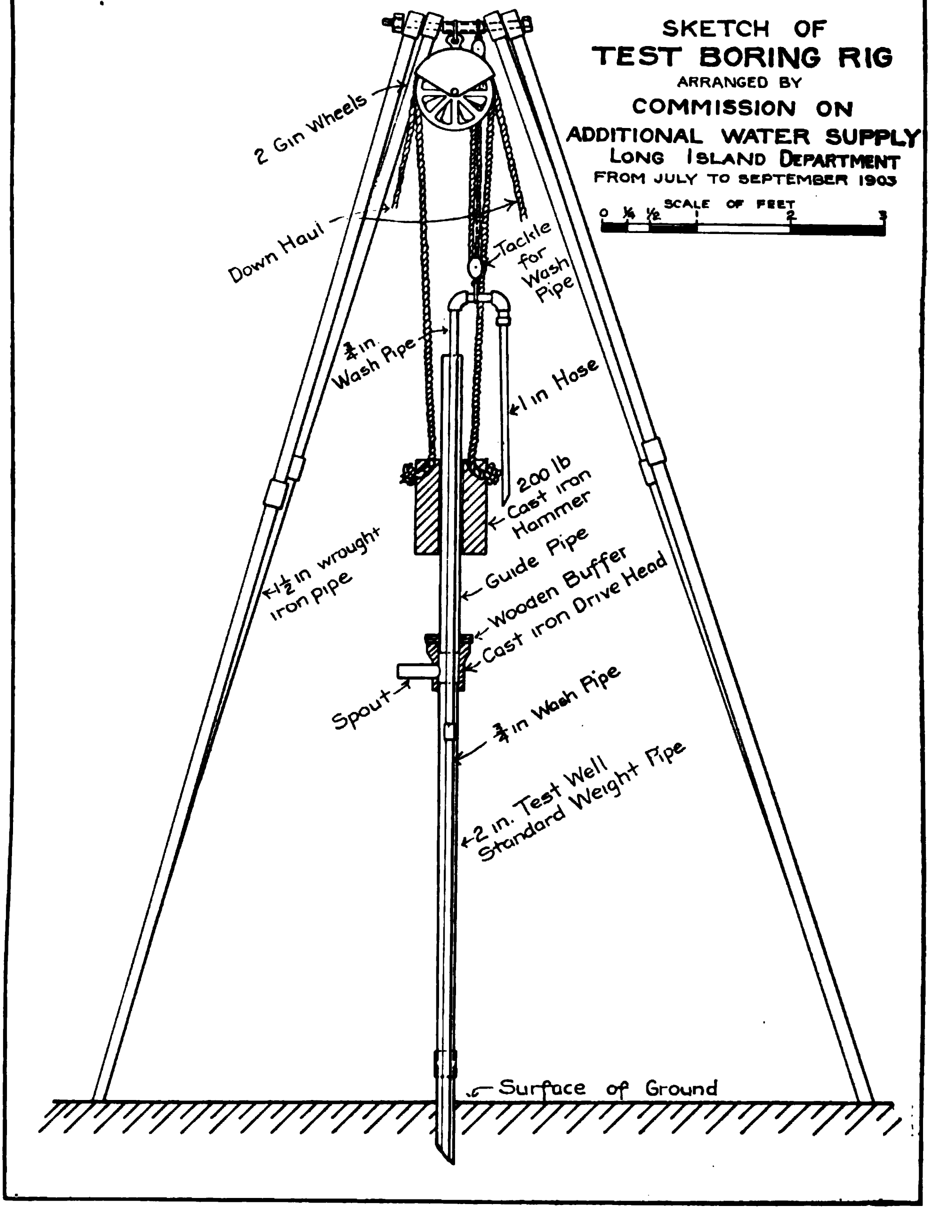
While this outfit, in common with the last two described, requires a larger crew than the New York rig, the progress obtained and the samples secured outweigh any possible gain in economy. As far as could be determined from the cost of the work, there is little to choose between the Boston rig and the modified type that was finally adopted; both, however, are superior to the Providence rig. In the long run, the rig adopted by the Commission is unquestionably the best of the hand rigs that have been used for driving wells in loose sands and gravels and obtaining fairly correct samples. The cost of this rig complete was about $150.

(*c*) *Organization of the Test Boring Work.*

With the exception of four wells that were driven in March, during the preliminary reconnaissance work by the well contractors, P. H. & J. Conlan, the test boring was entirely done on force account. The work was begun early in April, and during the three months to the first of July, from one to seven wash boring rigs were employed in Queens Borough, Nassau County and Suffolk County; from July to the 5th of September, when the forces were transferred to the other departments, four wash boring rigs were used for the greater portion of the time.

Each gang employed on a wash boring rig made its headquarters in the town near which the work was located, and were in charge of a foreman who directed the driving of the wells and took the samples under the supervision of an engineering inspector. Because of the necessity of covering as large an area as possible during the early summer, the outfits were located in the centre of the areas into which the territory that was being investigated was di-

FIG. 10 APP. VII



RIG ARRANGED BY THE COMMISSION.

vided; this arrangement required an inspector for each outfit and made effective superintendence very difficult, since it was hardly possible for the superintendent to visit all the outfits oftener than once a week.

(*d*) *Inspection and Reports.*

The engineering inspector assigned to each test boring outfit located the wells and, through the foreman, directed the work of driving. In addition to these duties, the inspector measured up the pipe that was driven, classified the samples and took all notes that were required. On the completion of each well, these notes were sent to the Jamaica office of this Department on specially printed blanks. Besides this final report, daily reports were sent to the office of the Geological Survey, at the request of Mr. A. C. Veatch, the geologist in charge.

(*e*) *Samples.*

Samples of the substrata were taken at all wells unless closed end points were used or unless a number of wells were grouped together, when samples from only one well were preserved. At each test well from which a knowledge of the material was required, dry samples of the soil and the subsoil immediately below were secured, and washed samples of the deeper substrata were taken every 5 feet below the surface of the ground and at any change of material between those intervals.

(1) *Washed Samples*—When the inspector directed a washed sample to be taken, the entire discharge from the casing was caught in a large pail or tub of 8 to 15 gallons' capacity, which was not allowed to overflow. The tub containing the sample was set aside for 15 to 30 minutes, after adding two cubic centimeters of hydrochloric acid to hasten the precipitation of the fine material. When most of this had settled, the slightly turbid water was poured off and a sufficient amount of the material to fill the sample bottle was removed from the tub and the bottle was properly labeled and packed in the sample case, provided for the purpose. The turbidity of the water that was poured off was observed and recorded in order to have a measure of the material lost.

It was hoped, at the beginning of the work, that it would be possible to use nothing but clear water in washing up the samples, but the distances over which it was generally necessary to haul the water and the large amount that was sometimes lost in driving through the coarse sands and gravels, made it necessary to use, on many wells, water containing considerable fine material; a limit to the turbidity of the water was fixed, however, and any water having a turbidity exceeding 200 on the silica standard was thrown away. In all the washed samples, the amount of fine material obtained did not therefore represent the actual quantity in the sample when in place, because of the rejection of turbid water from the sampling tub and the occasional use of turbid water for jetting.

The washed samples taken from the wells on which perforated pipe or open-end well points were used and those that were washed up with the small " house lift " pumps were not always as satisfactory as the others, because when washing through a mixture of gravel and sand the amount of water that returned to the surface was not sufficient in volume or velocity to readily bring up the coarse material. This was left in place after the sand in the mixture had been removed, and could sometimes be washed up only with great difficulty.

(2) *Core Samples*—In many wells entire samples were obtained with an open end or choke bore pipe, or a sand bucket, to serve as a check on the washed samples when the character of the material was such that the washed sample did not appear to be correct.

(3) *Classification of Samples*—The inspectors took one set of samples for the Commission and another for the United States Geological Survey, which they shipped to the office of the Long Island Department at Jamaica. Altogether, in the 333 wells that were driven, 1,927 sets of samples were taken and classified. Later, the samples belonging to the Commission were compared with the standard sands to check the inspector's classification. The standard sands adopted by this Department were made up from the soil standards of Professor Milton Whitney of the Bureau of Soils, using, however, the conventional names chosen for similar work by Professor W. O. Crosby, as shown in Table No. 1.

TABLE NO. 1.

Table of Standards for Classification of Material.

Number of Material.	Conventional Name.	Corresponding Diameter in Millimeters.
1	Coarse Gravel	50. - 5.0
2	Fine Gravel	5.0 - 1.0
3	Coarse Sand	1.0 - 0.5
4	Medium Sand	0.5 - 0.25
5	Fine Sand	0.25 - 0.10
6	Superfine Sand	0.10 - 0.05
7	Rock Flour	0.05 - 0.01
8	Superfine Flour	0.01 - 0.005
9	Clay	0.005 - 0.0001

(4) *Mechanical Analyses*—The samples from 49 wells, 604 in number, which are fairly representative of the territory investigated, have been analyzed mechanically, and their effective sizes and uniformity coefficients determined; 584 samples from 47 test wells were analyzed by the

Geological Survey, under the direction of Professor W. O. Crosby; the remainder, in addition to a number of samples also analyzed by Professor Crosby, by the Chemical and Biological Department at the Mount Prospect Laboratory. The classification and the results of the mechanical analyses of the samples from the most important wells, as far as determined, are given in Table No. 32, following this report.

Most of the soils and subsoils were too fine to permit the effective size to be determined without resorting to elutriation and, as the result of such analyses would not warrant its expense, the size of the material is given by the diameter " than which 60 per cent. is finer."

(*f*) *Number of Wells.*

The plan of the work was to first fill in the large areas in which no existing wells were found by driving wells four to five miles apart; later, to locate other test wells at intervals of a mile or two, so that, with the existing wells, the surface of the ground water could be everywhere determined and accurately contoured.

Queens Borough, and the greater portion of Nassau County, were explored as originally planned, but, when the test boring work was suspended on September 5, there still remained in Suffolk County several large areas in which very little information concerning the elevation of the ground water and the character of the substrata had been obtained. Several deep wells in the moraine should have been driven to accurately fix the summit of the water table, but the hand rigs were not adapted to driving through the hard compact till found there, and the deep 4-inch wells that it was hoped to secure were not driven through the lack of time that the preparation and awarding of contracts required.

Altogether, 333 2-inch test wells were driven, of which 46 are in Queens Borough, 249 in Nassau County, and 38 in Suffolk County; these wells contain 11,605 feet, or almost 2¼ miles, of 2-inch standard weight pipe. Of these 333 test wells, 159 were driven for the purpose of obtaining samples of the substrata, and of determining the elevation of the ground water; 40 (with closed end points) for the purpose of obtaining the elevation of the ground water alone; 30 for the pollution experiments of the Chemical and Biological Department; and 104 for the underflow measurements by the " Slichter " method. In the 170 wells in which samples were taken, 1,927 sets of samples were secured.

(*g*) *Cost of Test Wells.*

An estimate of the total cost of the test boring, including the cost of inspection and supervision, and all other expenses of this Department that were incurred in the field and office on this work, is shown in Table No. 2, under the several items into which the cost may be divided.

TABLE No. 2.

Cost of Test Boring.

Item.	Total Amount.	Cost per Foot of Pipe Driven. [11,605 Feet.]
Superintendence and Inspection (including engineering and supervision)	$2,815 36	$0.243
Labor—Foremen, $3 and $3.50 per day; laborers, $1.50 and $1.75 per day	5,074 30	.437
Teams employed with outfits, $3 and $3.50 per day	1,612 20	.139
Transportation, car fare, livery, freight and express	559 73	.048
Cost and rental of test boring rigs	618 43	.053
Two-inch pipe, perforated pipe and points	1,723 90	.149
Miscellaneous expenses, sample bottles, cases, classifying material, blasting, etc.	315 02	.027
Total	$12,718 94	$1.096

In the loose gravels of the south shore the cost of the boring was not far from 60 cents per foot, but in the compact till that covers the northerly portion of the Island, where dynamite was used, the cost ran up to $2 per foot, and some wells even higher.

To make the total cost per foot comparable with other work of this character which, however, has usually been confined to much smaller areas, the items of inspection, superintendence and pipe and fittings must be reduced, and the greater part of the item for teams taken out; for it is not generally customary to place more than one engineering inspector on several outfits, if any at all be assigned; the casings are usually pulled up, and the pipe used repeatedly; and water can ordinarily be piped to the work from a town supply, or from a small temporary pumping plant. If, then, we take 15 cents per foot from the item of inspection, 10 cents per foot from that of teams, and 10 cents per foot from the cost of the pipe, we reduce the total cost per foot to 85 cents. Considering the cost of labor, which was paid at the rate of $1.75, excepting during the first few weeks, and also the quality of labor that it was necessary to employ, this is a reasonable figure for the work which, in part, was done in such hard material as exists in the moraine.

(*h*) *Test Pits.*

When continuous observations on the height of the ground water were not required, and the water was within 5 to 10 feet of the surface, it was found cheaper to dig holes with post-hole augers than to drive 2-inch iron casings.

Twenty-two test pits were dug near the south shore with 4½-inch and 6-inch post augers, at an estimated cost of $14.50, or $0.66 each. The total number of feet in these test pits amounted to 102, so that the cost of these wells per foot was only $0.14, which is probably $0.40 cheaper than 2-inch driven wells would have been, even in the favorable conditions along the south shore.

(*E*) *Ground Water Statistics.*

Perhaps the most important part of the work of the Long Island Department was the observation of the height of water in the wells to determine the rate of percolation of the rain to the surface of saturation and the fluctuations in the elevation of the ground water.

The ground water observations were begun on existing wells as soon as the Department was organized in March, in order to determine the spring height of the ground water table. Measurements were made on the wells when located and were repeated as soon thereafter as men could be found to place in the field. On some wells, unfortunately, the interval following the first observations was long, because it was necessary to push the location of all the existing wells in Nassau County in order to properly lay out the test boring work and avoid sinking a test well near an existing well that could be observed.

(*a*) *Organization of Work.*

The corps of ground water observers was not fully organized until the 16th of April, when three assistants were assigned to the territory included within Queens Borough and the southerly portion of Nassau County. The number of ground water observations required rapidly increased as the location of existing wells was extended eastward to Peconic Bay, and new test wells were also driven, so that the force of observers became much larger than originally planned. When the whole area of Queens Borough, Nassau County and Suffolk County, as far east as Riverhead, was fully covered by our observations, eleven assistants were required. This area was divided into eleven districts, to each of which was assigned an observer, who made daily trips over his section. Several of them, in addition to their ground water observations, looked after the meteorological instruments and stream gauging stations.

With eleven observers, about 350 ground water observations were obtained each day. This number was limited, of course, by the locations of the wells and the number of miles, generally from twenty-five to thirty, that could be covered in a day.

In the shallow wells, it was soon found that at least one observation each day was necessary to follow the rise and fall of the surface of saturation; in the deeper wells, however, fewer observations were required, because the fluctuations were less frequent.

(*b*) *Method of Observation.*

(1) *Bench Marks*—A bench mark was established on each well when first located, from which measurements were made with a steel tape to the surface of the ground water in the well. On a driven well, this bench mark was, of course, the top of the casing pipe, and, at a dug well, any convenient point on the curb or shelter that could be permanently marked with red chalk or a copper tack.

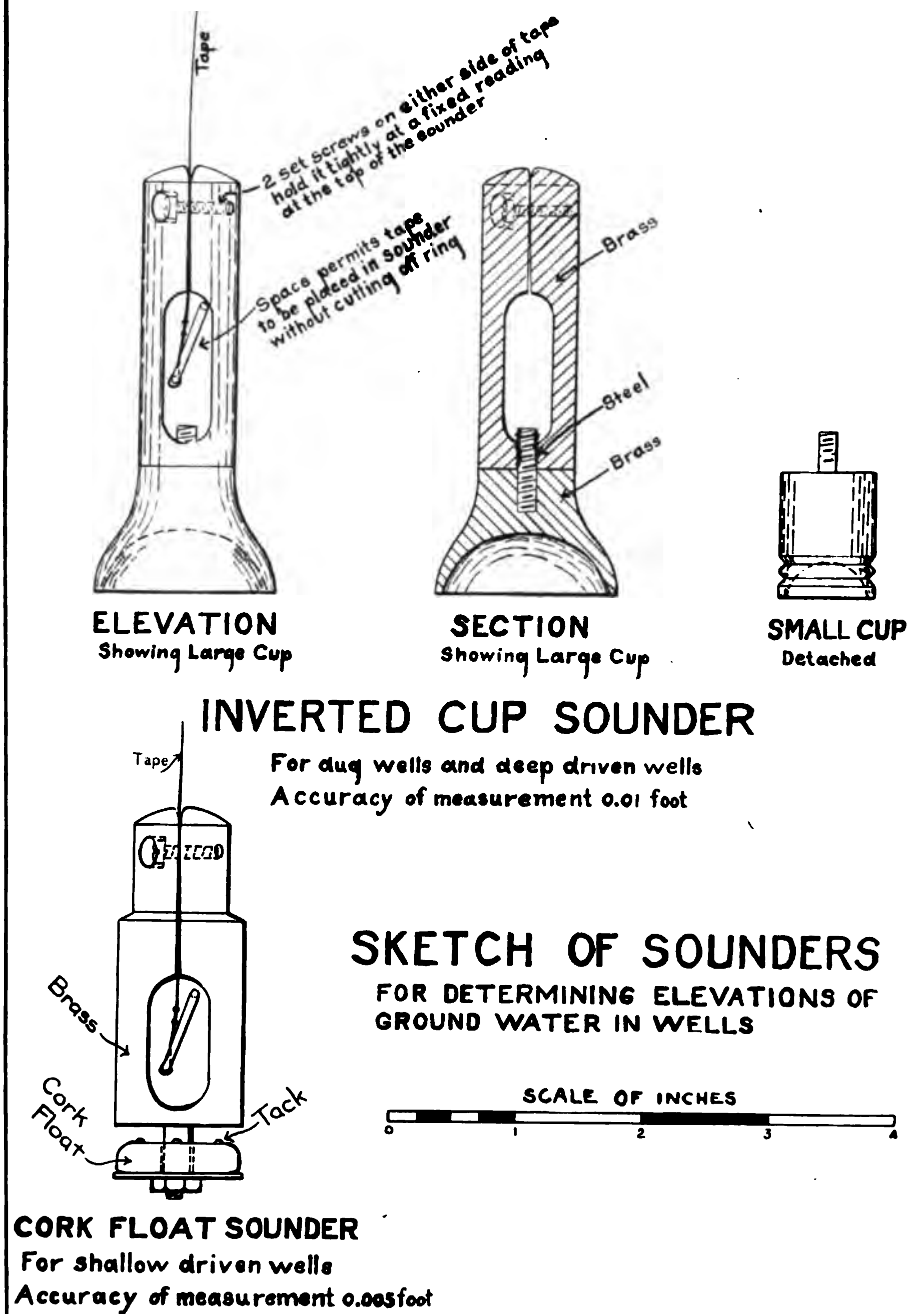
(2) *Tapes*—Standard 50 and 100 foot steel tapes, graduated in feet and decimals, were used for these measurements; there were but few districts that did not contain wells over 50 feet in depth, so that the 100-foot tapes were used for nearly all the work. Some wells were too deep even for a 100-foot tapes and measurements were made with a long piece of copper wire.

(3) *Sounders*—The measurements were made by means of a sounder attached to the steel tape; in this work two types of sounders were used, which are shown in Fig. 11. One, the "Inverted Cup" type, which is somewhat similar to those of the Brooklyn Water Department, is suitable for most measurements in dug and driven wells. It consists of a cylinder of brass, cupped out on the bottom, and designed at the top to permit a steel tape to be readily attached without cutting off the ring. By quickly raising and dropping this sounder one or two-hundredths of a foot, a sharp click is made as the cup strikes the water, and with a little practice the elevation of the water can be determined within a hundredth of a foot, even if the water surface is as much as 100 feet below the surface of the ground. For a deeper well than this a similar sounder with a still larger cup was used.

The other type of sounder, the "Cork Float" type, gives more accurate results, but cannot be used except in small, shallow wells, for the sound from the impact of the brass tacks in the cork against the brass surface above, as the cork floats when the sounder is lowered into the water, is too faint to be heard over 20 feet from the surface, in the 2-inch wells. This sounder gives results, however, that can be depended upon to 0.003 to 0.004 foot.

(4) *Recording Gauges*—In addition to the daily observations, autographic records of the height of the ground water table were also made, in order to determine such fluctuations in the elevation of the ground water as could not be obtained by the daily observations. Three recording depth

FIG. 11. APP. VII.



gauges were used, of which one was placed in a well of moderate depth at Floral Park, another in a similar well at Brentwood, and a third in a shallow well near Valley Stream.

(c) Objections of Owners of Wells to the Ground Water Observations.

Some diplomacy was required by the ground water observers to secure readings from many of the existing domestic wells on the Island, particularly along the south shore in Nassau County and Suffolk County, where the feeling toward the Brooklyn Water Department has not been cordial for some years. A great many owners of wells, from time to time, refused to permit further observations, but a clear explanation of the purpose of measurement was usually sufficient to secure permission to continue the readings.

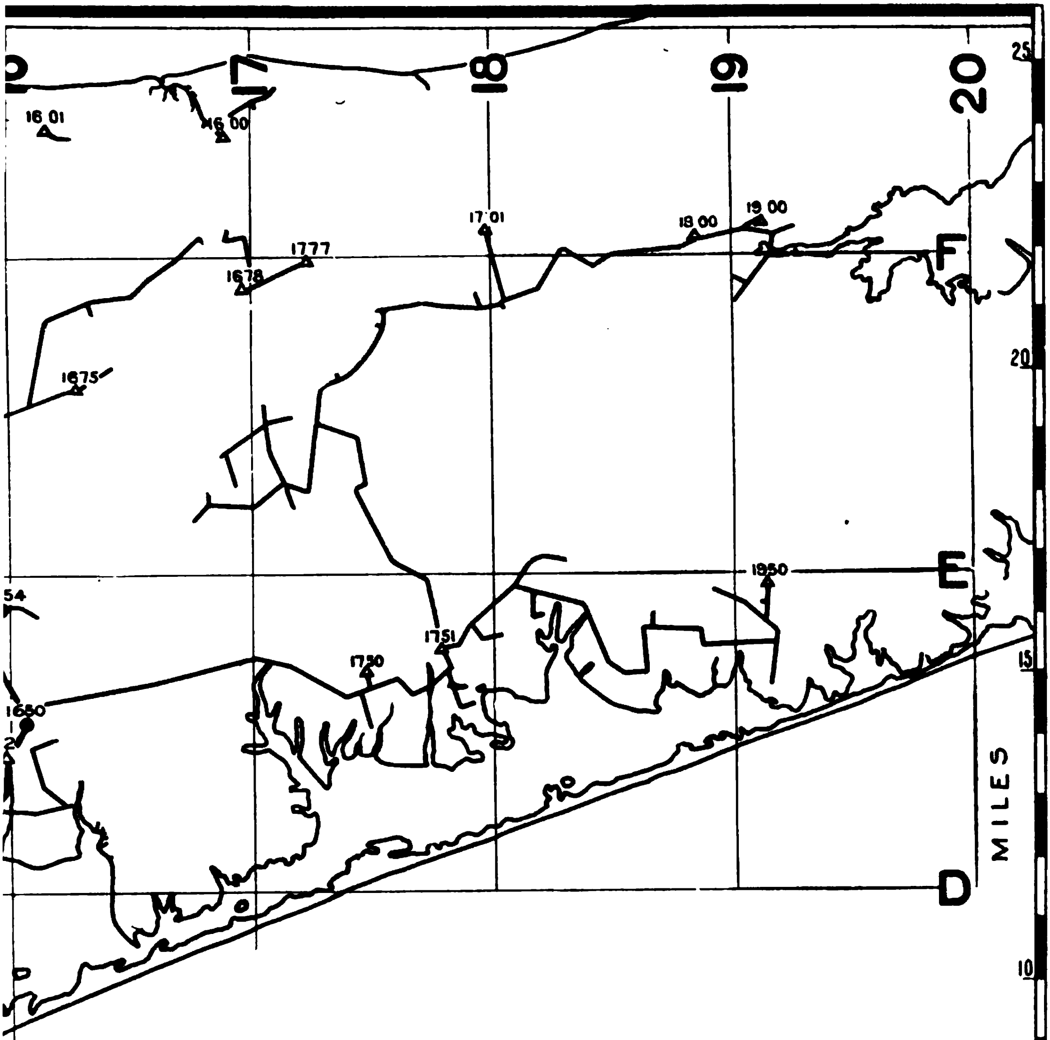
Some of the objections made to the observations were quite reasonable; most of them were otherwise, and were engendered by hostility toward New York and Brooklyn. The owner generally stated that he had "no water for Brooklyn"; the observer, however, was fortunate if any reasons at all were given. When a man refused permission to observe the well through the fear that the water would be polluted by the introduction of the sounder and tape, it was not considered wise to dispute him or to go to the trouble of sterilizing the sounder, particularly as another well was generally found, when locations were first made, that served the same purpose. When the observations were discontinued, there were about forty wells the owners of which had made objections to further measurements.

(d) Cost of Observations.

Altogether, 37,042 observations on the elevation of the ground water were made, from March 13 to November 1, at an estimated cost of $8,073, or $0.219 per observation. A large part of this cost is transportation; bicycles were used to a small extent during the latter part of the work, but with the exception of a few main roads and bicycle paths in the westerly end of the Island and near the south shore, the condition of the highways and particularly the "short cuts" were such that little progress could be made on a wheel.

(F) *Levels.*

The mapping of the surface of the ground water and the study of the structure of the water bearing gravels required that all the wells, surface streams and ponds be connected by a network of levels, which



CITY OF NEW YORK

COMMISSION ON ADDITIONAL WATER SUPPLY

LONG ISLAND DEPARTMENT

CATION OF BENCH MARKS

AND THE

LINES OF LEVELS

OF THE LONG ISLAND DEPARTMENT

APRIL TO NOVEMBER 1903

Drawn by D.E. Bellows. November 2, 1903

60 65 70

APP. VII. PLATE 1.

should cover the whole territory investigated, an area of approximately 1,000 square miles.

(*a*) *Datum Plane.*

Two datum planes have been in general use over large areas of Long Island; (1) that of the Brooklyn Department of Water, which was stated to have been originally fixed at mean high water at the Brooklyn Navy Yard; and (2) the "Willett's Point" datum plane of the United States Geological Survey, which was mean sea level at Willett's Point.

The Brooklyn base was naturally chosen for the work of this Department, and it was found to be 1.087 feet above the "Willett's Point" datum.

(1) *Datum of the Brooklyn Department of Water*—The original datum of the Department of Water was established between 1850 and 1860, when a line of levels was run from the bench mark on the southwest corner of the coping of Dry Dock No. 1, at the Brooklyn Navy Yard, which is the bench mark to which all of the present datum planes of the Brooklyn Departments are referred. Its elevation above mean high water was fixed by tide observations made shortly after 1840, just prior to the construction of the old dry dock.

This bench mark on Dock No. 1 has always been considered by Brooklyn engineers to be 5 feet above mean high water; on page 6 of the "Report Descriptive of the Construction of the Brooklyn Water Works," by James P. Kirkwood, Chief Engineer, it is stated:

"The heights above tide always refer to mean high water at the "Brooklyn Navy Yard as conventionally fixed at 5 feet below the coping "of the Brooklyn Dry Dock."

The Brooklyn Water Department now use 4.997 feet; the Sewerage Department, 4,999 feet.

(2) *Change in Datum of Brooklyn Water Department*—The line of levels, above described, which was run from the Navy Yark to the Ridgewood Engine House, just prior to 1860, was continued to a bench mark at Smith's Pond on the "east rim of the pump well" at the end of the old conduit line; in 1895, a return line of levels was run from the Smith's Pond bench mark, which had been fixed by the previous line at El. 10.992, to the original bench mark at Ridgewood, which indicated that the latter was El. 36.678, or 0.429 foot lower than the elevation first established in 1858-1860 (i. e., 37.107). The Smith's Pond bench was accepted as correct, and the benches west of Smith's Pond adjusted to this new line of levels.

The precise levels of this Department, during the past summer, from Smith's Pond to Ridgewood, showed the elevation of the bench mark at the Old Ridgewood Engine House to be 36.980, or only 0.127 foot lower than the original height of 37.107 instead of 36.678, the Brooklyn value of 1895.

From Ridgewood the levels were continued to the Brooklyn Navy Yard, and on the Smith's Pond base the elevation of the old bench mark on the coping of Dry Dock No. 1 was found to be 4.937, which is 0.063 foot less than the elevation at which the original line of levels was started. This indicates that the Smith's Pond datum, that was adopted for the Long Island investigations is very close to the original base established by Mr. Kirkwood.

(3) *Relation of Brooklyn Datum to Present Mean High Water*—A series of tide observations were made at the Brooklyn Navy Yard by the Bureau of Yards and Docks, from June, 1902, to June, 1903; these observations made the old bench mark on Dry Dock No. 1, 4.43 feet above mean high water, which is 0.57 foot less than the distance at which the coping was fixed above mean high water by the tide observations made about 1840. The present datum of the Brooklyn Water Department (Smith's Pond Base) is, then, 4.937—4.43=0.51 foot below the present elevation of mean high water at the Navy Yard.

(4) *Datum of the Geological Survey, "Willett's Point" Base*—When the engineers of the United States Geological Survey began their Long Island topographical surveys, they started their levels from a bench mark of the United States Engineers at Willett's Point, the elevation of which above mean sea had been fixed by a series of tide observations from 1891 to 1895. Their primary lines were made with care and the permanent bench marks which they established checked out well with the runs of this Commission and were of great assistance in the extreme easterly portions of the Island where the elevations of wells and streams were determined by short lines of levels between the Survey's bench marks.

(*b*) *Subsidence of the Land.*

(1) *Navy Yard Records*—The greater elevation of mean high water relative to the old bench mark on the coping of the dry dock in 1903 over that at which the coping was originally set, pointed to a subsidence of the land, providing that a settlement had not taken place in the dry dock. This could only be determined by a comparison of the present height of the dry dock bench mark with other old bench marks on firm ground in Brooklyn, the elevation of which had been previously determined from the Navy Yard bench.

The levels from the Navy Yard to the old bench mark at Ridgewood Engine House showed that the coping of the dock was 0.064 foot higher than by the determinations of 1858-60, if the Ridgewood bench had not settled that amount, which, however, may be possible, although it is located on firm ground, and shows no sign of settlement.

Levels in 1900 to two old bench marks of the Brooklyn Sewerage Department near the Navy Yard indicated a slightly greater elevation of the bench mark on the dock than when the previous levels were run. The bench mark at corner of Myrtle and Cumberland streets was found to be 0.096 foot lower than in 1886; that at Dean street and Fourth avenue 0.083 foot lower than in 1891. As these benches were on curbs, they cannot be considered permanent marks, and they may possibly have settled the amount of the differences noted.

Other bench marks were sought in the vicinity of the Navy Yard, but, during the limited time available, none were found that had been compared with the Navy Yard bench mark. It will be noted that the recent comparisons of the bench marks described above with the old bench mark on the dry dock gave elevations of those bench marks that agreed within 0.1 foot of the original determinations, proving that the elevations of the dock have not changed more than that amount. Considering the comparative instability of the structures that carry the bench marks in Brooklyn and at Ridgewood, and the present excellent condition of the dry dock, it is probable that the observed change in relative elevation has been less in the foundations of the dry dock than in the outside bench marks.

The information certainly shows that the dry dock at the Brooklyn Navy Yard has not settled; possibly the coping has been elevated by a swelling of the joints, similar to, but much less in amount than, that noted by Mr. John R. Freeman, at the Charlestown Dry Dock, ("Report of Chief Engineer of the Committee on Charles River Dam," Appendix No. 20).

From the Navy Yard data above, it would appear that the change in the relative elevations of the land and the sea, from 1840 to 1903, was 0.6 foot, or that the land was subsiding at the rate of about 1 foot per one hundred years. Other data indicate that the rate for the past sixty years has been less than this, although even greater during the past twenty-five years.

(2) *Other Evidence of Subsidence*—After obtaining this result from the Brooklyn Navy Yard records, a further investigation was begun to learn if other tide records had not been made about New York City that would shed further light on the question of the subsidence of the land which, aside from general interest, seemed to have a bearing on the Long Island ground water problems. For, if further development of the ground water were to be made along the south shore of Long Island,

where the land is now only a few feet above the sea, it is important to know whether the sea is likely to encroach to such an extent on the land, during the next fifty or one hundred years, as to even occasionally flood the marshes near the pumping stations or galleries, and thus saturate the surface soils with salt water, and increase the chlorine and other salts beyond the present somewhat high values.

Tide Observations About New York—It was found that several other tide records had been made about New York City besides those at the Brooklyn Navy Yard. These tide records were made by the United States Coast and Geodetic Survey at Governor's Island, at Sandy Hook, and at Fort Hamilton, and by the New York Department of Docks at Pier A, and at West Fifty-seventh street, North River. The periods covered by these observations are as follows:

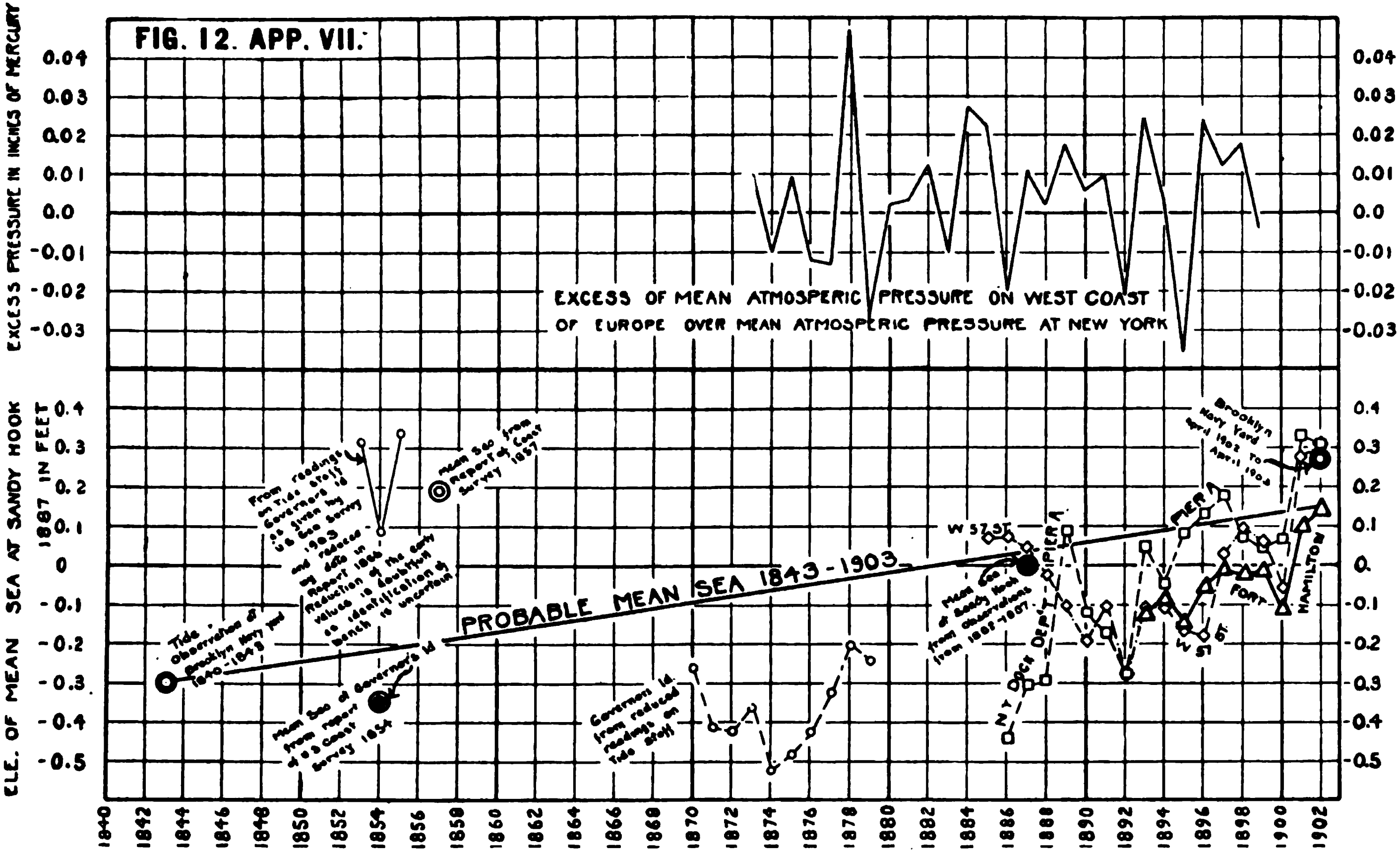
Governor's Island	1853 to 1879, inclusive.
Sandy Hook	1882 to 1887.
Fort Hamilton	1892 to date.
West Fifty-seventh street, North River	1885 to date.
Pier A, North River	1886 to date.

Besides the records at these stations, numerous other observations exist, but they cover so short a period, generally less than a lunation, that they have not been considered.

The elevations of the bench marks, to which all the above tide observations were referred, were reduced to the United States Coast and Geodetic Surveys datum of mean sea at Sandy Hook by means of the elevations established by the Coast Survey through their precise levels of 1887, and the annual means of all the long term tide records have then been expressed as elevations above this Sandy Hook datum and are thus plotted on Fig. 12.

United States Coast and Geodetic Survey Observations—The relation of the Governor's Island records to the Sandy Hook base is not as well established as the others. The early observations are particularly doubtful as the identity of the bench mark to which they were referred was not clearly proven, and the relation between the tide gauges and the bench mark for some years is unknown.

The tide observations at Fort Hamilton were made with great care by an officer of the Coast Survey, now stationed there; the mean of the Sandy Hook observations is, however, the best determination for mean sea, as it is the result of several years of careful observations, during which time the relation between the elevation of the sea at Sandy Hook and many other points in the North and in the East River were determined. The differences between the elevation of the sea at Sandy Hook and at the several points of observation about New York City was very small and showed the reasonableness of the comparisons that are made in Fig. 12.



SUBSIDENCE OF LAND—PROBABLE RATE OF SUBSIDENCE OF COAST.
NEAR NEW YORK CITY—TO ACCOMPANY REPORT ON LONG ISLAND SOURCES

Observations of the Department of Docks—The records at Pier A are undoubtedly low, owing to the flattening of the high water summits which was observed on the diagrams from their recording gauge; furthermore, it is said that the early records at Fifty-seventh street and Pier A are less reliable than the later ones, which is borne out by the lack of agreement between the records from the two stations during the first few years.

(3) *Probable Rate of Subsidence*—From the reduced elevation of mean sea at the Brooklyn Navy Yard, a line was drawn through the more recent observations giving special weight to the Sandy Hook observations, 1882 to 1887, and the Fort Hamilton records. *During the sixty years from 1843 to 1902, the apparent subsidence was 0.45 foot, or at the rate of 9 inches in 100 years.* The rate of subsidence from the two series at the Navy Yard indicate a greater rate than this, but it was considered that the last series at the Navy Yard was a short one and the sea during the period somewhat above the normal. This is somewhat less than the value of 12 inches in 100 years, which the Chief Engineer of the Committee on Charles River Dam determined as the probable rate of subsidence of the land at Boston, Mass. The evidence at New York and at Boston indicate that the rate of subsidence is by no means uniform, but has been greater and less than the mean rate determined from the records of the last seventy years.

(4) *Other Determinations of Subsidence and Explanations Suggested for Change in Relative Elevations of Land and Sea*—Mr. George W. Tuttle, Assistant Topographical Engineer, New York City, has studied the tide records about New York City and has concluded from the more recent records that the rate of subsidence of the land is somewhat greater than the value determined above (see Eng. Rec., Dec. 12, 1903, p. 733), but it is impossible to discredit the old observations at the Brooklyn Navy Yard, although a uniform rate of subsidence between 1843 and 1902 does not agree with the recent observations.

Mr. Tuttle's studies led him to investigate the possibility of this change in the relative elevations of the land and water being accounted for by changes in barometric pressure. He determined the excess of the mean annual barometric pressure on the other side of the Atlantic over that at New York to learn if an increasing excess in pressure in Europe would not account for the apparent subsidence of the land. These excesses in mean barometric pressure are plotted on the diagram, but it is clear that they are, on the whole, uniform throughout the period of the records and do not, therefore, account for the rise of mean sea level.

(*c*) *Levels by the Commission.*

(1) *Methods*—The levels of this Department were run from the bench mark on the rim of the pump-well at Smith's Pond Pumping Station which,

as stated above, was the standard bench adopted by the Brooklyn Water Department in 1895. The Island was first enclosed with polygons, the sides of which were the cross-sections of the Island that were selected for the study of the water-bearing strata and the slope of the surface of the ground water; when these large polygons of control were adjusted, the areas within them were covered by short lines which were adjusted between the bench marks previously established on the polygons.

(2) *Bench Marks*—Bench marks were established at intervals of two or three miles, generally at road crossings, where they could readily be picked up by the leveling parties who ran the intermediate lines. The most permanent bench marks are, of course, the tops of the driven wells which were leveled upon to obtain the elevation of the surface of saturation. The locations and elevations of the bench marks established were arranged in a card catalogue system.

(3) *Instruments*—The greater portion of the precise leveling over the polygons of control was run with a precise level of the "Molitor" type, made by C. L. Berger & Sons, Boston, and a special target rod of the "Boston" pattern, which was designed for the precise levels of the Essex Water Power Company, Lawrence, Mass. The features of this rod are the clamp which has a screw of a large pitch, by which the target may be rapidly moved up or down a thousandth or two at a time and the special "watch dial" target which is superior to the one ordinarily used.

For most of the leveling, however, three Y levels with two special "Boston" rods, above described, and one plain "Boston" rod were used. During the latter part of the work, self-reading rods were adopted; these afforded greater speed and gave sufficient accuracy for the short lines to the wells and streams. A transit and self-reading rod were used on some of the unimportant lines on the moraine, and much time was saved by determining elevations by means of vertical angles and stadia distances.

(4) *Accuracy of Levels.*

The large polygons of control, which were thirty to forty miles in length, were closed within an amount corresponding to 0.005 foot per mile; on secondary lines, an error of 0.05 foot per mile was permitted.

(5) *Cost of Levels.*

From March to December, 1,001 miles of levels were run in Queens Borough, Nassau County and Suffolk County, and 181 bench marks established, as shown on Plate I. The location of the test wells, the elevations of which are known, are shown on Plate VIII. The cost of this work, including salaries, board bills, livery, traveling and office expenses, was $5,377, which makes the cost per mile $5.37.

(*G*) *Stream Gauging.*

The Brooklyn Water Department has gauged nearly all the streams on the south shore of Long Island between Jamaica and Riverhead, but, with the exception of a short period in the fall of 1852, when the flow of the streams between Baisley's Pond and East Meadowbrook were determined, and a few months in the fall of 1894, when these streams, together with a number of the most important rivers and creeks as far east as the Peconic River were measured, the gaugings have consisted of two or three observations on each stream at intervals of several years. All the measurements were made during a period of drought for the purpose of obtaining information on which to make an estimate of the minimum yield from the surface flow of the Long Island streams. In order to determine the relation between the rainfall and the run-off of the streams, continuous gaugings for a long period are necessary.

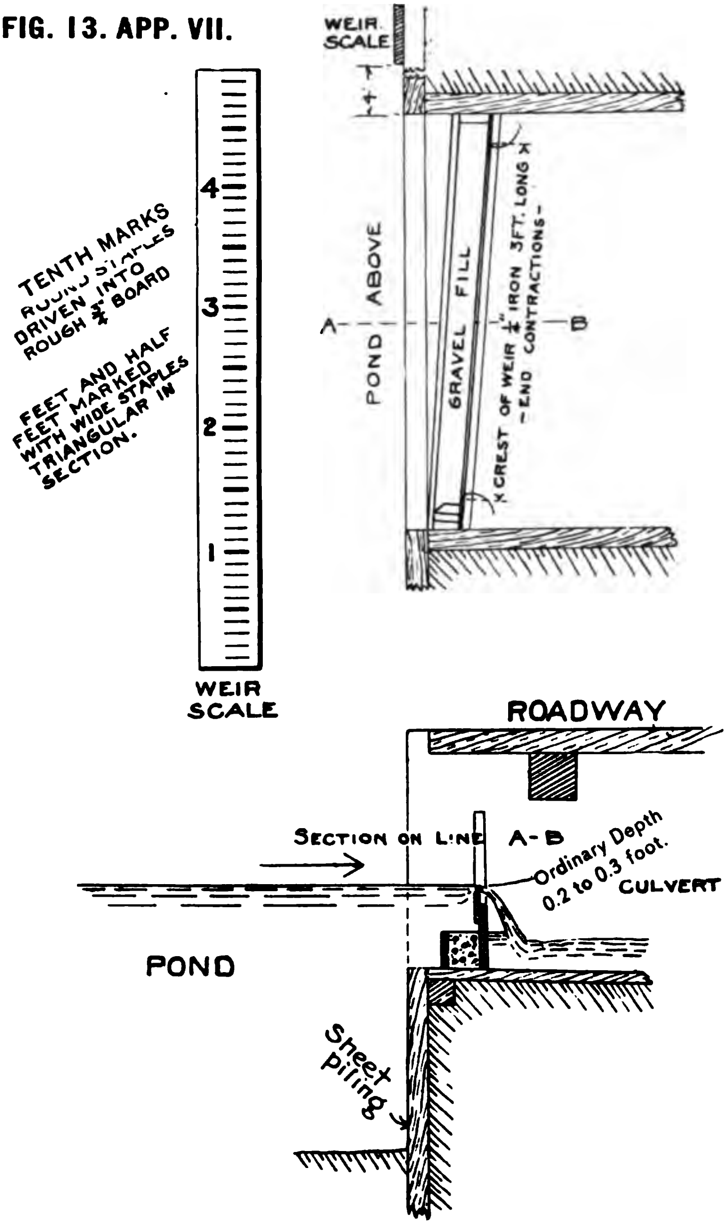
(*a*) *Stream Gauging of* 1903.

This portion of the investigations was assigned to the United States Geological Survey and ten gauging stations were established by Mr. R. E. Horton, of the Survey, in April and May of this year; of these stations, two were in Nassau County and the remainder were distributed along the south shore in Suffolk County. The gaugings of the Geological Survey proved not to be sufficient in accuracy and their stations were not suitably located to give the results that the Commission sought, namely, an accurate and continuous measurement of the total run-off of an area that was sufficiently large to permit a fair estimate to be made of the underground run-off as well as the surface run-off; consequently it became necessary for the Commission to take up this work and gaugings of the important streams between Freeport and Massapequa were made.

(*b*) *Gaugings of the United States Geological Survey.*

The Geological Survey gauged the flow of the East Meadowbrook, Massapequa Stream (near Farmingdale), Carll's River, Sampawam's Creek, Doxsee's Creek, West Connetquot Brook, East Connetquot Brook, Carman's or Connecticut River and the Peconic River. The gauging stations on these streams were all current meter stations, with the exception of those on Massapequa Stream, Doxsee's Creek and West Connetquot Brook, which were weir stations. Some changes were made in a few of their stations, during the last of May, which somewhat increased the accuracy of their measurements. Three typical gauging stations of the Survey are shown in Figures 13, 14 and 15.

FIG. 13. APP. VII.



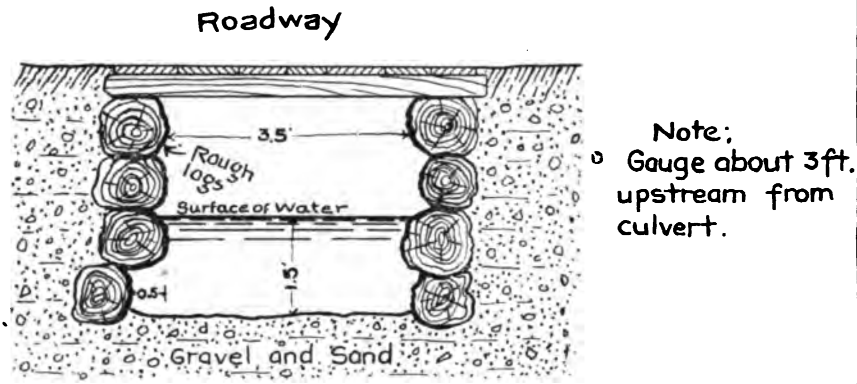
DOXSEE'S CREEK GAUGING STATION

ESTABLISHED BY THE U. S. GEOLOGICAL SURVEY

SCALE OF FEET

0 1 2 3 4

FIG. 14. APP. VII.



OROWOC CURRENT METER STATION
OF THE
U. S. GEOLOGICAL SURVEY
SKETCH OF CROSS-SECTION AT POINT OF METER OBSERVATIONS
SCALE OF FEET
0 1 2 3 4

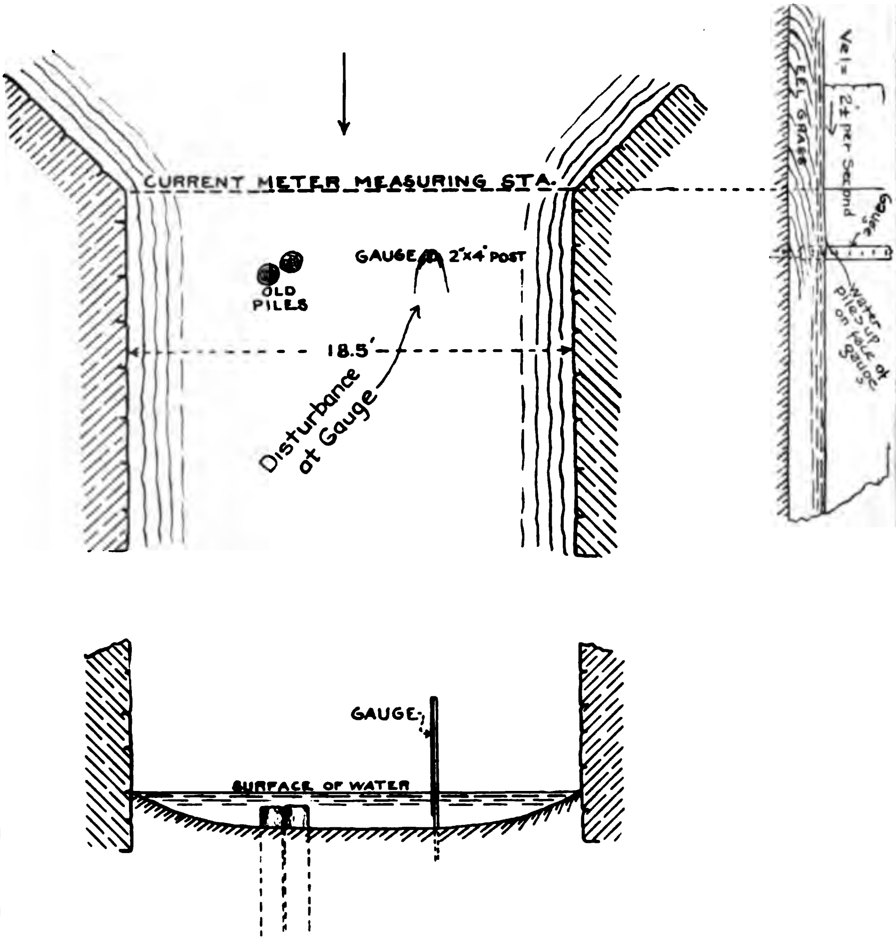
The Geological Survey stations were abandoned on the 15th of July, so that their gaugings cover but little more than two months and are, therefore, of no great value in the ground water studies. It is unfortunate, too, that their measurements could not have been begun earlier on some of the Long Island streams, in order that measurements of the flood flows of February and March might have been obtained.

(*c*) *Gaugings by the Commission.*

(1) *Weirs with Recording Gauges*—Good, permanent weirs were constructed on the six most important streams between Freeport and Massapequa; on the East Meadow Brook, West Newbridge Stream (Cedar Brook), East Newbridge Stream, West Wantagh Stream, East Wantagh Stream and Massapequa Stream. These weirs were located as near the Brooklyn Supply Ponds as the character of the ground permitted, in order to obtain as nearly as possible the total yield of the brooks at the outlet of the supply ponds.

With the exception of the two Wantagh stations, the weirs were placed where the banks and the ground on both sides were low and swampy, and in consequence of this and to avoid the loss of water through underflow, if the coarse material forming the bed of the streams were placed under any

FIG. 15. APP. VII.



PECONIC RIVER GAUGING STA.

ESTABLISHED BY U.S. GEOLOGICAL SURVEY

SCALE OF FEET

0 5 10 15 20

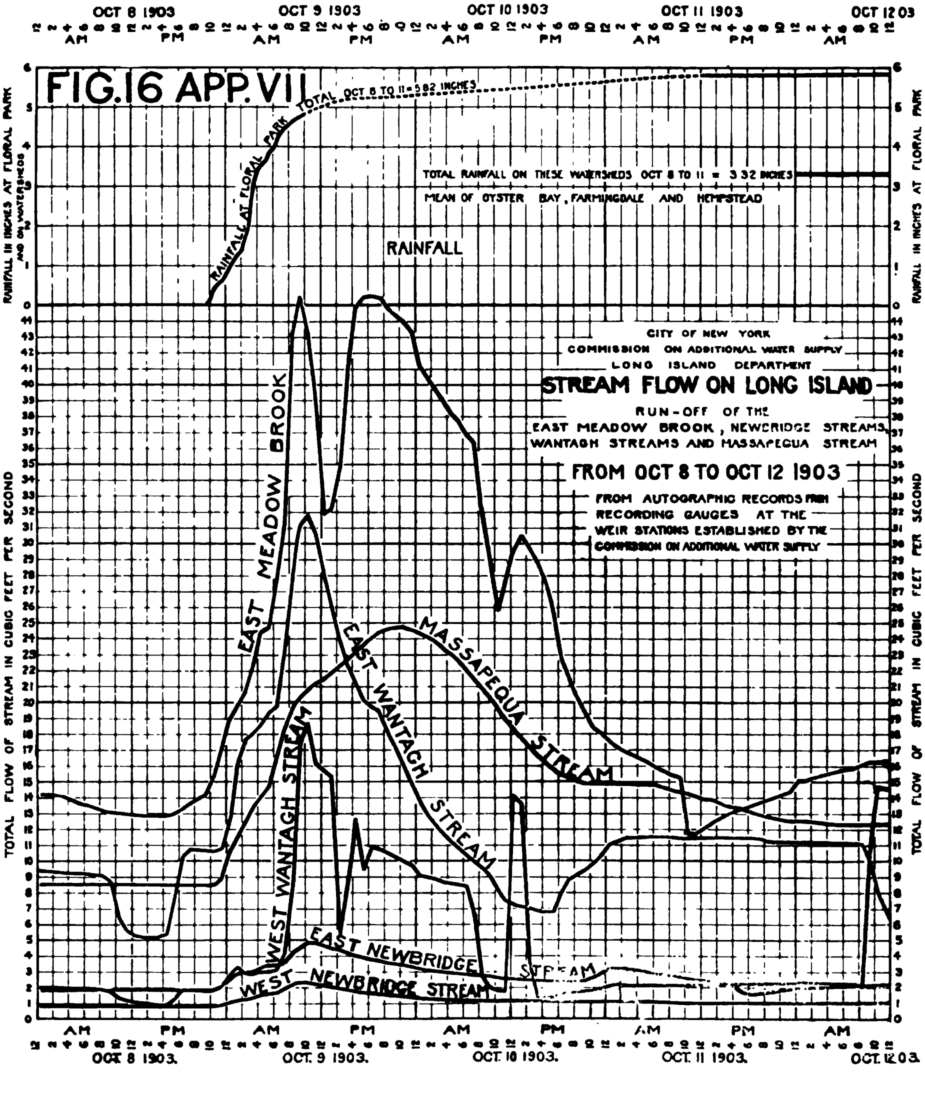


FIG. 16 APP. VII
TOTAL OCT 8 TO 11 = 5.82 INCHES
RAINFALL AT FLORAL PARK
TOTAL RAINFALL ON THESE WATERSHEDS OCT 8 TO 11 = 3.32 INCHES
MEAN OF OYSTER BAY, FARMINGDALE AND HEMPSTEAD
RAINFALL
CITY OF NEW YORK
COMMISSION ON ADDITIONAL WATER SUPPLY
LONG ISLAND DEPARTMENT
STREAM FLOW ON LONG ISLAND
RUN-OFF OF THE
EAST MEADOW BROOK, NEWBRIDGE STREAMS, WANTAGH STREAMS AND MASSAPEQUA STREAM
FROM OCT 8 TO OCT 12 1903
FROM AUTOGRAPHIC RECORDS FROM RECORDING GAUGES AT THE WEIR STATIONS ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY
EAST MEADOW BROOK
EAST WANTAGH STREAM
MASSAPEQUA STREAM
WEST WANTAGH STREAM
EAST NEWBRIDGE STREAM
WEST NEWBRIDGE STREAM
OCT 8 1903
OCT 9 1903
OCT 10 1903
OCT 11 1903
OCT 12 03
AM
PM
RAINFALL IN INCHES AT FLORAL PARK AND ON WATERSHEDS
TOTAL FLOW OF STREAM IN CUBIC FEET PER SECOND

from the Babylon turnpike, and 200 feet below the two forks of this brook. The land on either side is low, almost swampy, and is usually flooded in the spring.

The West Newbridge Station was on the westerly of the two brooks that enter the Newbridge Supply Pond, and about 200 feet above the head of the pond, on land owned by Mr. George W. Hewlett, who kindly gave permission to place a temporary gauging station there.

The East Newbridge Station was on the easterly tributary to Newbridge Supply Pond, in the cedar swamp, about 1,200 feet above the pond. The weir was on the easterly of two branches into which the brook divides about 100 feet above the station; the flow in the other branch was cut off, and the whole flow passed over this weir, which is on property acquired by the Water Department.

The West Wantagh Station was located at the head of the Upper Wantagh, or Seaman's Pond, on the westerly of the two streams that enter the pond. There the banks of sand were high enough to allow a weir and flume of sufficient height to take care of ordinary flood flows. A mill privilege on the stream above and the small fall in the brook from the mill to the gauging station did not, however, permit more than two weir planks to be put in.

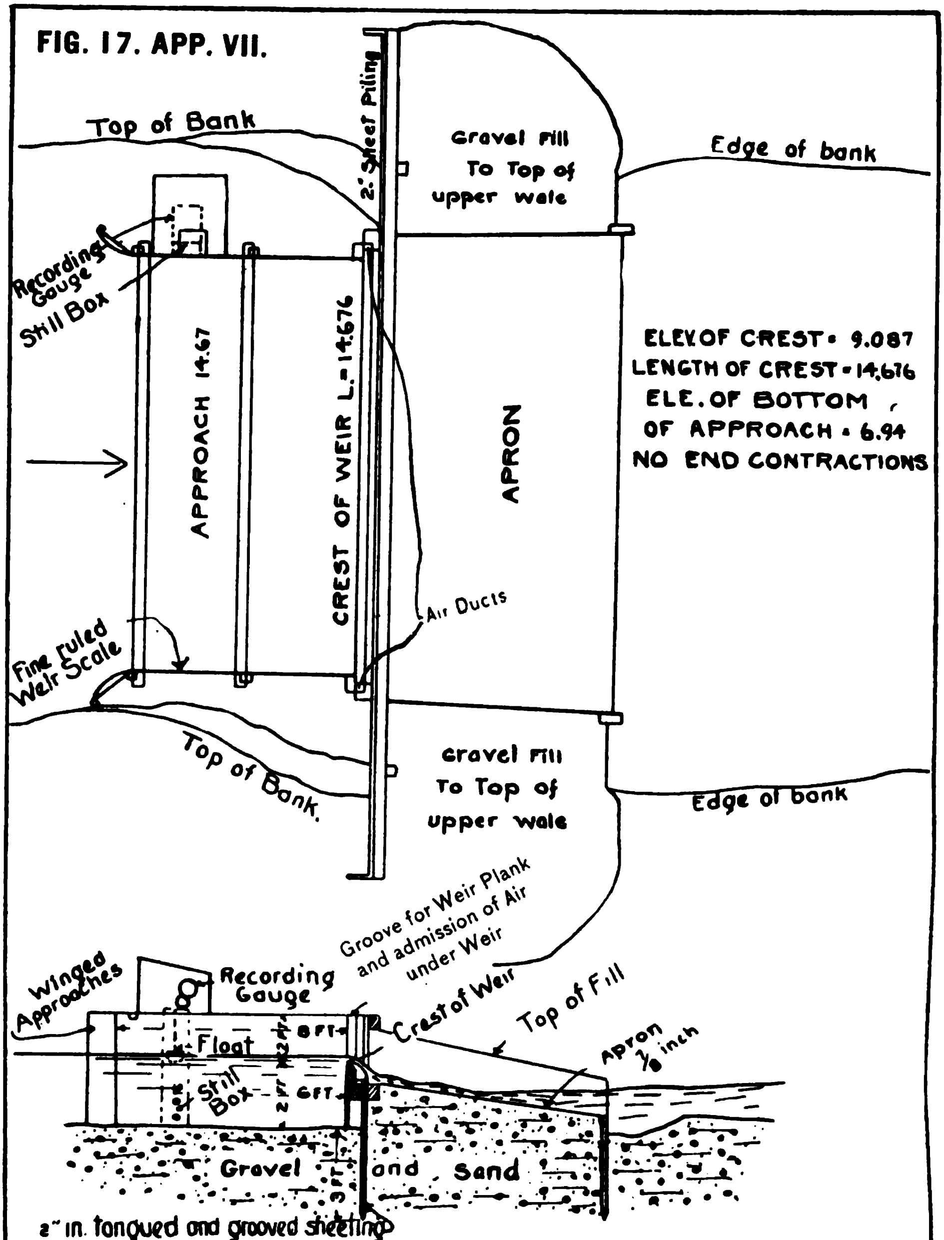
The East Wantagh Station was placed on the easterly tributary of Seaman's Pond, about 300 feet above the head of the pond. The banks there were moderately high, and a weir similar to that on the other Wantagh Stream was constructed. This easterly tributary is larger than the westerly but both receive the discharge from the mill pond on the westerly stream and, consequently, both are affected by the draft of the grist mill.

The Massapequa Station was on the Massapequa Stream (called "Massatayun" on the sheets of the United States Geological Survey), about 3,000 feet above the Massapequa Supply Pond. The swamp there is about 350 feet in width, and the weir, like that on the East Meadowbrook, is necessarily low; on the west side, an embankment about 2 feet high was constructed across the swamp to prevent loss around the weir during high water.

Construction of Weir Stations.

The details of each station are shown in Figures 17 to 22. In general, a line of tight tongued-and-grooved sheeting was driven across the stream to a depth of 3 or 4 feet below the bottom and several feet into each bank. In the centre of this sheeting, an opening of the proper length was cut and a smooth sill for the weir plank bolted on. Approaches 8 feet in length were put in, and a still box constructed at a distance of 6 feet above the crest, in which to place the float of the recording gauge. The sandy bottom was leveled up, and the conditions approximated very closely those of the weir

FIG. 17. APP. VII.



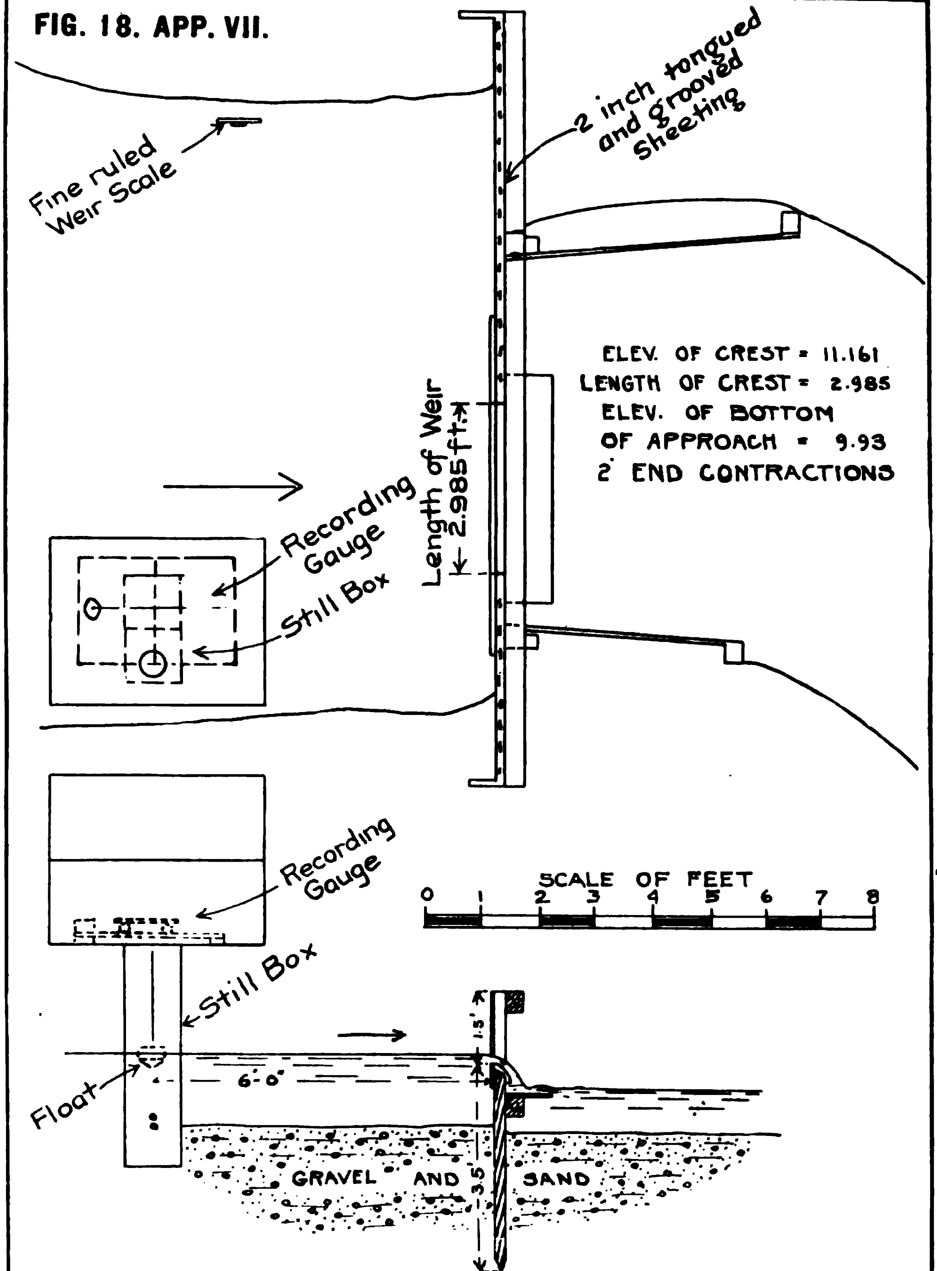
EAST MEADOW BROOK GAUGING STATION

ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY
LONG ISLAND DEPARTMENT IN JUNE 1903

SCALE OF FEET

0 5 10 15

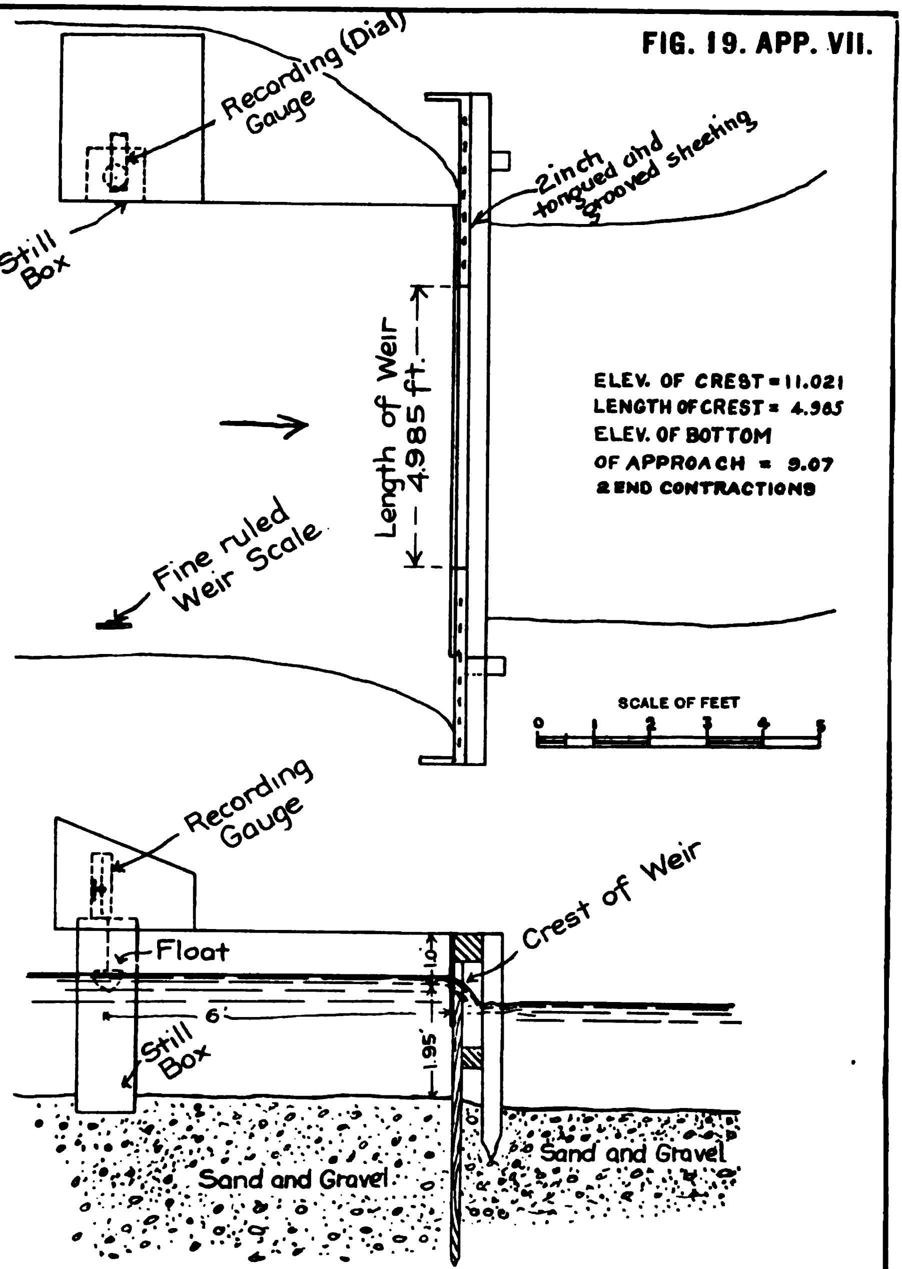
FIG. 18. APP. VII.



WEST NEWBRIDGE GAUGING STATION

ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY LONG ISLAND DEP'T. AUGUST, 1903.

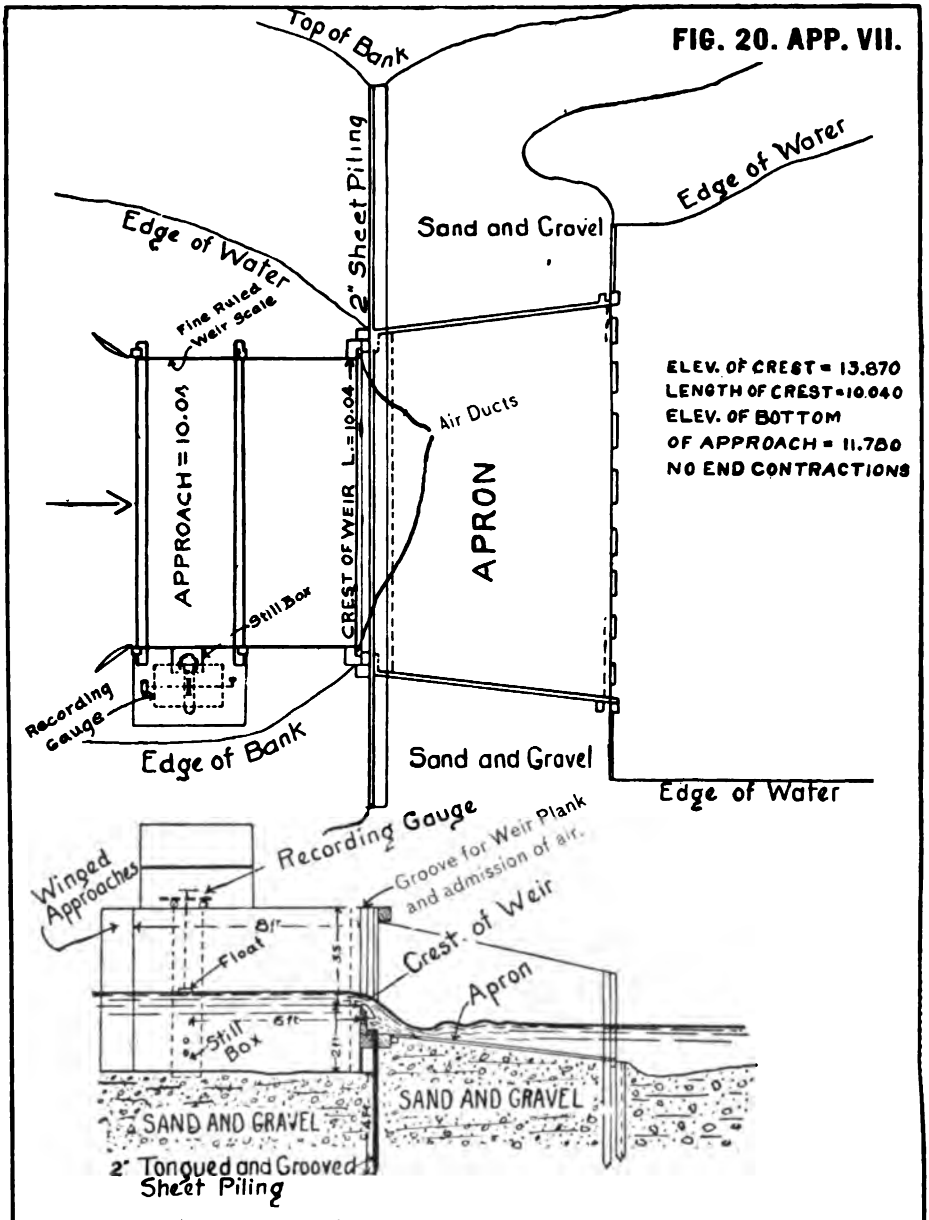
FIG. 19. APP. VII.



EAST NEWBRIDGE GAUGING STATION

ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY LONG ISLAND DEP'T. JULY 1903

FIG. 20. APP. VII.



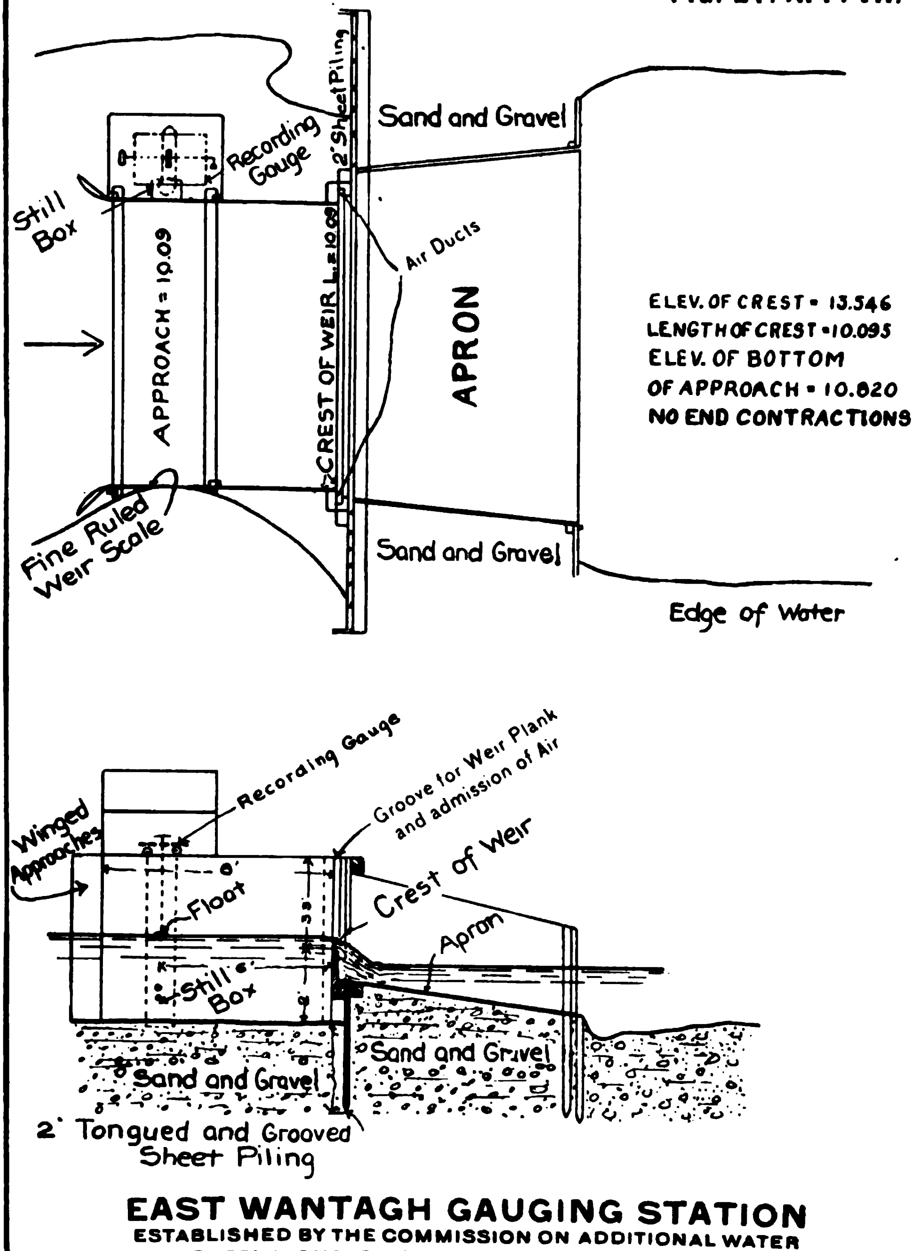
WEST WANTAGH GAUGING STATION

ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY LONG ISLAND DEP'T. JUNE 1903.

SCALE OF FEET

0 5 10 15

FIG. 21. APP. VII.



EAST WANTAGH GAUGING STATION

ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY LONG ISLAND DEPARTMENT IN JUNE 1903

SCALE OF FEET

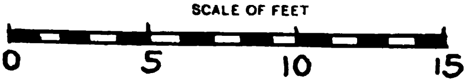
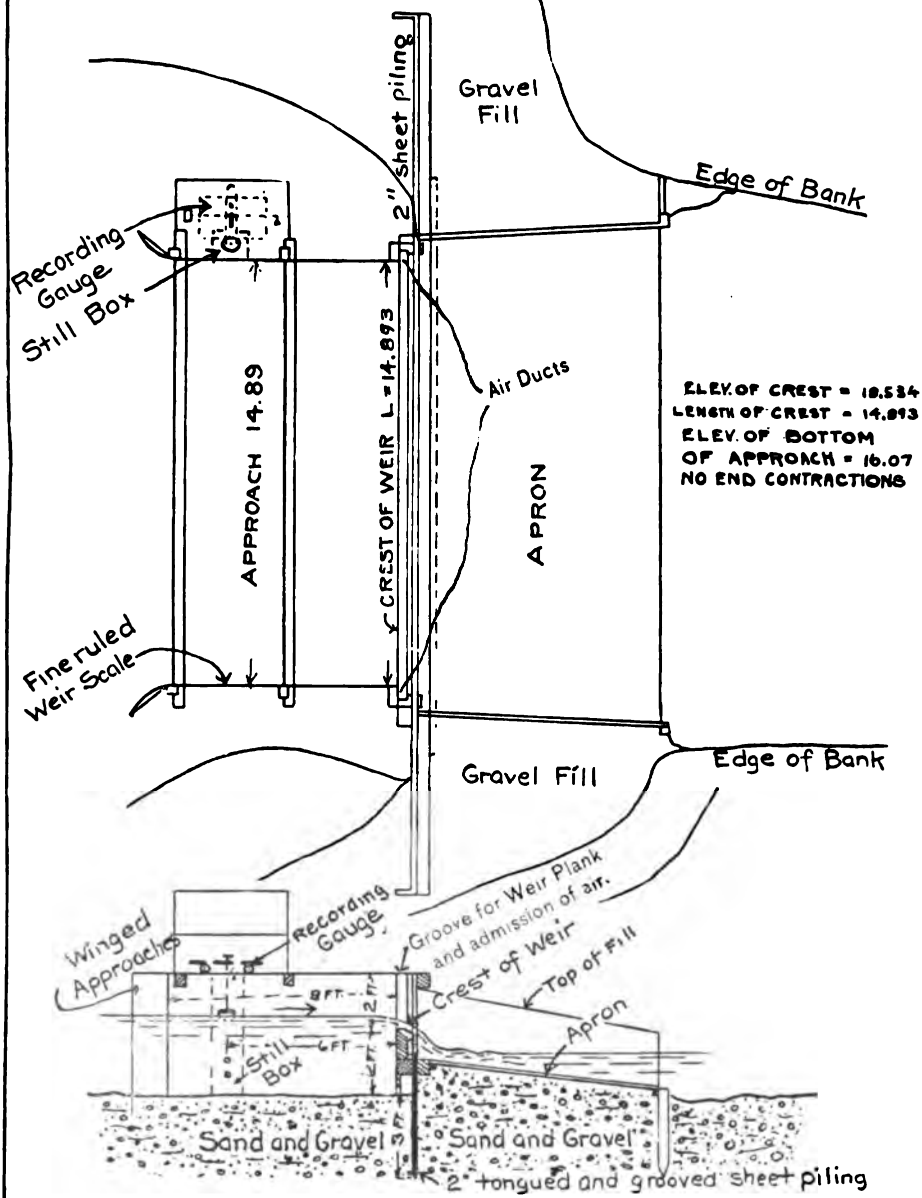


FIG. 22. APP. VII.



MASSAPEQUA GAUGING STATION

ESTABLISHED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY LONG ISLAND DEPARTMENT IN JUNE 1903

SCALE OF FEET

0 5 10 15

experiments of Francis, whose formula $Q = 3.33\, l\, h\, 3/2$ was used in working up the results.

Underflow—The loss from underflow, which it was feared would be an appreciable percentage of the flow, was minimized by the long line of tight sheet piling and the small head on the material about the weirs that was introduced by maintaining the crest of the weirs at the lowest possible elevation. Although the sand and gravel exposed in the bed of these streams seems very coarse, it is found upon excavation that the material below the surface is well packed and is graded from coarse to fairly fine sand. The maximum slope of the water-table about the ends of these weirs was found to be about 1 in 10, which perhaps corresponded to a velocity of about 25 feet per day. A rough computation of the excess underflow that would be caused by this velocity through an effective soil space of 100 square feet gives 0.1 cubic foot per second, which is only 0.7 per cent. of the normal flow of the larger streams.

Daily Observations—An engineering assistant made daily observations at all of these stations in order to secure corrections to the curves that were being traced by the recording depth gauges. For these corrections the depths on the weirs were determined each day by measuring with a hook gauge from a bench mark on the top of the still box to the surface of the water below; these depths were checked at each observation by "point gauge" readings of the height of the water outside below a bench on the approach at the same distance above the weir as the holes in the still box (6 feet); a further check on the elevation of the water above the weir was obtained by reading a fine-ruled weir scale which was set in flush with the side of the approach directly opposite the still box. The observations at the stream gauging stations were continued until November 1, when the gaugings were discontinued.

Recording Depth Gauges.

Three types of recording depth gauges were used, a Friez Water Stage Register, a dial gauge, and another type especially designed for these measurements.*

Friez Water Stage Register—The recording gauge at the East Meadowbrook Station was a Friez Automatic Water Stage Register of the "1903" pattern, which recorded actual depths at the weir without reduction. This gauge worked very well except when great changes in depth brought the pen around to a lap in the diagram when the record, at times, was lost for a few hours.

* The recording gauges were left for a week, without any attention, after the daily observations were discontinued on November 1, and it is interesting to note that, at the end of the week, all the gauges had kept perfect time and recorded the depths correctly for the seven days' run, with the exception of the Friez register; the clock of this gauge had stopped.

Dial Gauge—On the East Newbridge Stream a dial gauge hastily designed for the sewer experiments of Mr. John R. Freeman in Boston, was used and gave good results.

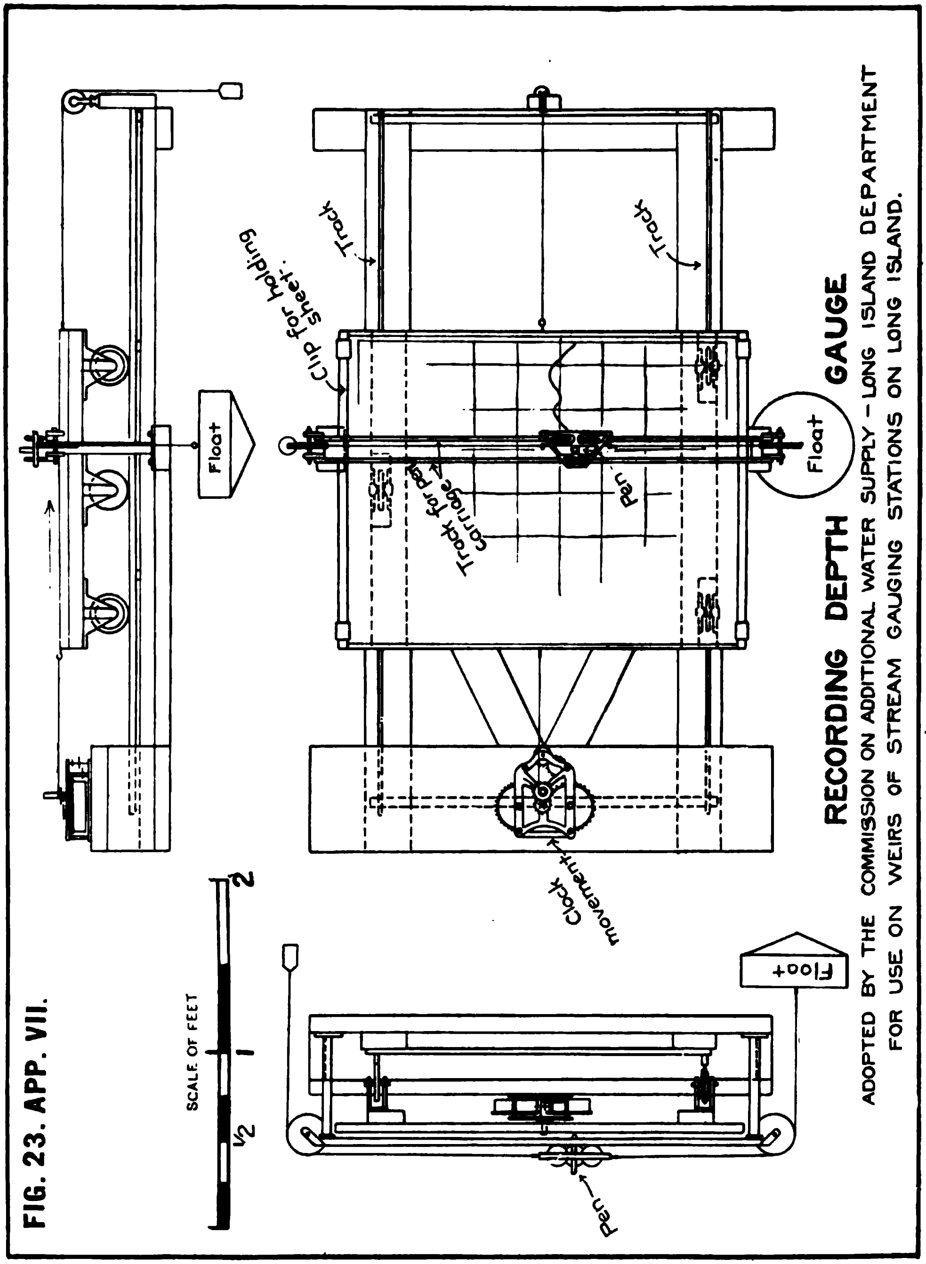


FIG. 23. APP. VII.

RECORDING DEPTH GAUGE

ADOPTED BY THE COMMISSION ON ADDITIONAL WATER SUPPLY – LONG ISLAND DEPARTMENT
FOR USE ON WEIRS OF STREAM GAUGING STATIONS ON LONG ISLAND.

Special Gauges Made for the Commission—For the other four stations, gauges similar to that used by Mr. Desmond Fitzgerald in his evaporation experiments at the Chestnut Hill Reservoir were made. A sketch of this gauge is shown in Figure 23. The large, rectangular diagram, 18 by 23 inches, gave a range of 1.5 feet in depth and an open time scale which greatly facilitated the computations of the quantities. The results obtained with these gauges were very satisfactory, and, while not as compact nor as neat as the Friez Water Stage Register, they cost only $41 each against $125 which was paid for the Friez gauge.

(2) *Weir Stations with Weir Scales Only*—Besides these six gauging stations that were provided with recording instruments, four other stations were established where existing conditions afforded opportunities to obtain approximate measurements of flow by daily observations on fine-ruled weir scales. A scale ruled in 0.01 foot was set above the spillway of Baiseley's Pond, another above the small pond on Seaford Creek just north of the railroad, and two more at the Geological Survey stations on the Upper Massapequa and on Doxsee's Creek, after they had been reconstructed.

The Jamaica Creek Station was at the wasteway of Baiseley's Pond, where the smooth granite spillway offered an opportunity to approximately determine the flow by assuming a curve of discharge from experiments on crests of similar form. Readings on the weir scale at this station were made by one of the ground water observers until October 15th.

The Seaford Creek Station was located at the outlet of a small pond just above the conduit. By sharpening the crest of the stop planks, there, a very fair measurement of the flow was obtained, but an indeterminate amount of underflow caused by leakage into the conduit 50 feet below the pond made the flows obtained unsatisfactory. The daily observations were made by the assistant who looked after the recording gauges at the weir stations.

The Massapequa Station of the United States Geological Survey was changed after it had been abandoned by the Survey, in order to secure perfect end contractions, and readings three times each day were made by a special observer. Considerable leakage developed at this station in October and the observations were stopped on October 16th, as the records of this station were not of sufficient value to warrant the expense of reconstructing the flume and embankments.

The Doxsee's Creek Station of the Geological Survey was reconstructed and the weir moved up stream to give a better approach on sides and bottom. The daily observations there were made by one of the ground water observers and were discontinued on September 5th.

The details of the ten gauging stations and the period covered by the measurements at each station are given in Table No. 3. The approximate locations of these staions are shown on Plate V, following page 672.

TABLE NO. 3.

Stream Gauging Stations Established on Long Island by the Commission on Additional Water Supply.

Stream.	Method of Measurement.	Length of Weir.	No. End Contractions.	Width of Approach.	Depth of Approach below Crest of Weir.	Date of Measurement.
		Feet.		Feet.	Feet.	
1. Baiseley's Pond.......	Weir scale at stone overflow.	21.00	None.	21.00	....	Aug. 12 to Oct. 15
2. East Meadow Brook ..	Recording gauge with sharp crested weir...............	14.676	None.	14.68	2.15	June 1 to Nov. 8
3. West Newbridge Stream (Cedarbrook)	Recording gauge with sharp crested weir...............	2.985	2	6.00	1.23	Aug. 1 to Nov. 8
4. East Newbridge Stream	Recording gauge with sharp crested weir...............	4.985	2	9.00	1.95	July 23 to Nov. 8
5. West Wantagh Stream	Recording gauge with sharp crested weir........... ...	10.040	None.	10.04	2.09	July 20 to Nov. 8
6. East Wantagh Stream.	Recording gauge with sharp crested weir.	10.095	None.	10.10	2.72	July 21 to Nov. 8
7. Seaford Creek.........	Weir scale with sharp crested weir	1.040	2	7.50	2.50	Aug. 1 to Oct. 31
8. Upper Massapequa Stream.............	Weir scale with sharp crested weir	1.860	2	2.50	1.50	Aug. 1 to Oct. 16
9. Massapequa Stream...	Recording gauge with sharp crested weir...............	14.893	None.	14.89	2.46	June 20 to Nov. 8
10. Doxsee's Creek.......	Weir scale with sharp crested weir	3.003	2	....	3.00	Aug 15 to Sept. 5

(*d*) *Examination of Watersheds.*

The watersheds of the streams between East Meadow Brook and Massapequa stream, which were gauged with the greatest care, were studied in some detail. The divides were carefully traced out on the maps of the United States Geological Survey to determine as closely as possible, at a reasonable expense, the actual drainage areas above the gauging stations and the surfaces of the watersheds were inspected to determine the proportions of these areas that are covered by woodland, grassland, pasture, cultivated land, impervious surfaces and water surfaces, as well as to make an approximate estimate of the population on the watershed of each stream.

(*H*) *Underflow Measurements.*

Measurements of the velocity of flow of the underground waters on the south shore of Long Island were made, with the co-operation of the Geological Survey, and, later, were continued by the Commission to determine, if possible, the amount of ground water that escapes into the sea through the pore spaces of the sands and gravels without appearing in the surface streams, and also to study the effect of pumpage on the velocity of the ground water near the present Brooklyn driven well stations.

(a) Underground Run-off.

The locations that were selected for these measurements were on a section between the stream gauging stations established by this Commission on the streams from East Meadow Brook to Massapequa Stream. By this plan it was hoped that an estimate could be obtained of the total southward flow of the ground water across this section. This underflow, with the run-off of the surface streams, would account for all the rainfall, with the exception of that portion which was evaporated.

Nine stations were located and from these twelve measurements of the underground flow were secured. The deepest wells were 80 feet, but the sand in those at that depth was very fine and no velocity was found. The work of driving wells was suspended on September 5th and other and deeper wells that were planned were not driven; consequently the knowledge of the deep underground flow is very meagre. The results are discussed on page 559, under "Ground Water."

(b) Experiments at Driven Well Stations.

One or more sets of wells were placed at the Agawam, Merrick, Matowa, Wantagh and Massapequa driven well stations. These wells were located between the stations and the conduit line, and it was planned to measure the velocities of flow before and after the pumping plants were started. In all, ten measurements were made, but little information was obtained before operation, and but little afterwards, as only two stations had been started this year.

Through the saturation of the upper strata by the artesian flow from the deep wells at Matowa and Wantagh, no velocities were found at these stations, and at the Merrick Station, which is the only one of the five that is located on high ground away from the surface streams, a slight northward flow, caused by the drainage of the ground water into the aqueduct, was measured.

Only the Wantagh and Agawam stations have been operated this year. One measurement at each station was made at a depth of 20 feet below the surface during a period of pumping of two days; and, later, another series was made at Agawam at depths of 8, 15, 26 and 40 feet.

(c) Other Measurements.

Besides the measurements at the driven well stations and on the sections above the supply ponds, three sets of wells were driven below the Wantagh Supply Pond to determine the velocity of flow at the proposed infiltration gallery that is being constructed by the Brooklyn Water Department.

(*d*) *Method of Measurement.*

The method of measurement of the underflow, which has been devised by Professor Charles S. Slichter, of the United States Geological Survey, is that of determining electrically the time required for the ground water to flow through the sands and gravels from one driven well to another, by changing the electrical resistance of the water in the soil and in the downstream well through the introduction of a solution of common salt or ammonium chloride to the upstream well. A brief description of this method of measurement may be of interest.

(1) *Wells Required*—As only the approximate direction of the underflow is generally known, sufficient wells must be driven to cover any possible deviation. Usually four 2-inch wells are driven; one, the upstream well, which is to receive the electrolyte, one downstream from this on a line which, from the contour of the surface and the drainage lines, appears to be the most probable direction of flow, and two more, each at the same distance from the first as the second, and at an angle of about 30 degrees from the assumed direction of flow or line between the first and the second well. When the direction of flow is quite doubtful, one, and sometimes two, additional wells are driven at the same distance from the first at angles of 30 degrees from the other wells.

The distance between the first, or upstream, well and the others is usually made 4 feet for wells up to depths of 25 feet, and 6 and 8 feet for deeper wells; the upstream well is generally driven to a depth 2 feet less than the others to make sure that the electrolyte, which has a higher specific gravity than water, does not drop below and miss the other casings.

It is necessary, of course, that each well has a perforated section at the depth at which a measurement is made, in order to provide a free passage for the ground water through the well. A common well point serves admirably for this purpose, and Professor Slichter states that a clean well point causes no lag in the measurement of the velocity of flow.

On shallow wells up to 25 or 30 feet in depth, or to even greater depths in loose sand, brass jacket closed-end well points 4 feet long are used; on deeper wells brass jacket well points of the same length, with open ends are required, in order to permit the removal of the material penetrated, and thus facilitate driving. With open points, it is, of course, necessary to plug the end or "gravel the well" to prevent the filling of the screen section, and, in fine material, it is often advisable, for this reason, to drive a 5-foot length of plain pipe below the screen in order to be better able to plug the well.

(2) *Pumping and Cleaning Wells*—It is of the greatest importance that the wells should be clean and the strainers free before a measurement is made, because a strainer that is clogged with rust or fine sand will offer so much resistance to the flow that a good measurement may not be obtained. Each well is, therefore, thoroughly washed out and pumped before a measurement.

A 2-inch common force or "house lift" pump is attached to each well, and pumping is continued until the delivery is perfectly free and the water clear. Turning a badly clogged well will sometimes aid in cleaning the strainer.

(3) *Salting the Wells*—The electrolyte commonly used is ammonium-chloride (sal-ammoniac). This is introduced into the upper well in solid form or in a saturated solution. If crystals are used, the salt should be lowered into the well by means of a perforated bucket, for, if simply dropped in, the pipe would be clogged. The best method of salting a well is to introduce a hot solution of the salt, for the higher temperature of the water gives a stronger solution of the salt than cold, and a specific gravity more nearly that of water. Even with a hot solution, the water in the wells falls several feet upon the introduction of the electrolyte, and does not recover its normal elevation until the salt has quite disappeared from the well. For shallow wells, a dose is about 10 or 15 pounds of ammonium chloride, or about a pailful of the solid salt, which makes three or four pails of saturated solution; for deeper wells as much as 20 pounds is required. This large amount is necessary in order to displace all the ground water in the well, and thus make sure that a strong solution of the salt reaches the screen section of the well.

The diffusion of the salt as it leaves the well is small; Professor Slichter has found that the solution of the salt diffuses about 3 inches upstream, and on both sides from the casing of a 2-inch well, and only spreads out over a width of about 18 inches at a distance of 4 feet from the well in the direction of flow. This small diffusion, of course, limits the width between the downstream wells. A somewhat greater diffusion is obtained through the generation of ammonia at the bottom of the well by dropping into the well 5 pounds of crystals of caustic soda or caustic potash about an hour before the well is salted with the sal-ammoniac.

(4) *Measurements*—The velocity of the water between the upstream well and the lower wells is measured by observing the change in the electrical resistance between the casing of the lower wells and the electrodes within, and between the casing of the upper and lower wells. The electrical connections are, therefore, made to measure, at regular intervals, the current passing between the casing and electrode of each of the lower wells, and at the same time the current between the casing of each of the lower wells and the casing of the upper well. These circuits are shown diagramatically in Figure 24, together with the switchboard and ammeter.

The connections to the casings are made by means of binding posts on galvanized iron couplings which are screwed tightly to the top of the well. The electrodes are simply nickel-plated brass rods, 5-16ths-inch in diameter and 4 feet in length, insulated from the pipe, top and bottom, by two wooden blocks. Number 16 copper wire, covered with rubber, is generally used for all connections in the wells and on the surface.

The switchboard, which has been designed by Prof. Slichter and has been described by him, greatly increases the speed at which the observations have been made and gives fairly uniform contacts. This switchboard and the batteries are arranged together in a neat box, in which all the circuits are brought together, and, by means of a switch for each circuit, one can be thrown in after another and the current noted by reading the ammeter. The ammeter that was used by the Commission is a small pocket instrument, made by Louis M. Pignolet, of New York, which has two scales, one graduated every 0.02 ampere up to 1.5 and the other from 0.1 up to 5 amperes.

Dry batteries of sufficient strength are used to give an appreciable deflection (0.05 to 0.1 ampere) on the circuit between the casing and the electrode before the electrolyte is added; three or four dry cells, in series, are usually sufficient. These give a current of 2 to 3 amperes in the lower well when the salt reaches it.

The progress of the salt through the ground is sometimes shown by a constant rise in the measured current between the upper and the lower casings. Its appearance in the lower well is indicated by a sudden rise in the current between the electrode and casing. The recorded values of the latter current, plotted on a suitable time scale, give a curve shown in Figure 26. The point of inflection of this curve indicates the point of greatest intensity of salt in the well and is taken to mark the end of the time period covering the passage of the salt from the upper to the lower well. Unless the velocity of flow is exceptionally fast, hourly observation will give a sufficient number of points for plotting the curve, and if the salt does not appear in the first

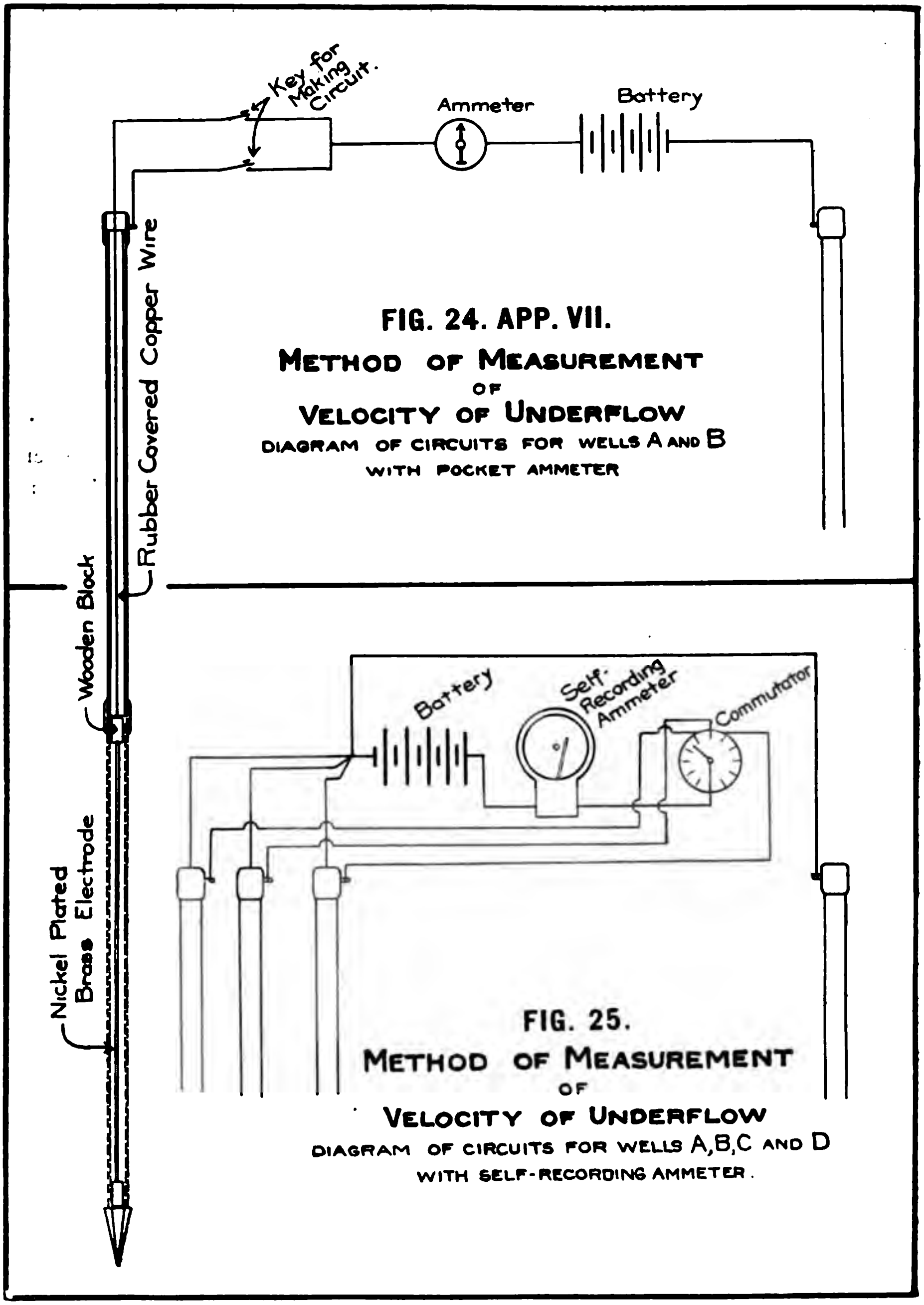


FIG. 24. APP. VII.
METHOD OF MEASUREMENT OF VELOCITY OF UNDERFLOW
DIAGRAM OF CIRCUITS FOR WELLS A AND B WITH POCKET AMMETER

FIG. 25.
METHOD OF MEASUREMENT OF VELOCITY OF UNDERFLOW
DIAGRAM OF CIRCUITS FOR WELLS A, B, C AND D WITH SELF-RECORDING AMMETER.

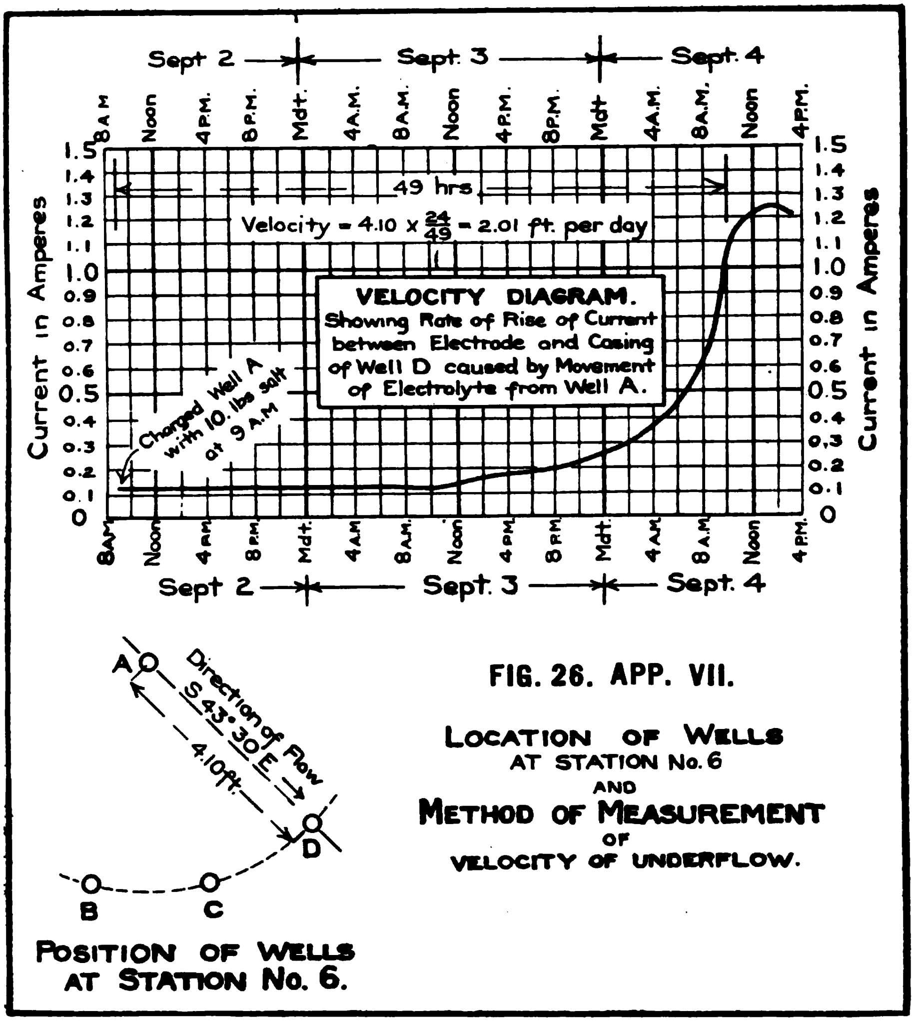


FIG. 26. APP. VII.

LOCATION OF WELLS AT STATION No. 6 AND METHOD OF MEASUREMENT OF VELOCITY OF UNDERFLOW.

twenty-four hours after salting the upper well, observations at two or three hours intervals will suffice.

When the screens are clogged or the flow passes between or outside of the lower wells, an estimate of the velocity can sometimes be made from the measurements of the current between the casing of the upper and those of the lower wells; the results by this method are, however, not as satisfactory as the first described.

Prof. Slichter used on many of his underflow measurements a recording ammeter which he has fully described in the *Engineering News.* The use of the recording instrument avoids the frequent observations and night work that the ammeter requires. Figure 25 shows the circuit for the recording instrument.

(I) *Studies of the Effect of Pumping.*

The records that have been made by the Brooklyn Department at their driven well stations, particularly those at the Agawam, Merrick, Matowa, Wantagh and Massapequa stations, have been studied in considerable detail.

The Agawam Station was operated for two weeks, from August 31 to September 14. Previous to starting up the station, 26 test wells were driven by the Commission, in addition to the 16 of the Brooklyn Water Department that already existed, and all were observed before pumping, throughout the run, and for several days after, to determine the rate at which the ground water was lowered, the rate of its recovery and the amount and extent of the depression of the surface of the ground water. Mercury pressure gauges were placed on the section to observe the loss of head, and a recording depth gauge was set up at the measuring weir to obtain a continuous record of the discharge of the pumps.

The information obtained was not what it was hoped to secure; the wells had become clogged to such an extent that, even with a vacuum of 24 inches, but little over 2 million gallons per day was obtained, which is two-thirds of that delivered last December and less than half the original delivery of this station; consequently, the surface of the ground water was not pulled down as much as if the station had been in better condition and the information obtained has, therefore, less value.

Studies were also made on the extent of the surfaces of the ground water about the Spring Creek, Baiseley and Oconee Stations as they were affected by the pumpage. Further studies of this kind were planned, but time did not permit their completion.

I.—RAINFALL.

(*A*) *Early Rainfall Observations.*

Meteorological observations were made in this country at an early date, but they were at first confined to recording the temperature of the air. The early rainfall records were, in general, made through private effort or by the leading schools and colleges and were begun in the middle of the eighteenth century.

A great variety of crude gauges were used in these early observations and, in general, there appears to be such a lack of appreciation of the requirements that are now considered necessary to secure correct results that this early work is of doubtful value.

(*B*) *Government and State Observations.*

The first systematic meteorological observations, which in precision and in uniformity of method compare with similar observations of to-day, were made by the Medical Department of the United States Army. From the organization of the Medical Department, in 1821 to 1836, only the temperature and the direction and force of the wind were observed; early in 1836, however, rainfall observations were commenced, which were carried on, with few interruptions, until 1891.

Shortly after the work of the Medical Department was begun, similar work was undertaken by the States of New York, Pennsylvania and Ohio; that in New York was begun in 1826, under the direction of the Regents of the New York Academies.

In 1846, when the Smithsonian Institution was organized, the existing methods of rainfall measurement were much improved, and, in 1848, more extended meteorological observations than before attempted were begun by this organization and were continued for almost thirty years.

The greater part of the meteorological work of the Smithsonian Institution was taken up by the Signal Service, which was organized under the War Department in 1870; under the Signal Service, the present system of daily meteorological observations and weather predictions was worked out. In July, 1891, this work was transferred to the Department of Agriculture and the Weather Bureau created.

From 1888 to about 1899, the State of New York maintained, with the co-operation of the United States Weather Bureau, a weather and crop service, under a director, with headquarters at Ithaca. This State organization was gradually absorbed by the national bureau, until now the State service is merely a department of that organization.

(a) Regents' Stations.

The most important as well as the first of the early series of rainfall observations on Long Island were those made by the principals of the State Academies under the supervision of the New York Board of Regents.

These stations were established shortly after the army post stations, but their rainfall observations antedate those of the post surgeons by ten years. When the Smithsonian observations were begun many of the Regents' stations reported to the Smithsonian Institution. The Long Island stations that were established by the Regents are shown in the following table, together with the periods of observation.

1. Flatbush—Erasmus Hall	Jan. 1826 to Dec. 1865
" "	Jan. 1868 to Dec. 1869
" "	Jan. 1872 to Dec. 1872
2. Jamaica—Union Hall	Jan. 1826 to Dec. 1864
3. Easthampton—Clinton Academy	Jan. 1827 to Dec. 1843
" "	Jan. 1852 to Aug. 1852
4. Oyster Bay—Oyster Bay Academy	1834 and 1837

The first two stations, at Flatbush and Jamaica, which are the most important, were investigated with great care and, although but little was learned of the Easthampton and Oyster Bay Stations, all the evidence collected indicates that the character of the observations at the State Academies was very good for that period. These early State Academies ranked very high, and it seems reasonable to expect that men of the ability and earnestness of the principals of these schools must have made careful, painstaking observations.

(1) *Flatbush—Erasmus Hall*—The old academy can be found on Flatbush avenue near Church avenue, Brooklyn, where the original building, with several additions, now serves as one of the high schools of Brooklyn. As far as can be learned, the rainfall observations were made at two locations; the first, from 1826 to, perhaps, 1846, was in the open field behind (east of) the hall; the second, from 1846 to 1872, about fifty feet from the northwest corner of the building, as shown in Figure 27.

The rain-gauge at the first location was a conical gauge and was placed, it is said, four to five feet above the ground; the second instrument of which there is a record, the Smithsonian funnel type, was set with the top of the funnel level with the ground. It is very likely that the 8-inch Smithsonian gauge was also used at Erasmus Hall for the later observations, but no record of this was found.

The records from this station, with those from Fort Columbus and Fort Hamilton, were considered in 1867 by the Chief Engineer of the Brooklyn Water Works, Mr. James P. Kirkwood, when he made up his estimates of yield of the original Brooklyn Watershed.

(2) *Jamaica—Union Hall*—The Regents' Station at Jamaica was on what is now known as Union Hall street. The old building stands on its original location on the west side of the street, just north of the Long Island Railroad, but it has been converted into a tenement house and now bears little resemblance to a school. Considerable open ground still remains about the building, and the evidence that has been gathered, that the rain-gauge there was located in an open space, can be readily accepted.

The gauge used at this station, during, at least, the last twenty-five years of the record, was a 10-inch cylindrical gauge, as will be described. It is quite likely, however, that the conical gauge may have been employed for the first observations.

(3) *Easthampton: Clinton Academy*—The gauge at Clinton Academy is said to have been in a good location, "60 or 70 feet from any building". Nothing, however, could be learned as to the type of gauge that was used.

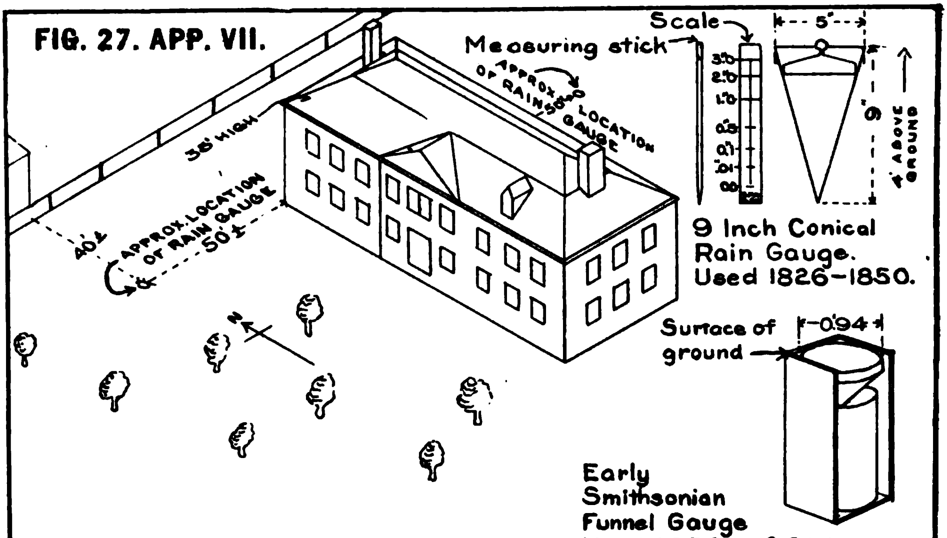
Rain Gauges Used at the Regents' Stations.

During the investigations, it was found that at least three types of rain gauges were used at the Regents' Stations; a conical gauge, a 10-inch cylindrical gauge, the Smithsonian funnel gauge, and later it is believed that the Smithsonian 8-inch gauge was adopted.

The catalogue of the instrument makers of the period covered by the early observations at these stations show only the first two types, so that it is probable that the Easthampton and Oyster Bay stations were equipped with either the conical gauge or the 10-inch cylindrical gauge.

The Conical Rain Gauge—The first rain gauge used at Erasmus Hall and, perhaps, at the other Regents' stations, was made by Benjamin Pike & Sons, 166 Broadway, New York City, and was similar in pattern to that adopted by the Surgeon General for the United States Army posts. A good description of this "Pike" gauge is given on the printed slip pasted on the back of the thin piece of board accompanying the gauge, to which is attached the paper scale by which the rainfall measurements were made. A copy of this description is given below.

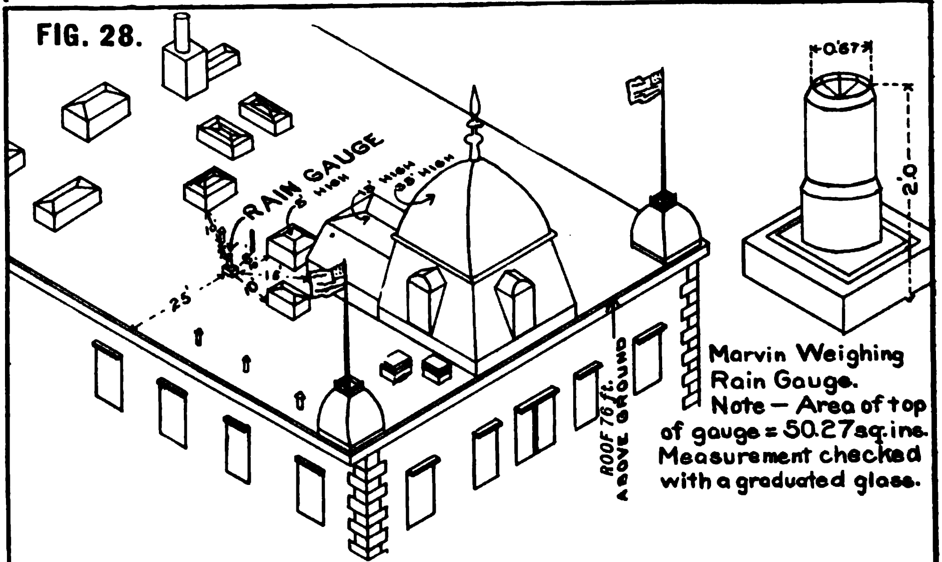
FIG. 27. APP. VII.



LOCATION OF RAIN GAUGE AT
ERASMUS HALL, FLATBUSH,
BROOKLYN, BROOKLYN BO. N.Y.
MEASUREMENTS MADE 1826–1865
JAN. 1868–DEC. 1869. JAN. 1872–DEC. 1872.

W. L. W. DEL.

FIG. 28.



LOCATION OF RAIN GAUGE AT
MUNICIPAL DEPARTMENT BUILDING,
BROOKLYN, BROOKLYN BO. N.Y.
MEASUREMENTS BEGUN NOV. 1894.

"DESCRIPTION OF THE CONICAL RAIN GAGE."

"The Rain Gage is a simple cone of copper, of a given shape and capacity, which is placed in any situation where it will receive its due proportion of rain. It is usually placed in a piece of wood bevelled out to fit the cone, and fastened to a post about eight feet high; the cap is placed in the cone with its base downward. However closely it may fit, by being pressed into it, there will still be sufficient room between it and the sides of the Gage, to permit the water to pass to its bottom. Immediately after every shower or fall of rain, the water must be measured and the contents registered, and then discharged. On this will depend the accuracy of the account; for, from the construction of the Gage, the degrees of the scale near its bottom being the largest, small quantities may be measured with greater accuracy by this than by the Gages commonly used. The cap is intended to prevent evaporation before the measurement is made, should that be accidently delayed. The measurement is made by putting down to the bottom of the Gage the point of the measuring stick, and applying the distance between it and the water mark to the scale.

"The graduation of the scale is by hundredths of an inch for the first three-tenths of an inch, and above that by tenths and half-tenths. The intermediate distances may be measured by the eye, and set down in decimals. When showers or rains of short duration fall, it will be well to note the A. M. and P. M., with the hours between the beginning and end prefixed, in order that the time may be compared with that of observations made at other places. If the rain continues for any length of time, the observations should be made at suitable intervals before the water rises in the Gage.

"It is important that the measure be taken without delay after every fall of rain, as experience has proved that the water in the Gage will soon become diminished by the rising along the inside of the Gage by capillary attraction, and then become dissipated by evaporation.

"The usual precaution must be observed in giving the Rain Gage such a position as that nothing may obstruct the rain in its most oblique direction from entering it, and no sediment must be suffered to remain in it.

"The Rain Gage must be kept remote from all elevated structures, to a distance at least equal to their height, and still farther off where it can be conveniently done, and be not more than ten feet above the surface of the ground.

"In freezing weather, when the Rain Gage cannot be used out of doors, it may be taken into a room, and instead of it a tin vessel should be procured for receiving the snow or sleet that may fall; this vessel must have its opening exactly equal to that of the Rain Gage, and widen down to a sufficient depth, with a considerable slope. It should be placed where nothing can obstruct the descending snow from entering it, and where no drift snow may be blown into it. During a continued snow storm the snow may be occasionally pressed down into it. The contents of the vessel must at proper times be melted over a fire, and the water produced poured into the Gage to ascertain its contents, which must be entered in the Gage column of the Register.

"Manufactured and Sold Wholesale and Retail by

"BENJAMIN PIKE & SONS,
"Optician and Philosophical Instrument Makers,
"166 Broadway, New York."

This gauge is shown in Figure 27, together with the measuring stick and a sketch of the scale.

An inspection of this scale clearly shows that for small amounts of rainfall, up to one-tenth of an inch, the accuracy of the measurements was quite as great as with our present instruments, provided that the pointed measuring stick reached the bottom of the gauge at each measurement; for a rain of two inches or more, the precision of measurement was small and, as the gauge held only three inches depth of rain, it is quite likely that, at times, much rain was lost through the running over of the gauge, an incident that is not unknown to-day with certain types of instruments of small capacity.

Another feature of the conical gauge was unfortunate; the angle and height of the inside cone or "cap" that was designed to prevent evaporation were such that much rain must have been lost in a heavy shower through spattering.

An appreciable error was undoubtedly caused in the early rainfall measurements with the conical gauges through elevating the gauges four or five, or, as the instructions require, eight feet above the ground. Experiments have since shown that, in a high wind, a gauge at an elevation of even five feet may give results as much as ten per cent. less than the true amount of precipitation.

The Funnel Gauge—The early Smithsonian rain gauge was used at Erasmus Hall during a period following 1846. This gauge is described on page 686, under "Smithsonian Rain Gauges."

The 10-inch Cylindrical Gauge*—The rain gauge used at Jamaica, after 1838 and perhaps for the previous observations, had a conical receiver with an opening ten inches in diameter, from which the rain flowed into a cylinder having a diameter of only four inches. In this cylinder was a float to which was attached a brass rod which ran up through a brace across the top of the gauge. A scale on the float rod which was graduated in inches the depth was read at the top of the brace, and the amount of rainfall thus directly determined.

The Commission is indebted for information concerning this Jamaica gauge to Mr. E. A. Brinckerhoff, a son of one of the principals of Union Hall. Mr. Brinckerhoff made up his father's reports to the Regents for many years and for a while recorded the observations on the rain-gauge.

---

*A gauge very much like that which Mr. Brinckerhoff describes is shown in a catalogue of Benj. Pike, Jr., one of the members of the original firm of Benj. Pike & Sons, who manufactured the Erasmus Hall gauge. This catalogue of Benj. Pike, Jr., was published in 1848, and is well illustrated. Besides a conical rain gauge, he advertised a "Cylindrical Rain Gauge."

A cut of the cylindrical gauge is shown in this catalogue, and it is explained that it was designed to be ornamental as well as useful. The top of the gauge was about four feet above the ground and consisted of a conical basin ten inches in diameter at the top, communicating through a hole in the bottom with a long cylinder about three inches in diameter, which was supported by a frustrum of an inverted cone similar to that on top and intended to be filled with sand to give sufficient stability. A graduated glass tube was connected, top and bottom, with the three-inch measuring cylinder; the area of the tube and the cylinder was one-tenth that of the opening on top, so that one-tenth on the scale of the glass tube was read as 0.01 inch of rain. The water in the gauge could be drained away by a cock at the bottom, but as this could not always be done at once it was found that the cylinder and glass tube sometimes froze up and burst. The price of the gauge, with graduated glass tube, was $7.50; with a float (similar to the Union Hall gauge) within the measuring tube, instead of a glass tube outside, only $6.

He is now using, at his residence at Englewood, N. J., a rain-gauge similar to the Union Hall gauge, which he describes:

> "The tube or cylinder is 22 inches long and 4 inches in diameter. The cone fitting over same is 9 inches deep and 10 inches in diameter at top. This top of cone is 5 feet above ground, the gauge being attached to post standing far away from elevated objects. * * * The brass rod with float at bottom is spaced into degrees and measures up to 2 inches." * * *

Speaking of the old gauge at Jamaica, he states:

> "The care of the gauge during the years that responsibility of record was left me covered about same points as above, viz.: in open space and elevation; in heavy rains, it was watched and emptied if exceeding 2 inches full and filling again by continued rain."

From an inspection of the Union Hall records, it appears that the results were quite as good and, perhaps, more reliable than those at Flatbush, as the Jamaica gauge was better, being larger, and the method of measurement more accurate. Furthermore, a rainfall exceeding three inches would not have been lost in the 10-inch gauge, as in the conical gauge, for after the cylinder was filled there was room for perhaps four or five inches more in the cone above.

Mr. J. P. Kirkwood noted, in his report of 1867, that the Flatbush and Jamaica records did not agree and accepted the records from the former station. Without, however, more knowledge of the comparative accuracy of the observations, the Jamaica record is apparently the better of the two.

(*b*) *Army Post Stations.*

Beginning in 1836, in addition to the observations on temperature, wind and general weather conditions, the observer at each army post made daily measurements of rain and snow fall.

All of this material was reported to the Surgeon General, under whose supervision the observations were carried on, and was originally published in the "MSS. from Surgeon General's Office." When the Weather Bureau was created, in 1891, and the weather service was transferred from the War Department to the Department of Agriculture, the observations at the army posts were discontinued.

The army posts on and near Long Island with the periods of the rainfall observations made at each station, are as follows:

1. Fort Columbus.............................Jan. 1836 to Dec. 1891
2. Fort Hamilton.............................Jan. 1839 to June 1885
   " ....Sept. 1888 to Feb. 1892

3. Fort Wadsworth	June 1873 to July 1875
"	Nov. 1888 to Dec. 1891
4. Willett's Point	June 1870 to Dec. 1873
"	Dec. 1888 to Dec. 1899

It has been difficult to learn much about the observations at many of these army post stations; they were discontinued over ten years ago and since that time many changes have occurred among the officers stationed at each post and, as no notes were filed, it is impossible to exactly locate the position at which some of the rain-gauges were exposed.

(1) *Fort Columbus, Governor's Island*—The rainfall observations at Fort Columbus were begun January, 1836, and continued without interruption until December, 1891, except for a few months in 1866 and in 1867.

Fortunately, at this station, Mr. David Robertson, the apothecary at the post, who made the observations at Fort Columbus from about 1856 to 1891, was found. From Mr. Robertson it was learned that the rain-gauge was located in an isolated position about 75 feet northeast of the building, now known as the "Department Headquarters," as shown in Figure 30.

The first gauge, the conical type, was used until 1869, and was placed at a height of about 4 feet above the ground; the second, the 2-inch cylindrical gauge, which was used for the remaining observations, was set up on a thermometer shelter, at a height of 8 feet.

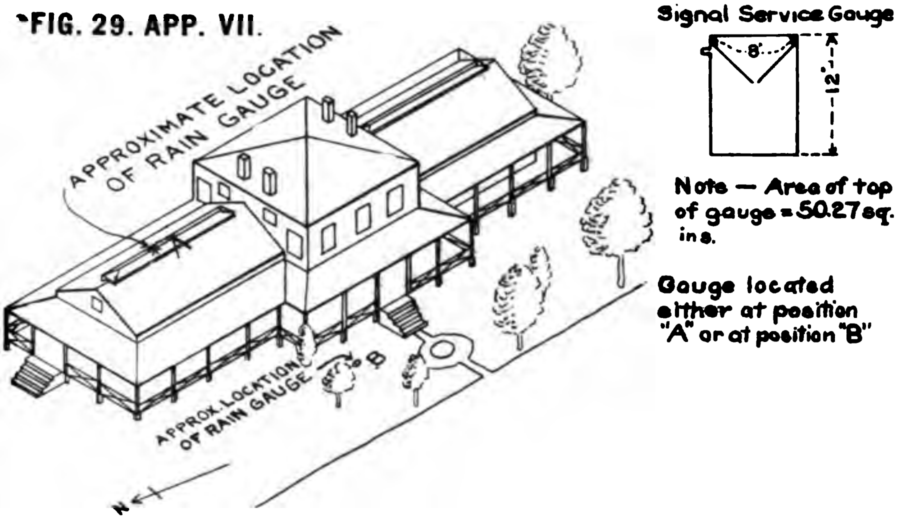
The observations at Fort Columbus are referred to in the Smithsonian reports as having been made with great care and accuracy and are undoubtedly the best of those made at the army post stations.

(2) *Fort Hamilton*—The rain-gauges at this station were identical with those at Fort Columbus; each, in turn, was located at a point in an open space about 35 feet southwest of the post hospital. The records from this station are not, on the whole, as good as those from Fort Columbus, as there is a suspicion that at times the gauge was neglected and the quantities "fudged" in.

(3) *Fort Wadsworth*—No opportunity was found to gather any facts concerning the station at this fort, but it is fair to assume that the instruments used here were the same as those at Fort Columbus and Fort Hamilton, and that the exposure was, at least, as good as that of the Willett's Point gauge.

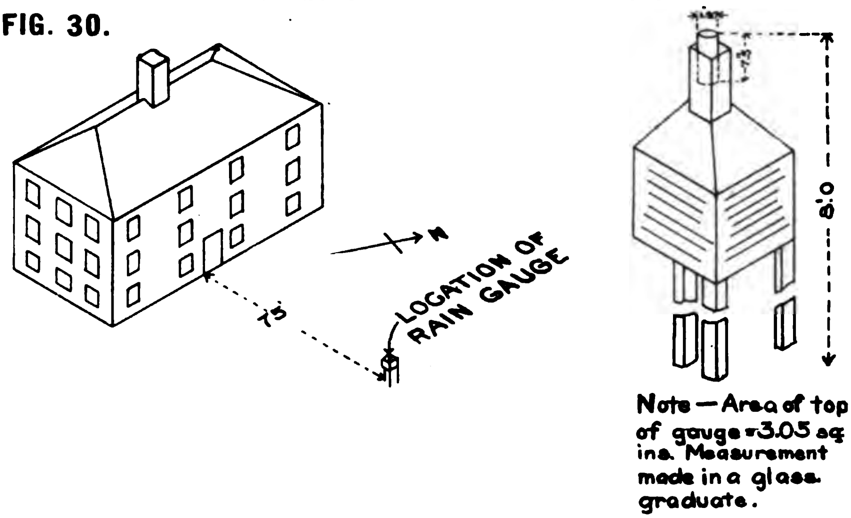
(4) *Willett's Point*—The observations at this station cover comparatively short periods, 1870 to 1873, and 1888 to 1899. The traditions at this post favor the location of the rain-gauge near the north end of the roof of the post hospital, but some evidence points to its location on the ground about 30 feet west of the hospital.

*FIG. 29. APP. VII.



LOCATION OF RAIN GAUGE AT
WILLETS POINT, QUEENS BO. N.Y.
MEASUREMENTS MADE JUNE 1870 to
DEC. 1873 — DEC. 1888 to DEC. 1899.

FIG. 30.



LOCATION OF RAIN GAUGE AT
FORT COLUMBUS, GOVERNORS ID. N.Y.
OLD CONICAL GAUGE IN SAME LOCATION
ON POST FOUR FEET HIGH UNTIL 1869.
MEASUREMENTS MADE JAN. 1836 – DEC. 1891.

W.L.W. DEL.

The sketch in Figure 29 makes it clear that the exposure of the rain gauge on the roof or near the building could not have given the best results and this has been considered in weighting these observations.

Rain Gauges Used at Army Post Stations.

All the early observations of the post surgeons, from 1836 to 1868 inclusive, were made by means of the "conical" rain-gauge; in 1869, this gauge was discarded in favor of a 2-inch cylindrical gauge, which was used for the remaining observations. At Willett's Point, which was a Signal Service station, the rainfall measurements were made with the standard 8-inch Signal Service gauge.

Conical Rain Gauge—This gauge was identical with the conical gauge used at the Regents' stations already described.

The snow gauge used during the early observations at Fort Columbus, and presumably at the other forts, was of copper with an opening at the top of five inches, and a much greater diameter at the base; the vessel had a total height of 18 inches, and was placed directly on the ground.

In common with the Flatbush observations, the measurements of rainfall at the army post stations were liable to the same errors from the overflowing of the gauges when the rainfall exceeded three inches, and from loss through spattering from the protecting cone.

Two-inch Cylindrical Gauge—After 1868, another type of rain gauge was used. This was a brass cylinder, 1.97 inches in interior diameter, and 7½ inches high, with no protecting cone to prevent evaporation; the gauge was placed on a post or on the thermometer shelter at a height of 8 feet above the ground.

Accurate snow measurements were, of course, impossible with this small gauge by the ordinary method of exposure, and the observers were directed to obtain a section of the snowfall on a level field by pushing the inverted gauge down into the snow, melting the core obtained, and measuring in the same manner as rainfall.

The measurements of rain or melted snow were made by pouring the water from the gauge into a glass graduate which read in cubic centimeters; the diameter of the gauge was such that 1 inch of rainfall was equivalent to 50 cubic centimeters. This type of gauge was too small and was certainly set up too high to give the best results.

(*c*) *Smithsonian Institution Stations.*

Although many rainfall stations were maintained by the Smithsonian Institution immediately after its organization in 1846, it was two years later, in 1848, that their extended system of observations, which was carried on continuously until 1870, except for some interruptions occasioned by the Civil War, was begun.

Their Long Island stations were well distributed, but the records cover comparatively short periods, and, consequently, have less value than the long series made at the army posts and the Regents' stations. Rainfall records from the following stations were reported to the Smithsonian Institution and published in the "Smithsonian Collections" and "Smithsonian Contributions to Knowledge":

1. New York Deaf and Dumb Asylum.......Jan., 1846, to Dec., 1870.
2. Sag Harbor............................ Jan., 1854, to Dec., 1858.
3. Blackwell's Island.......................Jan., 1856, to Dec., 1857.
4. Bellport................................Aug., 1857, to June, 1862.
5. Brooklyn................................Jan. 1, 1870, to Jan. 31, 1870.
   "   ....June, 1870, to Dec., 1873.
6. Cooper Union..........................Jan., 1871, to Jan., 1877.
7. Brookhaven............................Jan., 1874, to May, 1882.
8. Hempstead, Parsonage Creek Reservoir.... Jan., 1874, to May, 1874.
9. Flushing................................May, 1875, to Feb., 1884.

Only a few of the most important of these stations have been investigated.

(1) *New York Deaf and Dumb Asylum*—The rainfall observations at this station, which was at the present site of Columbia University, were made by Professor Oran W. Morse. Dr. Daniel Draper, Director of the New York Meteorological Observatory, has Professor Morse's original records and states that they were carefully made and are fully the best records in New York City during the period covered.

(6) *Cooper Union*—Professor Morse's observations, after December, 1870, were made at Cooper Union; the gauge is said to have been located on the green in front of the Peter Cooper monument. It is further stated that the rainfall records obtained there are not reliable, because, from its exposed position, the gauge was often tampered with.

Smithsonian Rain Gauges.

The first rainfall gauge adopted by the Smithsonian Institution was the "funnel type"; later their rainfall observers were also furnished with the 8-inch cylindrical gauge, which was used for most of their later observations. In 1868, a smaller gauge, only 2½ inches in diameter, was adopted for a short time, but only a few of these were distributed, and it is probably safe to assume that all the stations in this vicinity were equipped with the larger gauges.

Smithsonian Funnel Gauge—The funnel gauge is best described in the Fifth Annual Report of the Board of Regents of the Smithsonian Institution, 1851.

> "The rain and snow gauges and also the wind vanes are made, under the direction of the Institution, by Messrs. Pike & Son, 166 Broadway, New York. The rain gauge is an inverted cone of sheet zinc, of which the area of the base is exactly one hundred square inches. This cone, or funnel, terminates in a tube which carries the water into a receiving vessel. The water which has fallen is measured by pouring it from the gauge into a cylinder, so graduated as to indicate hundredths of inches. A smaller cylinder is also provided, which gives thousandths of inches, and may serve, in case of accident, as a substitute for the larger cylinder. The rain gauge is placed in a cask sunk in the earth, with its mouth near the level of the ground.
>
> "The snow gauge is a cylinder of zinc of the same diameter as the mouth of the rain gauge. The measurement is made by pressing its mouth downwards to the bottom of the snow, where it has fallen on a level surface, then carefully inverting it, retain the snow by passing under it a thin plate of metal. The snow is afterward melted, and the water produced is measured in one of the graduated glass cylinders of the rain gauge."

This type was later simplified by combining the funnel with the receiving vessel, which resulted in the well known type of gauge that is identified with the Smithsonian observations. The diameter of the latter gauge that was furnished to the voluntary observers was 8 inches.

Smithsonian 8-inch Gauge—This gauge was made of tin with a copper rim, having an inside diameter very close to 8 inches. A diaphragm was soldered to the sides of the can, 5 inches below the top of the gauge, to prevent evaporation from the chamber below. The rain passed into the receiving chamber through a 1-12-inch hole in the centre of the protecting diaghragm, where it was depressed about ½ inch below the outer circumference. The rainfall was removed through a ½-inch tube in the side of the gauge just below the diaphragm and measured in a glass graduate about 3¾ inches in diameter and 9¾ inches high, which gave a multiplication of about 3¾ times. The gauge seems to have been placed, in all cases, directly upon the ground or else only slightly elevated, which indicates that the Smithsonian Institution appreciated the error of elevating the rain gauge, the method hitherto universally followed, before the introduction of the Smithsonian funnel gauge.

2½-Inch Cylindrical Gauge—In the report of the Secretary of the Smithsonian Institution in 1868, a gauge 2½ inches in diameter was recommended for their voluntary observers. The gauge was 12 inches in depth, without diaphragm, and the rainfall was measured by inserting a graduated scale in tenths and parts of tenths of an inch. Snowfall was secured by pressing the gauge, mouth downward, into the snow and isolating contents by passing a thin plate of metal under the gauge; the snow was then melted and measured as rainfall.

It was thought that better results could be secured with a gauge of this kind in which the depth of rainfall was not exaggerated, than with the 8-inch gauge previously described, as the loss of accuracy would be offset by fewer mistakes in the measurements. As previously stated, only comparatively few of these gauges were used and it is probable that they did not justify the hopes that were entertained of them. Without question, they were somewhat too small in diameter, but the error could not, ordinarily, have been large, for Cleveland Abbé states that, in rainfall measurements, "no error of more than one per cent. systematically attaches to gauges of ordinary forms and diameters anywhere between four inches and forty-four inches."

Shielded Gauges—Prof. Henry, who, with Espy, organized the Smithsonian system of meteorological observations, made numerous experiments on rain-gauges between 1848 and 1853, and, in 1853, suggested the "shielded gauge," which was afterward developed by Prof. Nipher, of St. Louis. By means of this gauge, the measurements of rainfall at any height will vary but little from that at the ground. There is no record, however, that Prof. Henry's shielded gauge was used by any of the voluntary observers on Long Island.

(*d*) *United States Signal Service Stations.*

In 1870, the present system of meteorological observations and weather predictions was established by the Signal Service of the War Department, under the supervision of the Chief Signal Officer. The work at the Signal Service stations where the daily reports were received and weather maps prepared was in charge of Observer Sergeants, enlisted men of the army, who were specially trained at the school of instruction maintained by the Service, but the great bulk of the observations was made, as at present, by voluntary observers. Many of the Smithsonian observers were taken over by the Signal Service and from time to time new observers were secured.

The only rainfall stations that were established in the vicinity by the Signal Service were the local forecast office in New York City and a voluntary station on Long Island.

1. New York City..................................Jan., 1871 to date.
2. Setauket ....July, 1885 to date.

(1) *New York City*—This station was located on Wall street in January, 1871; from there it was removed, on July 25, 1871, to the Equitable Building, No. 124 Broadway. The reports of the Signal Service indicate that the exposure of the instruments on the Equitable Building was favorable to good results and, aside from the height of the station which was on the roof of this building, the results appear to be reliable and trustworthy.

(2) *Setauket*—The Setauket Station was located at the residence of Mr. Selah B. Strong, who became one of the voluntary observers of the Signal Service in 1885; upon the transfer of the Signal Service work to the Weather Bureau, he served in the same capacity for that bureau. The location and description of the Setauket Station is given in the report of the New York State Weather Service, 1894, vol. 2:

> " The station is one mile northeast of Setauket post-office, upon a neck of land projecting into estuaries of Long Island Sound. * * * The rain gauge stands on nearly level ground and is well removed from obstructions to a free air circulation. Its height above ground is 12 inches."

In January, 1890, the station was equipped with instruments of the State Weather Service. Fig. 31 shows the location of the gauge at Setauket, and it is evident that, while not excellent, the exposure is not such as to lead to any serious errors in the results.

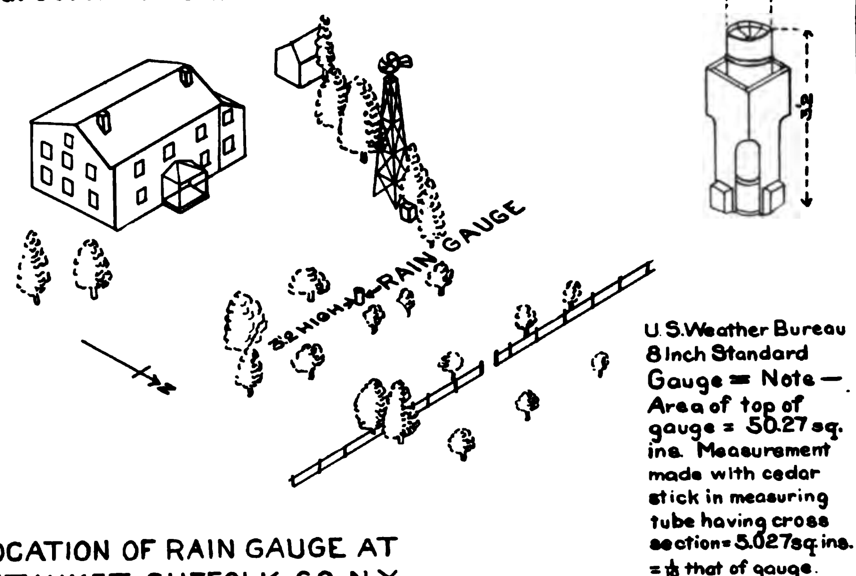
Signal Service Rain Gauge.

The rain gauge furnished by the service to voluntary observers is mentioned on page 76 of the " Report of Chief Signal Officer for the year ending June, 1871," and appears to have been similar to the present 8-inch gauge of the United States Weather Bureau. From this report the following is quoted:

> " Rain gauge to be placed, whenever practicable, with top of funnel-shaped collector 12 inches above ground. To be examined daily and in morning and measured carefully with graduated rod, graduated in inches and tenths—proportion cylinder to funnel, 10 : 1.
>
> " Snow will be melted and then measured and reported in same manner as rain."

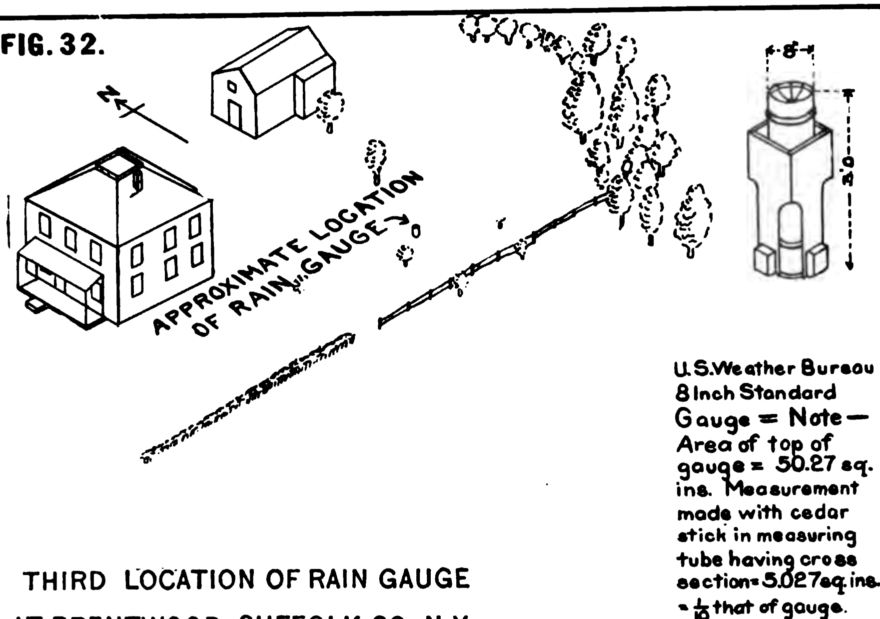
It is clear, however, that the top of the gauge was placed only 12 inches above the ground instead of 30 inches, as afterwards fixed by the Weather Bureau, but the methods of observation differed but little from those of the Weather Bureau.

FIG. 31. APP. VII.



LOCATION OF RAIN GAUGE AT
SETAUKET, SUFFOLK CO. N.Y.
MEASUREMENTS BEGUN JULY 1885.

FIG. 32.



THIRD LOCATION OF RAIN GAUGE
AT BRENTWOOD, SUFFOLK CO. N.Y.
MEASUREMENTS MADE 1895 - 1900.

W.L.W. DEL.

(*e*) *United States Weather Bureau Stations.*

In July, 1891, the weather service that had been carried on under the War Department since 1870, was transferred to the Department of Agriculture, under which the United States Weather Bureau organized. This change brought the meteorological work, the weather service and the crop service under one organization.

The local forecast office in the Equitable Building was retained, the Setauket Station continued, and the following additional stations were established.

1. Brentwood ....March, 1891, to June, 1900.
2. Cutchogue ....January, 1901, to date.
3. Southampton ....January, 1901, to date.

New York City Station—This station was continued at the Equitable Building until March, 1895, when it was moved to the Manhattan Life Building; thence, in October, 1898, to the present location in the American Surety Building. This is a local forecast office, where daily reports from the whole country are received and weather maps issued; the work is at present in charge of Mr. E. H. Emory, who kindly placed the records and publications at his office at the disposal of the Commission and gave much valuable information.

Two rain gauges are maintained on the roof of the American Surety Building, a tipping bucket gauge and a Marvin weighing gauge. An inspection of these gauges showed them to be somewhat too near other instruments, anemometer frames, thermometer shelters and skylights to give the best results and furthermore, the location of the instruments on such a high building, 314 feet above sea level, makes the rainfall observations somewhat unreliable and the snowfall measurements, in general, of doubtful value; the depths of snow, however, are always determined elsewhere by measuring the depth of snow on the ground in an open lot, and when the amount thus measured exceeds that caught in the rain gauge, it is recorded as the true precipitation.

(1) *Brentwood Station*—The rain gauge at this station had three different locations during the nine years covered by the observations. During that time, the observer, Dr. W. H. Ross, occupied, successively, two houses in Brentwood, which, with the second and third locations of the rain gauge, are shown in Fig. 32 and Fig. 33 respectively. Both locations were about one-half mile south of the Brentwood depot. The location of the rain gauge, in 1891 and 1892, was in an open field which has since been occupied by a dwelling house.

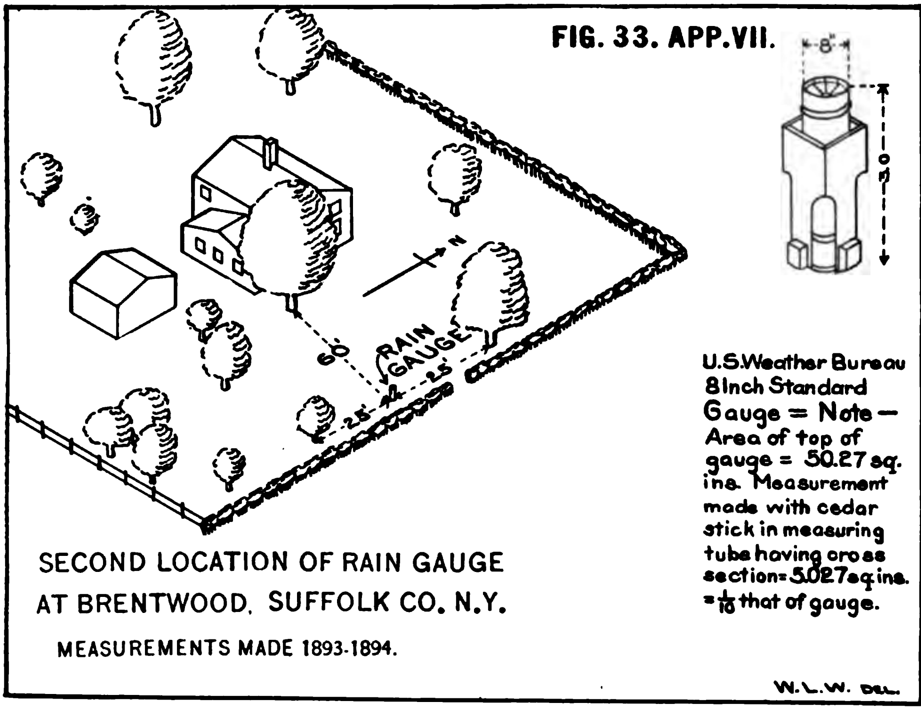


FIG. 33. APP. VII.

SECOND LOCATION OF RAIN GAUGE AT BRENTWOOD, SUFFOLK CO. N.Y.

MEASUREMENTS MADE 1893-1894.

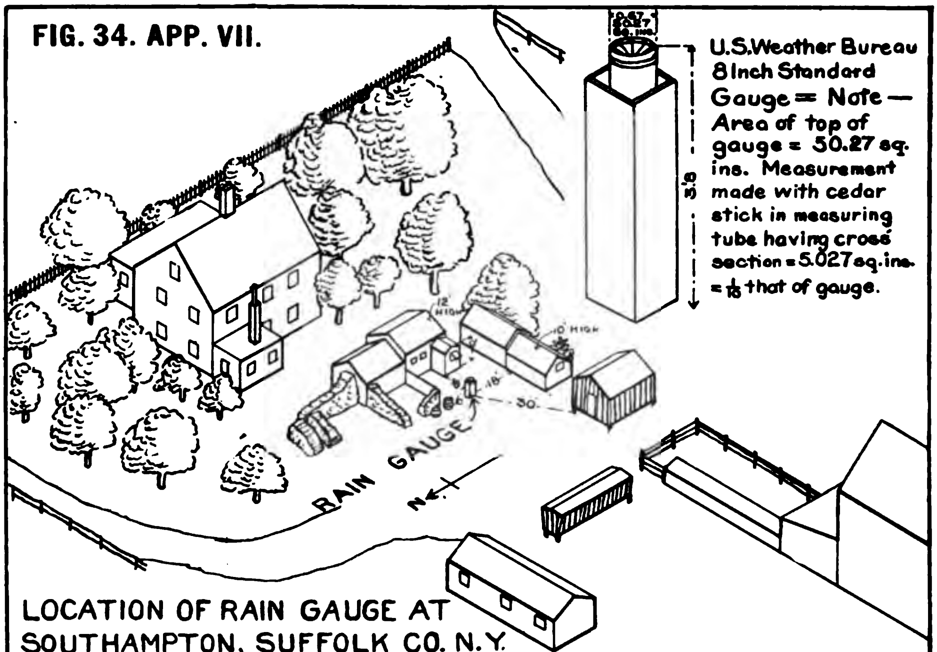
It is stated in the report of the State Weather Service for 1894, in which the second of the Brentwood locations is described, that "the rain gauge has a favorable exposure upon an open plot of ground."

These sketches, however, show that the second, as well as the third, location was not ideal and, from the fact that Dr. Ross' extensive practice as a physician caused him to lose many observations, the record at this station, which is complete for only three years, has not the value that it otherwise would have had from the general excellence of the observations.

(2) *Cutchogue Station*—The Cutchogue Rainfall Station is in the Village of Cutchogue, about a mile south of the Long Island Railroad depot, at the farm of W. A. Fleet. The location of the rain gauge is shown in Fig. 35, and, although the exposure of the gauge complies with the Weather Bureau specifications that no elevated object shall be nearer than its height, it will be noted that the gauge is closer to a hedge than the best practice approves and it is likely that in heavy storms, with the wind from the northeast, this obstruction might cause a sensible error in the measurement.

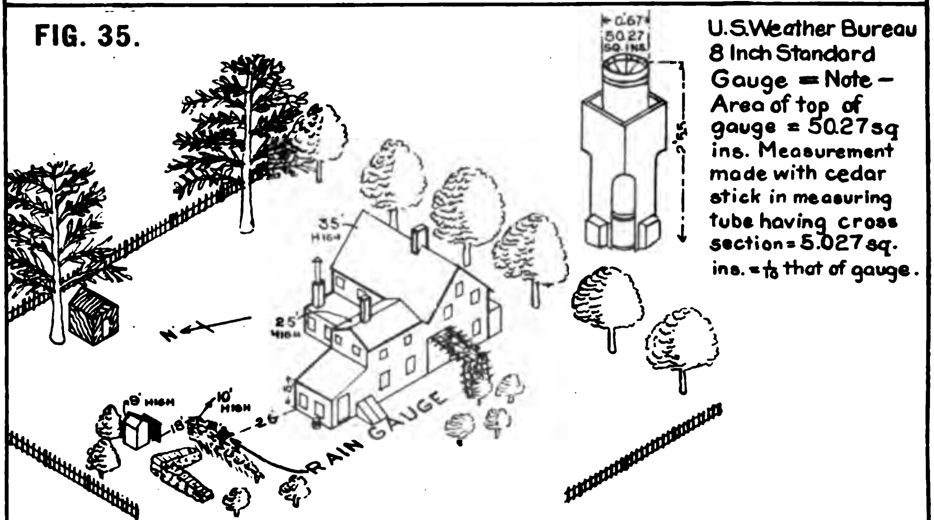
(3) *Southampton Station*—This station is near the Village of Southampton, one-half mile north of the Long Island Railroad depot, at the farm

FIG. 34. APP. VII.



LOCATION OF RAIN GAUGE AT
SOUTHAMPTON, SUFFOLK CO. N.Y.
MEASUREMENTS BEGUN 1901

FIG. 35.



LOCATION OF RAIN GAUGE AT
CUTCHOGUE, SUFFOLK CO. N.Y.
MEASUREMENTS BEGUN 1899.

W.L.W. DEL.

of W. L. Jagger. The instrument is one furnished by the State Weather Service, and, as indicated in Fig. 34, is over a foot higher than the standard United States Weather Bureau instrument which is shown with the sketch of the Cutchogue station. The exposure of the gauge is fair, but it is somewhat too near the buildings for the best results.

The United States Weather Bureau Rain Gauge.

The standard rain gauge that is furnished to the voluntary observers of the Weather Bureau is well described in the " Instructions for Voluntary Observers " issued by the Bureau, and is too well known to require a description here.

Stations Established by New York City in Manhattan Borough.

(C) Two rainfall stations are maintained by the City of New York in Central Park; one, the New York Meteorological Observatory, on the Arsenal Building, and the other at the Central Park Reservoir.

(1) *New York Meteorological Observatory*—This observatory is maintained by the Department of Parks, and is by far the best meteorological station in this vicinity. It was established in 1869, and has been under the direction of Dr. Daniel Draper since that date. The meteorological instruments at the Arsenal Building were especially designed by Dr. Draper, and many of them excel those in use by the United States Weather Bureau. The rain gauges as well as the other instruments are in duplicate and not a single rainfall observation has been lost at the station in thirty-five years.

The two self-recording rain gauges at the observatory were modeled from standard 8-inch Smithsonian gauges. The flat diaphragm within the gauge was removed and replaced by a cone, from which a tube leads to the registering apparatus under the roof immediately below. The top of the gauges are each 2 feet above the surface of the roof and are well exposed. By means of a gas jet in the room below, the space under the cone is heated during the winter months and the snow that falls into the gauges is immediately melted and recorded as rain. A criticism of this arrangement has been made, that the heating of the gauge causes loss through evaporation. Since, however, during most storms, the air is almost saturated, it is likely that the loss of snowfall through evaporation cannot be large.

(2) *Central Park Reservoir Station*—The New York Water Department has maintained a gauge at the Central Park Reservoir since January, 1891. Until recently, the gauge was attached to an iron fence at the top of the slope to the water in the reservoir near the keeper's house. In this position the top of the gauge was about 5 feet above the ground on one side

and still farther above the water on the other; in consequence of this exposure and the existence of a much better station at the Arsenal Building, the record at the reservoir has not been used.

A new rain gauge was located, this summer, on the lawn near the keeper's house, in a much better position than that on the reservoir fence, so that the record may now be considered to be fully as good as that at the Meteorological Observatory, aside from the greater accuracy of observation at the latter station, which, in common with other stations on high buildings, cannot furnish measurements as satisfactory as observations at the surface of the ground.

(D) Brooklyn Stations.

Four rainfall stations have been established on Long Island by the Brooklyn Water Department.

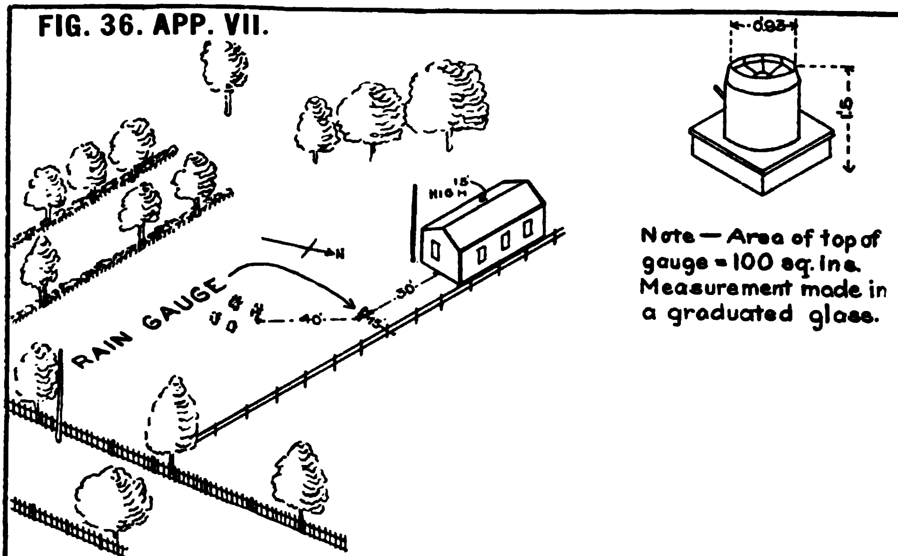
1. Hempstead Storage Reservoir..................Jan., 1879, to date.
2. Municipal Department Building................Nov., 1894, to date.
3. Ridgewood Pumping Station....................Jan., 1896, to date.
4. Ridgewood Reservoir ....Jan., 1897, to date.

(1) *Hempstead Storage Reservoir Station*—This station was located, from January, 1879, to January, 1898, between the keeper's house and the reservoir; in 1898 it was moved some distance east of its position to its present location in an open field near the present office building.

During a continued storm, rainfall observations are made three or four times daily, and, in addition to these, temperatures of the air are taken every day at 8 A. M., at noon, and at 4 P. M.

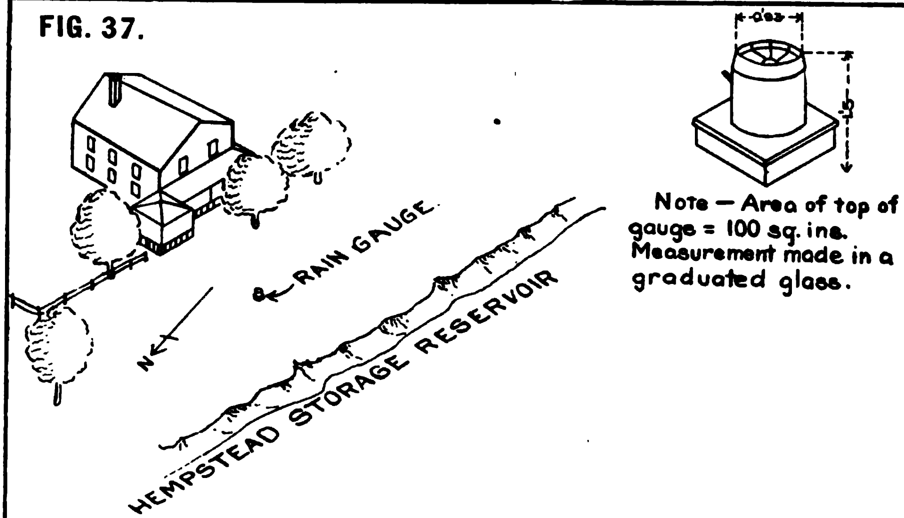
(2) *Municipal Department Building Station*—The rainfall measurements at this station were begun in November, 1894, when the present gauge was set up on the roof of the building occupied by the Brooklyn municipal departments. The gauge is similar to that of the United States Weather Bureau station in New York City; the exposure, however, of the Brooklyn gauge is much less good than that of the Weather Bureau and is one that could with little trouble be improved. The gauge is within about 15 feet of a corner of the main tower of the building, and, during a storm accompanied by heavy winds from the west ,the measurement of rainfall obtained may be far from the truth. Furthermore, the observations which have been made by the engineers of the Water Department have not been continuous; many entries have been supplied from the New York Weather Bureau station when it was presumed the gauge was out of order or the assistant in charge was busied elsewhere. A sketch of this station is seen in Fig. 28, p. 679.

FIG. 36. APP. VII.



LOCATION OF RAIN GAUGE AT
HEMPSTEAD STORAGE RESERVOIR,
ROCKVILLE CENTRE, NASSAU CO. N.Y.
MEASUREMENTS BEGUN 1898.

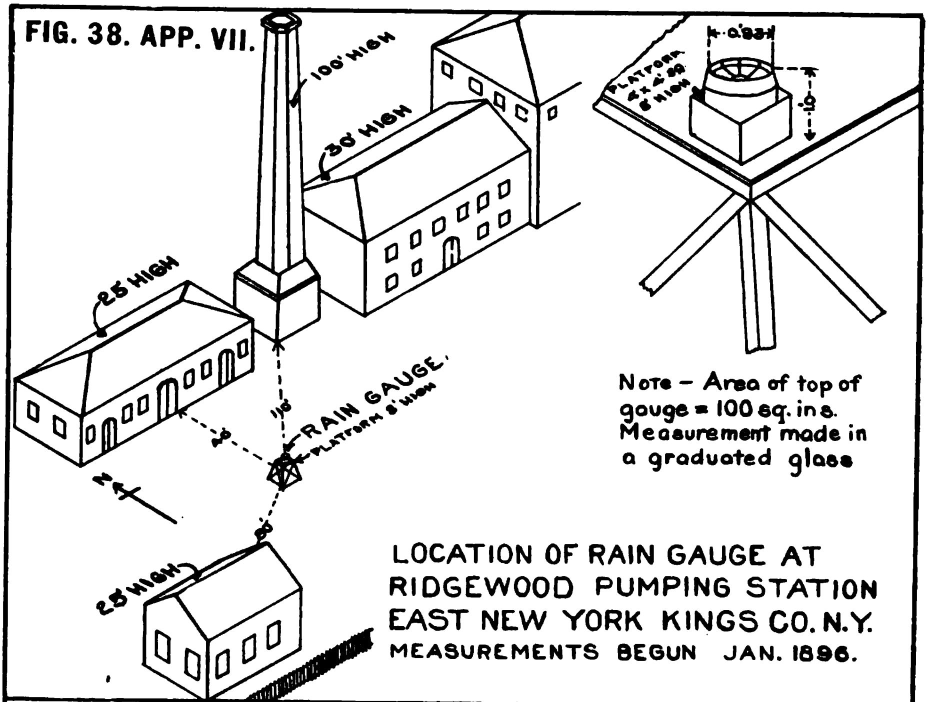
FIG. 37.



LOCATION OF RAIN GAUGE AT
HEMPSTEAD STORAGE RESERVOIR,
ROCKVILLE CENTRE, NASSAU CO. N.Y.
MEASUREMENTS MADE 1879–1898.

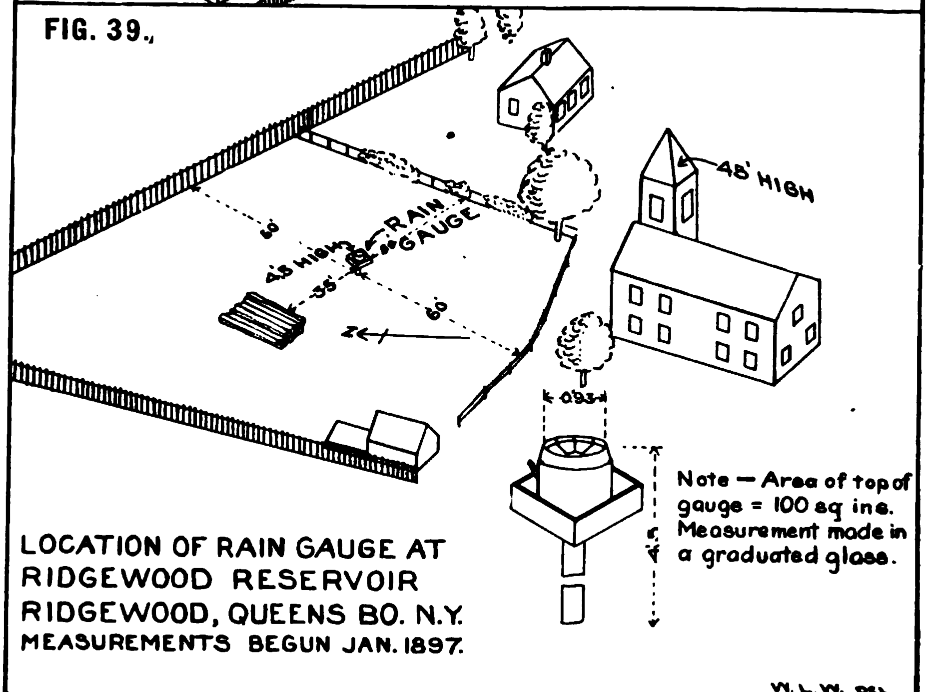
W.L.W. DEL.

FIG. 38. APP. VII.



LOCATION OF RAIN GAUGE AT RIDGEWOOD PUMPING STATION EAST NEW YORK KINGS CO. N.Y.
MEASUREMENTS BEGUN JAN. 1896.

FIG. 39.



LOCATION OF RAIN GAUGE AT RIDGEWOOD RESERVOIR RIDGEWOOD, QUEENS BO. N.Y.
MEASUREMENTS BEGUN JAN. 1897.

(3) *Ridgewood Engine-house Station*—The rain gauge at this station is on a platform 8 feet above the ground in front of the old pumping station (see Fig. 38). Its proximity to the building and its height above the ground make the results of the observations at this station of less value than the other Brooklyn stations and after the gauge at Ridgewood Reservoir was set up, one year after that at the engine-house, the record from the latter has not been considered.

(4) *Ridgewood Reservoir Station*—A good location of the rain gauge was made at this station; it is in an open field on the hill near the house occupied by the keeper of the Ridgewood Reservoir who makes the observations on the gauge (see Fig. 39). The station, however, is not ideal, for the gauge itself is 4½ feet above the ground, and, furthermore, the station is at a greater elevation above the sea than the other Long Island rainfall stations and somewhat above the average elevation of the Brooklyn watersheds.

Rain Gauges Used by Brooklyn Water Department.

Recording Gauges—The rain gauge at the Municipal Department Building is an 8-inch Marvin self-recording gauge which is the type adopted by the United States Weather Bureau. The top of the gauge is 2 feet above the roof, from which the electrical connections lead to the register in the office of the Water Department on the floor below. Like the Weather Bureau gauge of the same pattern, when the amount of rain in the gauge exceeds 3 inches in depth, the instrument will not continue to record unless the water is removed.

Standard Gauges—The gauges at the other stations, Ridgewood Engine-house, Ridgewood Reservoir and Hempstead Storage Reservoir, which are shown in the sketches of these stations, are similar to the 8-inch Smithsonian gauge. They are, however, considerably larger; the openings of the gauges are 0.94 foot in diameter, which gives an area of 100 square inches, or twice that of the 8-inch gauge. The rainfall is removed from the gauge through a small tube under the perforated protecting cone and is measured in the same way as with the Smithsonian gauge by pouring from the gauge into the glass graduate which is marked to read directly the depth of rainfall in inches over the area of the opening of the gauge.

(*E*) *Rainfall Stations of the Commission on Additional Water Supply.*

These stations have been described on pages 621 to 625. The observations were begun in April and continued until November 1, 1903. The results of the observations at these stations, together with those from other stations on Long Island and on the adjacent shores, are tabulated in Table No. 4.

Table No. 4.

Precipitation at Stations Established by the Commission, together with Records of Other Stations on Long Island and Adjacent Shores.

Date, 1903.	U. S. W. B. Surety Building.	Central Park.	Floral Park.	Hempstead.	Oyster Bay.	Farmingdale.	Brentwood.	Setauket.	Manor.	Cutchogue.	Southampton.	New Haven U. S. W. B.
April.												
14–16	1.29	1.45	0	2.07	0	0	2.17	1.48	0	1.35	1.12	0.74
24	0.02	0	0	0	0	0	0.01	T	0	T	0	T
Total	1.31	1.45	0	2.07	0	0	2.18	1.48	0	1.35	1.12	0.74
May.												
3	0	0	0	0	0	0	0	T	0	0	0	T
4	0.12	0.19	0.03	0.03	0.05	0.01	0.07	0.08	0.02	T	0.14	0.04
5	0	0	0	0	0	0	0.05	0.07	0	T	0.01	T
7	0.01	0.01	0	0	0.25	0	0.04	0.02	0.03	0.05	0.15	T
14	0	0	0	0	0	0.01	0.01	0	0	0	0	T
20	0.09	0.04	0.15	0.30	0.02	0.11	0	0	T	0	0	T
22	0.08	0.06	0.07	0.05	0.06	0.03	0.08	0.14	0.05	0.40	0.15	0.01
24	T	0	0.01	0.02	T	T	0.02	T	T	0.01	0.03	T
28	0.01	0	0.04	0	0.02	0.04	0.11	0.19	T	0	0	0.20
30	T	0	0	0	0	T	0.01	0	0.10	0.48	0.78	0.06
Total	0.31	0.30	0.30	0.40	0.40	0.20	0.39	0.59	0.20	0.94	1.26	0.39
June.												
7–8	0.44	0.55	1.76	1.41	2.07	2.06	2.11	1.77	2.65	1.23	0.96	0.95
9	0	0	0	0.02	0	0	0	T	0	0	T	0.01
10	0.06	0.04	0.03	0.02	0.01	T	0.01	T	T	0	T	0
11–12	1.90	2.26	2.13	2.24	2.05	2.06	1.73	1.15	1.30	1.69	1.83	1.50
13	0.10	0.08	0.09	0.16			0	0		T	0.08	0.01
14–15	0.51	1.24	0.64	0.73	1.87	1.14	0.83	1.03	0.44	0.36	T	0.83
15	0.28	0.35	0.55	0.68			0.09	1.18		0.53	1.04	0.01
17	0.01	0	0	0	0	0	0	0	0	0	0.05	0
17–18	0.20	0.24	0.13	0.18	T	0.20	0.11	0.07	0.09	0.12	0.06	0.11
19	0.15	0.26	0.29	0.28	0.25	0.14	0.11	0.08	0.02	0.04	0.01	0.05
20–21	0.27	0.79	0.72	0.50	0.70	0.66	0.60	0.67	0.45	0.91	0.21	1.57
22–24	0.98	1.12	1.15	1.18	1.32	0.97	0.74	0.54	0.30	0.29	0.23	0.04
25	T	0	0	0	0	T	0	T	T	0	T	0.10
29	2.49	2.57	2.32	2.14	1.90	1.66	0.92	1.35	0.45	0.91	0.20	0.89
30	T	0.28	0.19	0.04	0.03	0.01	0	T	0	0	0	T
Total	7.39	9.78	10.00	9.58	10.20	8.90	7.25	5.70	5.70	6.03	4.67	6.07

(Oyster Bay 1.87, Farmingdale 1.14 and Manor 0.44 are bracketed to cover June 13–15.)

July.												
2	0.29	0.53	1.10	0.77	0	0.10	0	0	0	0	0	0
3	0.05	0.08	0.08	0.04	0.05	0.09	0.02	T	0	0	0	T
5–6	0.05	0.07	0.11	0.11	0.09	0.03	0.08	0.05	0.10	0.08	0.16	0.15
10	T	0	0	0	0	0	0	0	0	0	0	T
11	0.35	0.20	0.27	0.20	0.10	0.31	0.06	0.03	T	0.03	0	T
12–13	0.17	0.18	0.20	0.37	0.22	0.31	0.21	0.19	0.27	0.22	0.28	0.16
14	T	0	0.01	0.02	0.47	0.01	0.04	0.48	0.47	0.28	0.28	0.12
18–19	1.13	0.97	1.00	1.19	0.73	1.15	1.13	0.58	0.70	0.71	0.44	1.01
20	0.06	0	0	0	0	0	0	0	0	0.20	T	0
20–21	0.01	0	0.02	0.09	T	0.89	0.01	0	0.22	0.02	0.10	0.04
22–23	0.60	1.16	0.24	0.11	0.59	0.51	0.03	0.10	0.07	0.08	0.10	0.21
25	0.04	0.22	0.03	0.02	0	0.02	0	0	0.14	0	0	0.14
30	0.47	0.51	0.40	0.23	1.02	0.17	0.33	0.83	0.40	0.06	0	0.02
31	0	0	0	0.01	0	0	0	0	0	0.21	0.30	0
Total	3.32	3.92	3.46	3.16	3.27	3.59	1.91	2.25	2.37	1.89	1.66	1.85
August.												
4–5	2.65	2.67	3.01	3.92	2.00	3.95	3.30	1.91	2.00	1.81	1.38	2.32
6–7	0.14	0.14	0.56	0.50	0.37	0.39	0.67	0.12	1.80	0.67	0.65	1.94
9	0.23	0.19	0.10	0.05	0.32	0.02	0.02	0.27	0.17	0.29	0.27	0.01
10	0	0	0	0	0	0	0.01	0	0	0	0.03	0
11	0.01	0	0.01	0.31	0	0.25	0.19	0.18	0.44	0.37	0.53	0.02
12	0	0	0	0	0	0	0.01	0	0	0	0	0
14	0.11	0	0.04	0.14	0	0.02	0	0	0	0	0	0
16–17	0.01	0	0	0	0	0	1.05	0	0.10	0.02	0	0
19	0.01	0.33	0.01	0	0	0	0	0	0	0	0	0
20	0.16	0.23	0.05	0.09	0.25	0.02	0.06	0.12	0.43	0.20	0.57	0.20
22	0	0.09	0.02	0.03	0	0	0.03	0.05	0	0	0	0
23	0.09	0.01	0	0.02	0.20	0	0.02	0.04	0.11	0.03	0.04	0
24	0.09	0.01	0.02	0.05	0	0.04	0.04	0	0	0	0	0
25	0.19	0.23	0.29	0.40	0.28	0.39	0.30	0.37	0.25	0.96	0.25	0.58
26	0.01	0	0	0	0	0	0	0.08	0.55	0	0.40	0.04
27–31	2.26	2.83	1.95	2.15	3.00	2.62	2.72	3.14	2.00	3.40	3.23	1.85
Total	5.96	6.73	6.07	7.67	6.45	7.70	8.59	6.28	8.03	7.77	7.37	6.96
September.												
1	0	0	0	0	0.03	0	0	0	0	0	0.01	0
3	0	0	0.01	0	0	0	0	0	0	0	0	0
5	0.15	0.49	0.35	0.04	0.09	0.04	0.10	0.55	0.11	0.09	0.37	0.48
11	0.07	0.08	0.02	0	0	0	0	0	0	0	0	0.19
15	0	0	0	0	0.06	0.42	0	0	0	0	0	0
16	1.30	1.63	0.67	0.66	0.61	0	0.16	0.37	0.08	0	0.04	0.22
17–18	0.71	0.79	0.51	0.49	0.76	0.64	0.48	0.52	0.16	0.14	0.07	0.42
24	0	0	0	0	0	0	0	0	0	0.02	0	0
27–28	0.37	0.68	0.63	0.86	1.00	0.58	0.61	1.17	0.47	1.00	0.75	0.89
Total	2.60	3.67	2.19	2.05	2.55	1.68	1.35	2.61	0.82	1.25	1.24	2.20

TABLE NO. 4—(*Continued*).

Precipitation at Stations Established by the Commission, together with Records of Other Stations on Long Island and Adjacent Shores.

Date, 1903.	U. S. W. B. Surety Building.	Central Park.	Floral Park.	Hempstead.	Oyster Bay.	Farming-dale.	Brentwood.	Setauket.	Manor.	Cutchogue.	Southamp-ton.	New Haven U. S. W. B.
October.												
2	0.03	0.47	0.29	0.28	0	0.24	0.03	0.16	0	0	0	0.08
3	0.34	0	0	0.04	0	0	0	0.02	0	0	0	0
5	T	0	0	0	0.04	0	0.02	0.02	0	0	0	0.04
6	0.01	0	0.02	0	0	0.04	0.01	0	0	0.04	0.13	0
7	0.01	0.01	0	0	0	0	0.01	0	0	0.04	0	0.05
8–11	10.37	11.93	5.82	4.55	2.60	2.65	1.91	1.94	1.65	1.07	1.16	1.25
12	0.01	0.02	0.05	0.05	0.15	0.10	0.14	0.48	0.75	0.53	1.13	0.13
13	0	0	0	0	0	0	0	0	0	0.13	0	0
17–18	0.71	0.72	1.20	1.73	1.53	1.39	1.56	0.95	1.90	1.60	2.10	0.31
23	0.07	0.16	0.18	0	0.23	0	0	0.07	0	0.01	0	0.08
26	T	0	0	0	0	0	0.01	0	0	0	0	0
28	0	0	0	0	0	0	0	0.01	0	0	0.01	0
Total	11.55	13.31	7.56	6.65	4.55	4.43	3.74	3.66	4.25	3.42	4.53	2.94

(*F*) *Other Rainfall Stations.*

Beside the rainfall records from these stations on Long Island and the vicinity of New York City, a number of records from other stations on the adjacent shores of New Jersey, Connecticut and Rhode Island have been obtained in order to be better able to reconcile apparent discrepancies in the Long Island and New York City records.

(*G*) *Computation of Average Rainfall on Long Island.*

(1) *Weight of Observation*—The information that the investigations of these rainfall stations afforded has been summarized in Table No. 5. From this material the weights of observation to apply to the records of each station have been determined and these, with the percentages of the area of the island that the stations represent, are tabulated in Table No. 6. In these percentages only the area of the island that has been investigated by the Commission was considered, that is, Queens Borough, Nassau County and Suffolk County as far as Riverhead. From the weights of observation and the percentages of area, the weights to be given the records, in order to compute the mean rainfall on Long Island, were found and are shown in the last column of Table No. 6.

(2) *Distribution of Rainfall Stations*--Large areas of the island were not, at times, well represented by the existing rainfall stations; this is particularly true of the easterly portion of the island between 1844 and 1853 and between 1863 and 1873 and of the whole area during the years immediately after the civil war, when only a few stations existed in the immediate vicinity of New York City.

TABLE No. 5.

Long Island Rainfall Stations from 1826 *to* 1903.

Location of Rainfall Station.	Observations Made by	Date of Record. From Inclusive.	Date of Record. To Inclusive.	Approx. Elevation of Station Above Sea Level.	Character of Observation: 1 Excellent. 2 Good. 3 Fair. 4 Poor.	Description of Rain Gauge. Inside Diam. of Gauge.	Description of Rain Gauge. Height of Rim of Gauge Above Surface of Ground.	Exposure of Rain Gauge: 1 Excellent. 2 Good. 3 Fair. 4 Poor.
						Feet.	Feet.	
Flatbush, Erasmus Hall, Brooklyn......	New York Regents.........	Jan., 1826	1850	40	Good	0.42	4	Fair.
		1850	Dec., 1865	40	"	0.94	0	"
		" 1868	" 1869	40	"	0.94	0	"
		" 1872	" 1872	40	"	0.67	0	"
Jamaica, Union Hall..................	New York Regents	" 1826	" 1864	30	"	0.83	5	Good.
Easthampton, Clinton Academy....	" "	" 1828	" 1843	16	....	0.42	...	"
		" 1852	Aug., 1852	16	....	....	...	"
Oyster Bay, Oyster Bay Academy......	" "	" 1834	Dec., 1834	50	....	0.42	...	....
		" 1837	" 1837	50	....	....	...	....
Fort Hamilton.........................	Post Surgeon United States Army ...	" 1839	June, 1885	25	Fair.........	0.42 / 0.16	8 / 8	Fair. / "
		Sept., 1888	Feb., 1892	25	"	0.16	8	"
Sag Harbor..............	E. W. Byran, Smithsonian Institution	Jan., 1854	Dec., 1858	40	....	0.94 or c.67	0 / 1	....
Bellport.............................	H. W. Titus, Smithsonian Institution............................	Aug., 1857	June, 1862	15	....	0.94 or 0.67	0 / 1	....
Brooklyn..................	Bea & Son, J. P. Miller, Smithsonian Institution......................	Jan. 1, 1870	Jan. 31, 1870	..	....	0.67	1	....
		June, "	Dec., 1873	..	....	....	...	....
Willett's Point	Post Surgeon United States Army....	" "	" "	60	Good	0.67	On roof.	Poor.
		Dec., 1888	" 1893	60	"	0.67	"	"
Brookhaven (Moriches).........	E. A. Smith and daughter, Smithsonian Institution.........................	Jan., 1874	May, 1882	39	....	0 67	...	....
Hempstead, Parsonage Creek Reservoir.	Voluntary Observer, Smithsonian Institution............................	" "	" 1874	39	....	0 67	...	....
Hempstead Storage Reservoir..........	Brooklyn Department of Water........	" 1879	Date.	35	Excellent....	0 94	1.5	Good.
Flushing	Smithsonian Institution................	May, 1875	Feb., 1884	..	....	0.67	...	...
Setauket, residence of Selah B. Strong..	United States Weather Bureau, voluntary observer	July, 1885	Date.	40	Good........	0.665	3.2	Fair.

Brentwood, residence of Dr. Ross	United States Weather Bureau, voluntary observer	Mar., 1891	June, 1900	80	Fair	0.665	3	Fair.
Brentwood, residence of Dr. Ross.......	Commission on Additional Water Supply	Apr., 1903	Oct., 1903	80	Excellent....	1.00	3.4	Excellent.
Brooklyn Municipal Department Building	Brooklyn Department of Water........	Nov., 1894	Date.	133	Good	0.67	2.0	Poor.
Ridgewood Pumping Station, East New York..........	" "	Jan., 1896	"	60	"	0.94	8.0	"
Ridgewood Reservoir	" "	" 1897	"	170	"	0.94	4.5	Excellent.
Cutchogue, residence of Wm. A. Fleet...	United States Weather Bureau, voluntary observer	" 1899	"	..	"	0.67	2.6	Good.
Southampton, residence of W. L. Jagger.	United States Weather Bureau, voluntary observer	" 1901	"	..	"	0.67	3.8	"
Floral Park, at J. L. Childs'............	Commission on Additional Water Supply	Apr., 1903	Oct., 1903	90	Excellent ...	1.00	3.4	Excellent.
Oyster Bay, residence of A. G. Russell..	" " "	" "	" "	60	Good	0.67	3.5	Good.
Farmingdale, residence of Bausch.	" " "	" "	" "	70	"	0.67	3.5	"
Manor, residence of J. N. Raynor.......	" " "	" "	" "	45	"	0.67	3 5	Excellent.

Rainfall Stations near Long Island.

New Haven, Conn......................	Yale College.........................	Jan., 1804 June, 1864	July, 1829 Apr., 1868	..	....	....	...	....
....	United States Weather Bureau.........	Jan., 1873	Date.	..	....	....	...	....
Fort Columbus...........................	Post Surgeon United States Army.....	" 1836	Dec., 1891	23	Good	0.42 0.16	4 8	Good.
Newark, N. J...........................	U. S. Weather Bureau..	May, 1843	Date.	..	....	....	...	....
New York Deaf and Dumb Asylum.....	Prof. Oran W. Morris, Smithsonian Institution...........................	Jan., 1846	Dec., 1870	..	Good	0.67	...	....
Blackwell's Island, East River..........	....	" 1856	" 1857	..	....	....	...	....
Columbia College.......................	Prof. Charles Joy......................	" 1865	Apr., 1870	100	....	....	...	....
Central Park, New York Meteorological Observatory........................	Dr. Daniel Draper, Department of Parks.	" 1869	Date.	97	Excellent....	0.67	2.0	Good.
New York Office United States Signal Service and United States Weather Bureau................................	United States Weather Bureau.........	" 1871	"	314*	Good	0.67	2.0	Poor.
Cooper Union...........................	Prof. Oran W. Morris.................	" "	Apr., 1877	46	"	0.67	1.0	"
New London, Conn.............	United States Weather Bureau.........	" "	Jan., 1896	..	....	....	...	....
Fort Wadsworth, N. J.	Post Surgeon United States Army....	June, 1873 Nov., 1888	July, 1875 Dec., 1891	85 85	....	....	...	....
Sandy Hook, N. J.......................	....	Jan., 1874	Dec., 1886	..	....	....	...	....
Block Island, R. I.......................	United States Weather Bureau........	" 1881	Date.	..	....	....	...	....
Central Park Reservoir, New York.....	Department of Water Supply..........	" 1891	"	..	Good	....	...	Fair.
Norwalk, Conn..........	United States Weather Bureau, voluntary observer........................	Feb., 1892	"	..	....	....	...	....
Bridgeport, Conn.......................	United States Weather Bureau, voluntary observer.......................	Jan., 1899	Dec., 1902	.	....	....	...	....

* Present Station.

Table No. 6.

RAINFALL ON LONG ISLAND.

Computation of Weights to be Applied to Rainfall Records to Determine Average Precipitation on Long Island.

Date of Records.	Location of Rainfall Station.	Relative Weights of Rainfall Records.				
		By Weight of Observations.	By Proportion of Territory.	Product.	Per Cent. of Whole.	Weight of Observation Used.
Jan., 1826, to Dec., 1827.	Flatbush, Erasmus Hall	1	5	5	5	1
	Jamaica, Union Hall	1	95	95	95	7
Jan., 1828, to Dec., 1837.	Flatbush, Erasmus Hall	1	2	2	2	1
	Jamaica, Union Hall	1	71	71	71	5
	Easthampton, Clinton Academy	1	27	27	27	2
Jan., 1828, to Dec., 1837.	Flatbush, Erasmus Hall	1	2	[illegible]	2	1
	Jamaica, Union Hall	1	19	19	19	2
	Oyster Bay, Oyster Bay Academy	1	63	63	63	3
	Easthampton, Clinton Academy	1	16	16	16	2
Jan., 1838, to Dec., 1838.	Flatbush, Erasmus Hall	1	1	1	1	31
	Fort Columbus, Governor's Island	1	1	1	1	31
	Jamaica, Union Hall	1	71	71	71	5
	Easthampton, Clinton Academy	1	27	27	27	2
Jan., 1839, to Dec., 1843.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Hamilton and Fort Columbus, Governor's Island	1	1	1	1	1
	Jamaica, Union Hall	1	71	71	71	5
	Easthampton, Clinton Academy	1	27	27	27	2
Jan., 1844, to Dec., 1845.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Hamilton and Fort Columbus, Governor's Island	1	1	1	1	1
	Jamaica, Union Hall	1	98	98	98	7
Jan., 1846, to Dec., 1853.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Hamilton and Fort Columbus	1	1	1	1	1
	New York Deaf and Dumb Asylum	1	1	1	1	..
	Jamaica, Union Hall	1	97	97	97	7
Jan., 1846, to Dec., 1853.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Hamilton and Fort Columbus	1	1	1	1	1
	New York Deaf and Dumb Asylum	1	1	1	1	..
	Jamaica, Union Hall	1	70	70	70	5
	Easthampton, Clinton Academy	1	27	27	27	2
Jan., 1854, [redacted] to July, 1857.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Hamilton and Fort Columbus	1	1	1	1	1
	Mean of New York Deaf and Dumb Asylum and Blackwell's Island	1	1	1	1	..
	Jamaica, Union Hall	1	64	64	64	5
	Sag Harbor	1	33	33	33	2
Aug., 1857, to Dec., 1858.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Columbus and Fort Hamilton	1	1	1	1	1
	Mean of New York Deaf and Dumb Asylum and Blackwell's Island	1	1	1	1	..
	Jamaica, Union Hall	1	40	40	40	4
	Bellport	1	55	55	55	4
	Sag Harbor	1	2	2	2	1

TABLE No. 6—*Continued.*

Date of Records.	Location of Rainfall Station.	Relative Weights of Rainfall Records. By Weight of Observation.	By Proportion of Territory.	Product.	Per Cent. of Whole.	Weight of Observation Used.
Jan., 1859, to June, 1862.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Columbus and Fort Hamilton	1	1	1	1	1
	Jamaica, Union Hall	1	41	41	41	4
	Bellport	1	56	56	56	4
	New York Deaf and Dumb Asylum	1	1	1	1	..
July, 1862, to Dec., 1864.	Flatbush, Erasmus Hall	1	1	1	1	1
	Mean of Fort Columbus and Fort Hamilton	1	1	1	1	1
	New York Deaf and Dumb Asylum	1	1	1	1	..
	Jamaica, Union Hall	1	97	97	97	7
Jan., 1865, to Dec., 1865, and Jan., 1868, to Dec., 1869.	Flatbush, Erasmus Hall	1	..	..	..	1
	Mean of Fort Columbus and Fort Hamilton.	1	..	..	..	1
	Mean of New York Deaf and Dumb Asylum and New York Meteorological Observatory	1	..	..	..	1
Jan., 1866, to Dec., 1867, and Feb., 1870, to May, 1870.	Mean of Fort Columbus and Fort Hamilton.	1	..	..	..	1
	Mean of New York Deaf and Dumb Asylum and New York Meteorological Observatory.	1	..	..	..	1
Jan., 1870, and June, 1870, to Dec., 1871.	Mean of United States Signal Service, Fort Columbus and Fort Hamilton	1	½	½	1	1
	New York Meteorological Observatory	1	½	½	1	1
	Brooklyn, Bea & Son	¾	3	2¼	4	1
	Willett's Point	½	96	48	94	3
Jan., 1872, to Dec., 1872.	Flatbush, Erasmus Hall	1	3	3	6	1
	New York Meteorological Observatory	1	1	½	1	1
	Mean of Fort Columbus and Fort Hamilton and United States Signal Service	1	1	½	1	1
	Willett's Point	½	95	47½	92	3
Jan., 1873, to Dec., 1873.	New York Meteorological Observatory	1	½	½	1	1
	Mean of United States Signal Service, Fort Wadsworth, Fort Columbus, Fort Hamilton	1	½	½	1	1
	Willett's Point	½	96	48	98	3
Jan., 1874, to May, 1874.	New York Meteorological Observatory	1	2	2	2	1
	Mean of United States Signal Service, Fort Hamilton, Fort Columbus, Fort Wadsworth	1	2	2	2	1
	Hempstead, Parsonage Creek Reservoir	1	32	32	40	4
	Brookhaven, Moriches	¾	52	39	48	4
	Willett's Point	½	12	6	8	1
June, 1874, to April, 1875.	New York Meteorological Observatory	1	½	½	1	1
	Mean of United States Signal Service, Fort Wadsworth, Fort Hamilton and Fort Columbus	1	½	½	1	1
	Brookhaven, Moriches	¾	48	36	63	5
	Willett's Point	½	41	20	35	3
May, 1875, to Dec., 1878.	New York Meteorological Observatory	1	½	½	1	1
	Mean of United States Signal Service, Fort Columbus and Fort Hamilton	1	½	½	1	1
	Brookhaven, Moriches	¾	54	41	68	6
	Flushing	¾	2	1	2	1
	Willett's Point	½	33	16½	28	3

TABLE No. 6—*Continued.*

Date of Records.	Location of Rainfall Stations.	Relative Weights of Rainfall Records. By Weight of Observation.	By Proportion of Territory.	Product.	Per Cent. of Whole.	Weight of Observation Used.
Jan., 1879, to May, 1882.	New York Meteorological Observatory....	1	½	½	½	1
	Mean of United States Signal Service, Fort Hamilton and Fort Columbus.......... ..	1	½	½	½	1
	Hempstead Storage Reservoir..........	1	37	37	44	5
	Brookhaven, Moriches.........	¾	52	39	47	4
	Flushing..................................	¾	6	4	5	1
	Willett's Point............................	½	4	2	3	1
June, 1882, to Feb., 1884.	New York Meteorological Observatory.....	1	½	½	½	1
	Mean of United States Signal Service, Fort Columbus and Fort Hamilton............	1	½	½	½	1
	Hempstead Storage Reservoir...............	1	89	89	91	9
	Flushing............	¾	10	7½	8	1
Mar., 1884, to June, 1885.	New York Meteorological Observatory......	1	3	3	3	1
	Mean of United States Signal Service, Fort Hamilton and Fort Columbus............	1	2	2	2	1
	Hempstead Storage Reservoir.............	1	95	95	95	10
July, 1885, to Nov., 1888.	New York Meteorological Observatory.....	1	3	3	4	1
	Mean of United States Signal Service and Fort Columbus..........................	1	2	2	2	1
	Hempstead Storage Reservoir.............	1	39	39	45	5
	Setauket...............	¾	56	42	49	5
Dec., 1888, to Feb., 1891, and Mar., 1891, to Nov., 1894, when Brentwood records are missing.	New York Meteorological Observatory......	1	2	2	2	1
	Mean of United States Signal Service, Fort Columbus, Fort Wadsworth and Fort Hamilton.....................	1	1	1	1	1
	Willett's Point............	½	12	6	8	1
	Hempstead Storage Reservoir..............	1	29	29	36	4
	Setauket..........................	¾	56	42	53	5
Mar., 1891, to Jan., 1896	New York Meteorological Observatory......	1	2	2	2	1
	Mean of United States Weather Bureau, Fort Columbus, Fort Wadsworth, Fort Hamilton and Brooklyn Municipal Building.....	½	1	½	1	1
	Willett's Point...........	½	12	6	8	1
	Hempstead Storage Reservoir.......	1	20	20	26	3
	Setauket...........................	¾	36	27	35	4
	Brentwood................................	¾	29	22	28	3
Jan., 1896, to Jan., 1899.	New York Meteorological Observatory......	1	1	1	1	1
	Mean of United States Weather Bureau and Brooklyn Municipal Building....	½	..	..	..	..
	Ridgewood Reservoir..............	1	4	4	5	1
	Willett's Point...........	½	10	5	6	1
	Hempstead Storage Reservoir	1	19	19	24	4
	Setauket..................................	¾	37	28	36	6
	Brentwood.........................	¾	29	22	28	4
Jan., 1896, to Jan., 1899.	New York Meteorological Observatory.....	1	1	1	1	1
	Mean of United States Weather Bureau and Brooklyn Municipal Building............	½	..	..	..	..
	Ridgewood Reservoir........	1	4	4	5	1
	Willett's Point..........................	½	10	5	6	1
	Hempstead Storage Reservoir.............	1	29	29	36	6
	Setauket..................................	¾	56	42	52	8

TABLE No. 6—*Continued.*

Date of Records.	Location of Rainfall Stations.	Relative Weights of Rainfall Records. By Weight of Observation.	By Proportion of Territory.	Product.	Per Cent. of Whole.	Weight of Observation Used.
Jan., 1893, to Jan., 1901.	New York Meteorological Observatory	1	1	1	1	1
	Mean of United States Weather Bureau and Brooklyn Municipal Building	½	..	..	..	..
	Ridgewood Reservoir	1	4	4	5	1*
	Willett's Point	½	10	5	6	1
	Hempstead Storage Reservoir	1	19	19	24	4
	Setauket	¾	26	20	25	4
	Brentwood	¾	29	22	28	4
	Cutchogue	¾	11	9	11	1
Jan., 1899, to Jan., 1901.	New York Meteorological Observatory	1	1	1	1	1
	Mean of United States Weather Bureau and Brooklyn Municipal Building	½	..	..	..	..
	Ridgewood Reservoir	1	4	4	5	1*
	Willett's Point	½	10	5	6	1
	Hempstead Storage Reservoir	1	29	29	35	6
	Setauket	¾	45	34	41	7
	Cutchogue	¾	11	9	12	1
Jan., 1901, to May, 1903.	New York Meteorological Observatory	1	1	1	1	1
	Mean of United States Weather Bureau and Brooklyn Municipal Building	½	..	..	..	..
	Ridgewood Reservoir	1	5	5	6	1
	Hempstead Storage Reservoir	1	37	37	43	7
	Setauket	¾	45	34	40	6
	Mean of Cutchogue and Southampton	¾	12	9	10	1
May, 1903, to Nov., 1903.	New York Meteorological Observatory	1	1	1	1	
	Mean of United States Weather Bureau and Brooklyn Municipal Building	½	..	..	..	..
	Ridgewood Reservoir	1	4	4	4	1
	Floral Park	1	10	10	10	3
	Hempstead Storage Reservoir	1	8	8	8	2
	Farmingdale	1	11	11	11	2
	Oyster Bay	1	12	12	12	2
	Brentwood	1	18	18	19	3
	Setauket	¾	11	9	9	2
	Manor	1	23	23	24	3
	Mean of Cutchogue and Southampton	¾	2	1½	2	1

*Make 2 in 1900 when Willett's Point record is absent.

Mean Monthly Precipitation (Rain and Melted Snow) on the Territory Additional Water Supply (Queens Borough, Nassau County and Suffolk County as far as Riverhead).

TABLE NO. 7.

DISTRIBUTION OF RAINFALL ON LONG ISLAND.

Comparison of Rainfall at New York Meteorological Observatory with that at Stations on Long Island and on the Adjacent Shores.

Year.	New York Meteorological Observatory Central Park.	Hempstead Storage Reservoir.	Setauket.	New Haven.	New London.	Block Island.
1879	39.01	39.61	.....	55.50	51.05	.....
1880	39.66	40.76	.....	46.52	43.23	.....
1881	39.26	39.53	.....	51.32	51.64	59.44
1882	45.27	39.83	.....	47.92	50.46	57.65
1883	35.77	37.22	.....	39.46	54.37	39.69
1884	52.25	45.39	.....	49.33	61.33	63.15
1885	35.37	36.85	.....	38.32	49.07	39.37
1886	39.38	51.38	48.51	42.32	58.86	54.52
1887	43.99	45.66	48.88	44.08	48.01	44.55
1888	53.32	48.45	51.46	55.96	45.61	27.18
1889	57.16	56.54	53.87	59.78	49.70	32.80
1890	45.63	52.15	53.94	48.95	48.85	31.51
1891	39.55	39.18	47.25	44.69	48.73	39.03
1892	35.60	37.75	39.41	37.78	34.75	43.06
1893	48.26	39.62	48.65	46.71	41.72	44.84
1894	41.01	36.88	46.03	37.74	39.20	37.46
1895	35.37	35.64	39.21	35.96	40.86	49.21
1896	41.96	38.82	37.36	38.39	.....	44.59
1897	44.55	46.41	58.00	57.89	.....	52.19
1898	47.90	51.22	58.00	53.72	.....	62.10
1899	38.57	43.60	39.63	35.28	.....	41.31
1900	41.19	41.43	47.34	34.83	.....	37.57
1901	48.69	49.92	51.98	52.61	.....	47.26
1902	52.77	51.98	48.90	44.33	.....	45.63
Averages 1879–1902	43.40	43.58	48.15	45.81	48.08	45.19
Averages 1886-1902	44.41	45.10	48.15	45.36	....	43.22

Table No. 8.

RAINFALL ON LONG ISLAND.

Mean Monthly Precipitation (Rain and Melted Snow) on the Territory Covered by the Ground Water Investigations of the Commission on Additional Water Supply (Queens Borough, Nassau County and Suffolk County as far as Riverhead).

Month.	1826.			1827.		
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Value Adopted.	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Value Adopted.
January	0.47	1.13	1.05	2.45	3.04	2.97
February	1.46	2.32	2.21	4.50	4.54	4.53
March	3.66	4.00	3.96	2.05	1.55	1.61
April	2.03	2.73	2.64	5.65	6.83	6.68
May	0.06	0.19	0.17	3.45	4.02	3.95
June	8.40	12.53	12.01	3.68	2.16	2.35
July	3.77	3.72	3.73	3.58	4.82	4.67
August	7.95	14.22	13.44	5.47	5.65	5.63
September	3.09	2.55	2.62	3.78	4.45	4.37
October	8.54	8.28	8.31	4.10	4.70	4.62
November	2.95	1.89	2.02	6.05	6.15	6.14
December	2.51	2.10	2.15	3.51	3.23	3.27
Total	44.89	55.66	54.31	48.27	51.14	50.79

Month.	1828.				1829.			
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, East-hampton.	Value Adopted.	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, East-hampton.	Value Adopted.
January	3.02	2.75	2.44	2.71	4.48	5.10	6.33	5.33
February	3.25	3.20	2.09	2.93	5.64	3.67	4.26	4.16
March	4.50	5.95	1.99	4.78	4.17	4.00	4.28	4.09
April	4.33	5.45	2.99	4.69	5.36	5.05	2.02	4.33
May	4.80	5.00	2.50	4.35	3.90	3.55	4.98	3.95
June	2.55	3.17	3.67	3.22	3.38	1.45	1.87	1.80
July	3.73	4.00	4.10	3.99	2.35	2.70	1.88	2.45
August	1.97	1.80	0.95	1.61	4.84	4.30	2.39	3.89
September	6.85	8.29	4.87	7.26	3.16	3.20	2.79	2.74
October	0.96	1.65	1.79	1.60	4.41	4.36	4.32	4.36
November	8.73	7.20	3.18	6.39	4.96	4.75	5.84	5.02
December	0.45	0.45	0.34	0.42	1.89	3.70	1.60	2.95
Total	45.14	48.91	30.91	43.95	48.54	45.83	41.56	45.07

TABLE No. 8—*Continued.*

Month.	1830. Erasmus Hall, Flatbush, Brooklyn.	1830. Union Hall, Jamaica.	1830. Clinton Academy, East-hampton.	1830. Value Adopted.	1831. Erasmus Hall, Flatbush, Brooklyn.	1831. Union Hall, Jamaica.	1831. Clinton, Academy, East-Hampton.	1831. Value Adopted.
January	2.87	1.71	3.87	2.39	4.72	3.30	1.67	3.07
February	2.07	1.58	1.60	1.65	3.46	2.00	1.77	2.13
March	8.08	5.15	3.94	5.21	4.24	3.28	1.25	2.89
April	3.30	1.54	2.69	2.05	5.98	5.75	6.81	6.04
May	3.77	3.25	4.73	3.68	2.36	3.30	4.64	3.52
June	4.68	4.60	3.16	4.25	1.48	1.60	3.00	1.93
July	5.49	5.87	4.80	5.55	6.17	4.12	3.14	4.13
August	2.49	1.22	3.62	1.98	2.55	1.25	1.67	1.52
September	1.33	1.75	1.93	1.74	3.14	6.20	5.40	5.62
October	4.78	4.70	3.02	4.29	4.47	4.70	4.85	4.71
November	6.69	5.45	5.82	5.70	2.02	1.35	3.02	1.85
December	7.92	6.50	7.47	6.92	1.93	1.90	1.27	1.75
Total	53.47	43.32	46.65	45.41	42.52	38.75	38.49	39.16

Month.	1832. Erasmus Hall, Flatbush, Brooklyn.	1832. Union Hall, Jamaica.	1832. Clinton Academy, East-hampton.	1832. Value Adopted.	1833. Erasmus Hall, Flatbush, Brooklyn.	1833. Union Hall, Jamaica.	1833. Clinton Academy, East-hampton.	1833. Value Adopted.
January	5.55	4.65	3.15	4.39	3.18	1.30	2.71	1.89
February	2.76	3.25	3.47	3.24	1.00	2.00	1.63	1.78
March	0.83	2.10	2.63	2.07	3.30	2.42	0.50	2.05
April	3.40	4.25	2.46	3.70	1.87	0.85	1.56	1.15
May	4.65	3.46	5.71	4.17	5.70	4.50	3.35	4.36
June	0.97	0.90	0.24	0.74	4.87	3.85	5.42	4.37
July	5.31	6.03	1.90	4.91	3.63	4.52	1.48	3.65
August	5.91	5.15	5.46	5.32	3.68	2.07	1.56	2.14
September	1.91	1.50	3.61	2.08	2.94	3.40	2.77	3.19
October	3.06	0.75	2.80	1.55	8.52	6.75	7.51	7.16
November	3.63	2.10	3.05	2.53	2.39	2.47	3.38	2.69
December	5.56	5.01	7.34	5.67	5.60	3.54	4.42	4.02
Total	43.54	39.15	41.82	40.37	46.68	37.67	36.29	38.45

TABLE NO. 8—*Continued.*

Month.	1834.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Oyster Bay Academy, Oyster Bay.	Adopted Value.
January	2.22	1.74	2.99	1.92	2.18
February	2.37	2.02	1.52	1.67	1.81
March	1.62	1.00	0.85	2.67	1.67
April	3.21	3.22	2.02	4.89	3.54
May	4.88	3.23	6.70	7.08	5.75
June	7.25	6.41	4.66	4.97	5.54
July	4.54	6.17	7.42	6.45	6.36
August	0.90	1.06	0.29	2.10	1.24
September	3.05	2.94	4.47	4.83	4.04
October	2.70	2.59	4.32	2.00	2.82
November	3.83	2.29	2.62	2.24	2.55
December	2.90	0.95	2.36	1.47	1.74
Total	39.47	33.62	40.12	42.29	39.24

Month.	1835.				1836.			
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, East-hampton.	Value Adopted.	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, East-hampton.	Value Adopted.
January	2.65	3.15	2.45	2.91	7.51	5.39	6.71	5.99
February	1.21	0.63	1.63	0.95	4.06	3.62	3.30	3.59
March	4.71	2.17	4.22	3.00	2.50	2.21	2.57	2.34
April	6.22	3.93	5.69	4.66	4.01	0.94	2.95	1.83
May	1.76	0.76	1.79	1.14	1.38	1.99	2.98	2.16
June	3.25	3.39	1.68	2.94	8.55	7.45	3.26	6.54
July	5.13	4.19	1.39	3.61	2.50	2.19	1.62	2.09
August	2.84	2.65	2.93	2.74	2.31	1.86	1.98	1.95
September	1.27	1.50	0.86	1.31	1.66	1.24	1.33	1.31
October	2.11	1.74	2.34	1.94	2.74	2.58	1.93	2.44
November	3.16	2.62	2.79	2.73	2.75	3.56	4.00	3.57
December	3.71	2.05	2.78	2.44	3.92	3.54	2.87	3.42
Total	38.02	28.78	30.55	30.37	43.89	36.57	35.50	37.23

TABLE NO. 8—*Continued.*

Month.	1837.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Oyster Bay Academy. Oyster Bay.	Value Adopted.
January	1.84	0.93	2.10	2.68	1.99
February	2.83	1.72	3.90	1.11	2.17
March	5.92	5.57	7.62	3.58	5.38
April	3.23	3.22	1.60	5.28	2.59
May	4.29	4.63	5.09	7.36	5.73
June	3.45	3.58	3.04	3.49	3.39
July	2.98	3.58	3.91	4.40	3.89
August	3.15	3.12	2.26	2.09	2.52
September	1.76	1.28	0.90	2.37	1.63
October	1.01	1.32	0.99	1.28	1.18
November	1.65	1.66	1.53	1.98	1.75
December	2.55	1.52	2.29	2.12	2.07
Total	34.66	32.13	35.23	37.74	35.29

Month.	1838.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Fort Columbus, Governor's Island.	Value Adopted.
January	2.22	2.05	2.42	3.93	2.36
February	1.50	0.96	1.15	3.70	1.37
March	3.42	2.21	1.05	4.10	2.30
April	3.07	2.46	1.50	2.50	2.32
May	4.54	3.05	1.56	3.99	2.99
June	4.90	2.02	1.65	3.12	2.38
July	2.19	3.29	0.97	1.83	2.49
August	1.74	1.36	0.74	4.79	1.65
September	8,22	6.64	9.18	4.96	7.19
October	3.98	4.03	4.94	3.64	4.18
November	3.91	4.89	2.50	3.10	4.05
December	1.42	0.74	0.40	2.24	0.91
Total	41.11	33.70	28.06	41.90	34.19

TABLE No. 8—*Continued.*

Month.	1839. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	1.82	0.33	1.24	1.25	0.80
February	2.52	1.52	3.11	2.38	2.08
March	1.88	2.33	1.44	2.18	2.07
April	3.64	2.86	4.87	3.35	3.45
May	5.74	3.78	2.46	7.30	4.10
June	4.84	3.90	2.98	5.67	4.00
July	2.75	2.19	2.86	2.07	2.39
August	3.91	3.34	9.00	5.12	4.86
September	3.09	4.37	4.69	4.16	4.28
October	1.99	1.77	5.13	1.90	2.56
November	3.88	3.25	1.61	3.49	2.98
December	6.84	3.80	7.00	8.15	5.33
Total	42.90	33.44	46.39	47.02	38.90

Month.	1840. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	2.00	2.18	2.35	2.17	2.20
February	2.84	2.11	2.69	2.32	2.34
March	2.58	1.77	3.55	2.92	2.38
April	4.95	5.52	5.04	3.44	5.12
May	2.82	3.08	6.33	2.88	3.75
June	1.90	2.93	2.32	3.75	2.77
July	1.10	3.01	1.05	3.17	2.38
August	3.71	5.18	5.88	5.22	5.18
September	1.84	1.97	2.42	1.78	2.03
October	4.62	3.29	4.52	4.59	3.86
November	3.33	3.20	6.02	2.90	3.81
December	4.26	1.23	1.15	1.00	1.52
Total	35.95	35.47	43.32	36.14	37.34

TABLE NO. 8—*Continued.*

Month.	1841. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	6.70	4.42	4.57	5.30	4.80
February	1.53	0.91	0.96	0.80	0.98
March.........	4.77	2.25	3.40	2.35	2.80
April..........	6.77	3.83	7.24	3.93	4.93
May	3.01	3.67	1.71	3.95	3.20
June...........	4.56	6.02	2.47	4.65	4.92
July...........	2.85	3.11	3.74	4.90	3.42
August..... ..	5.50	3.44	5.68	2.50	4.06
September.....	1.73	4.89	1.57	2.90	3.58
October........	4.50	6.67	4.47	4.40	5.69
November......	5.02	2.62	3.84	3.70	3.28
December	5.18	2.74	3.97	2.70	3.28
Total.....	52.12	44.57	43.62	42.08	44.94

Month.	1842. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy, Easthampton.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January........	1.34	2.67	2.07	1.07	2.21
February	4.13	3.19	3.02	2.85	3.22
March	2.08	1.66	1.26	1.25	1.57
April..........	4.58	3.74	5.24	3.60	4.18
May	4.63	4.60	3.70	3.60	4.27
June.	3.25	3.53	6.02	3.30	4.03
July	6.17	6.19	3.54	3.86	5.33
August........	5.86	5.73	1.94	2.81	4.58
September.....	2.82	2.50	2.35	2.10	2.46
October	4.17	1.98	0.40	4.30	2.13
November	3.50	2.86	0.93	1.80	2.39
December	4.51	2.94	2.60	3.50	3.10
Total.....	47.04	41.59	33.07	33.98	39.47

TABLE NO. 8—*Continued.*

Month.	1843. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Clinton Academy Easthampton.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	1.13	0.89	0.00	0.85	0.71
February	2.79	1.66	0.83	2.11	1.65
March	4.59	2.69	0.50	3.16	2.47
April	5.21	3.76	4.00	3.92	3.99
May	1.59	2.13	2.35	1.16	2.01
June	1.75	4.71	3.95	1.21	3.82
July	1.96	1.15	0.00	1 76	1.05
August	15.76	8.96	6.20	14.66	9.73
September	2.78	0.40	3.18	3.40	1.62
October	4.87	2.82	5.15	5.01	3.81
November	3.88	3.91	0.50	2.26	2.97
December	3.88	2.60	2.80	3.28	2.86
Total	50.19	35.68	29.46	42.78	36.69

Month.	1844. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean Fort Columbus and Fort Hamilton.	Value Adopted.	1845. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean Fort Columbus and Fort Hamilton.	Value Adopted.
January	3.66	3 96	2.81	3.80	3.84	2.10	4.57	2.57
February	1.50	0.96	0.98	1.02	4.45	3.52	4.46	3.73
March	4.37	3.19	4.42	3.46	2.50	1.85	2.77	2.02
April	0.53	0.80	0.54	0.74	1.04	1.28	1.11	1.23
May	3.83	3.48	3.11	3.48	1.55	1.20	1.61	1.28
June	3.48	0.79	2.35	1.26	3.36	4.41	3.65	4.21
July	5.42	6.25	5.44	6.07	1.67	3.56	1.85	3.16
August	3.71	6.06	2.23	5 37	3.82	3.46	3.84	3.54
September	2.75	5.07	4.40	4.74	2.65	2.98	2.45	2.88
October	4.22	3.74	3.93	3.81	1.92	2.72	2.13	2.56
November	1.79	2 35	1.89	2.24	3 08	3.42	3.18	3.36
December	2.81	3.15	2.44	3.03	2.81	3.21	2.98	3.14
Total	38.07	39.80	34.54	39.02	32.69	33.71	34.60	33.68

TABLE No. 8—*Continued.*

Month.	1846.				1847			
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean Fort Columbus and Fort Hamilton.	Value Adopted.	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean Fort Columbus and Fort Hamilton.	Value Adopted.
January	4.16	4.04	4.53	4.12	3.54	2.47	4.83	2.85
February	3.56	1.74	4.28	2.22	5.41	4.42	6.39	4.75
March	2.78	3.73	3.32	3.58	5.13	2.94	6.76	3.61
April	3.01	3.11	3.22	3.11	0.82	1.69	1.12	1.53
May	7.18	5.46	9.77	6.13	1.69	2.20	1.91	2.11
June	1.12	1.20	1.76	1.25	5.51	4.46	7.57	4.92
July	5.75	3.41	6.55	4.02	2.58	5.41	2.97	4.82
August	4.10	2.41	4.11	2.79	2.40	5.01	5.12	4.73
September	0.09	0.40	0.34	0.36	10.65	5.40	11.40	6.65
October	1.72	1.01	1.46	1.14	1.79	1.68	3.19	1.86
November	7.12	7.96	8.63	7.94	3.08	5.68	5.75	5.40
December	3.41	1.47	2.84	1.84	3.33	3.11	6.76	3.54
Total	44.00	35.94	50.81	38.50	45.93	44.47	63.77	46.77

Month.	1848.				1849.			
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean Fort Columbus and Fort Hamilton.	Value Adopted.	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean Fort Columbus and Fort Hamilton.	Value Adopted.
January	1.80	1.80	1.97	1.82	0.55	0.10	0.53	0.20
February	1.51	1.51	1.43	1.50	2.23	1.61	2.19	1.74
March	2.12	2.12	2.04	2.11	5.07	3.69	4.99	3.99
April	0.89	0.90	1.45	0.96	0.80	0.67	0.57	0.67
May	5.27	5.79	8.30	6.01	3.76	4.97	3.61	4.68
June	5.19	4.50	4.87	4.62	0.77	0.63	0.80	0.66
July	3.00	3.62	2.22	3.40	2.15	1.66	2.09	1.76
August	1.00	0.75	1.18	0.83	3.99	4.27	3.82	4.19
September	2.15	2.29	1.76	2.22	0.98	0.88	2.19	1.04
October	4.09	4.03	4.78	4.12	6.26	6.41	5.07	6.24
November	1.85	1.29	1.71	1.40	1.88	2.16	1.67	2.07
December	4.54	4.15	3.76	4.15	4.03	3.03	3.22	3.16
Total	33.41	32.75	35.47	33.14	32.47	30.08	30.75	30.40

TABLE No. 8—*Continued.*

Month.	1850. Erasmus Hall, Flatbush, Brooklyn.	1850. Union Hall, Jamaica.	1850. Mean Fort Columbus and Fort Hamilton.	1850. Value Adopted.	1851. Erasmus Hall, Flatbush, Brooklyn.	1851. Union Hall, Jamaica.	1851. Mean Fort Columbus and Fort Hamilton.	1851. Value Adopted.
January	5.70	1.21	5.13	2.14	1.63	1.50	1.92	1.56
February	3.33	1.23	2.19	1.57	4.24	4.83	4.47	4.72
March	3.75	0.99	5.09	1.75	3.34	2.27	2.79	2.44
April	2.68	1.98	2.08	2.07	7.02	6.22	6.13	6.30
May	7.21	8.27	7.97	8.12	4.00	3.60	3.81	3.67
June	2.53	2.16	2.59	2.25	2.00	1.59	1.29	1.60
July	4.43	3.90	3.80	3.95	3.85	2.71	4.01	2.98
August	7.43	7.86	6.69	7.46	3.23	2.72	3.06	2.81
September	4.19	6.64	4.46	6.13	1.06	0.78	1.28	0.87
October	1.85	2.68	2.50	2.57	4.47	4.20	2.97	4.09
November	1.10	2.13	2.16	2.02	3.98	5.65	4.46	5.33
December	4.08	5.51	5.56	5.36	2.00	2.70	3.19	2.68
Total	48.28	45.56	50.22	45.39	40.82	38.77	39.38	39.05

Month.	1852. Erasmus Hall, Flatbush, Brooklyn.	1852. Union Hall, Jamaica.	1852. Clinton Academy, Easthampton.	1852. Mean of Fort Columbus and Fort Hamilton.	1852. Value Adopted.
January	2.47	1.06	2.69	2.43	1.73
February	3.27	2.58	2.09	2.68	2.56
March	4.34	3.40	2.19	4.27	3.33
April	5.25	3.93	6.29	5.40	4.76
May	2.40	1.80	1.59	2.72	1.92
June	2.49	1.56	1.32	2.45	1.71
July	1.77	0.39	0.45	2.95	0.84
August	9.25	6.21	2.21	5.33	5.56
September	2.01	1.46	....	2.14	1.60
October	2.52	2.59	....	2.15	2.53
November	6.24	5.25	....	5.11	5.34
December	5.73	5.06	....	4.13	5.03
Total	47.74	35.29	....	41.76	36.91

TABLE No. 8—*Continued.*

Month.	1853. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	2.63	2.48	4.36	2.71
February	4.29	3.52	6.11	3.89
March	3.85	4.30	3.91	4.21
April	4.04	3.88	4.05	3.92
May	5.01	3.49	5.91	3.93
June	5.68	3.56	4.61	3.91
July	5.74	7.43	5.11	6.98
August	5.96	5.13	5.37	5.25
September	5.20	6.51	4.62	6.15
October	3.66	0.06	3.32	0.82
November	4.00	3.42	5.26	3.69
December	2.38	2.62	1.10	2.42
Total	52.44	46.40	53.73	47.88

Month.	1854. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean of Fort Columbus and Fort Hamilton.	Sag Harbor.	Value Adopted.
January	2.83	2.10	2.82	3.38	2.55
February	5.41	4.44	4.22	3.86	4.39
March	1.62	0.37	0.68	3.43	1.22
April	11.60	11.19	9.19	10.08	10.77
May	5.34	6 25	6.90	3.60	5.63
June	2.16	1.33	3.22	2 87	1.97
July	1.69	2.51	2.06	5.65	3.07
August	0.85	1.26	0.65	0.60	1.00
September	3.23	3.22	2.70	11.69	5.05
October	2.05	1.34	1.50	2.22	1.63
November	6.25	6.15	4.82	9.41	6.74
December	3.65	3.36	5.98	5.73	4.21
Total	46.68	43.52	44.74	62.52	47.23

TABLE No. 8—*Continued.*

Month.	1855.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean of Fort Columbus and Fort Hamilton.	Sag Harbor.	Value Adopted.
January	4.55	5.50	3.51	5.32	5.13
February	3.72	3.25	4.02	1.25	2.94
March	2.12	1.35	1.30	1.38	1.44
April	2.20	1.35	2.42	4.05	2.16
May	4.98	5.19	3.88	3.20	4.58
June	5.50	4.99	4.38	2.66	4.46
July	5.88	5.42	4.17	4.37	5.10
August	2.62	1.20	2.77	2.98	1.93
September	2.95	3.05	1.13	0.90	2.35
October	7.08	3.84	5.10	5.38	4.68
November	3.04	2.70	2.77	....	2.75
December	6.20	5.38	6.70	4.91	5.51
Total	50.84	43.22	42.15	....	43.03

Month.	1856.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Mean of Fort Columbus and Fort Hamilton.	Sag Harbor.	Value Adopted.
January	4.13	3.66	4.63	5.10	4.14
February	0.98	0.80	0.82	1.40	0.96
March	2.13	1.58	2.42	2.24	1.88
April	2.69	1.60	3.48	3.20	2.29
May	4.18	5.05	3.54	4.03	4.56
June	3.80	3.29	3.35	....	3.35
July	3.24	3.27	2.61	5.00	3.58
August	...	6.30	6.55	6.72	7.06
September	3.84	3.20	3.67	2.60	3.19
October	0.88	0.80	1.08	1.23	0.94
November	2.68	2.30	2.70	2.70	2.48
December	3.32	3.14	2.62	6.41	3.83
Total	....	34.99	37.47	....	38.26

TABLE NO. 8—*Continued.*

Month.	1857.					
	Erasmus Hall, Flatbush, Brocklyn.	Union Hall, Jamaica.	Mean of Fort Columbus and Fort Hamilton.	Sag Harbor.	Bellport.	Value Adopted.
January	1.99	3.22	3.10	4.36	....	3.32
February	1.56	0.55	1.26	1.33	....	0.91
March	2.14	1.24	1.62	2.75	....	1.72
April	7.50	4.15	6.19	4.97	....	4.93
May	6.13	5.25	5.07	3.05	....	4.84
June	4.57	3.67	4.40	1.94	....	3.47
July	6.37	4.97	5.14	4.44	....	5.03
August	3.81	3.53	3.76	4.17	4.56	4.01
September	3.48	2.84	3.11	1.65	2.00	2.51
October	3.88	2.54	3.49	3.80	3.57	3.24
November	1.90	1.86	1.04	2.70	2.83	2.22
December	4.94	4.87	3.39	2.05	6.80	5.19
Total	48.27	38.69	41.57	37.21	....	41.39

Month.	1858.					
	Erasmus Hall, Flatbush, Brooklyn,	Union Hall, Jamaica.	Mean of Fort Columbus and Fort Hamilton.	Sag Harbor.	Bellport.	Value Adopted.
January	2.77	2.69	2.15	2.47	2.81	2.67
February	2.24	2.66	2.37	2.80	0.95	1.99
March	1.60	1.39	0.66	....	2.58	1.81
April	4.86	0.90	2.25	....	4.58	2.90
May	4.95	5.44	5.06	....	2.98	4.37
June	5.34	3.79	4.63	4.40	5.14	4.55
July	5.06	4.12	4.14	2.31	1.31	3.02
August	2.77	2.88	3.16	3.73	2.17	2.72
September	2.90	3.30	3.05	5.75	6.64	4.68
October	1.92	2.30	1.62	2.10	1.46	1.88
November	4.49	3.29	3.79	4.15	4.82	4.08
December	4.33	3.94	3.88	4.90	5.71	4.70
Total	43.23	36.70	36.76	....	41.15	39.37

TABLE NO. 8—*Continued.*

Month.	1859. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Bellport.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	6.46	6.46	5.07	5.84	5.84
February	4.51	4.51	5.43	3.98	4.83
March	6.93	7.53	7.76	6.34	7.44
April	5.35	5.35	3.74	5.13	4.68
May	2.42	2.02	5.14	2.80	3.39
June	5.70	5.20	8.96	5.94	6.83
July	5.22	3.80	3.04	3.88	3.65
August	5.93	4.50	4.28	6.40	4.75
September	6.80	9.60	6.45	4.51	7.55
October	1.87	1.66	2.30	1.09	1.88
November	3.99	1.90	2.74	3.32	2.59
December	3.74	7.15	3.18	3.55	4.86
Total	58.92	59.68	58.09	52.78	58.29

Month.	1860. Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Bellport.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January	1.21	3.45	4.05	2.26	3.35
February	2.47	1.26	0.88	1.70	1.27
March	1.29	1.68	1.20	1.15	1.40
April	3.65	1.90	2.29	2.52	2.29
May	2.82	2.53	2.40	3.53	2.61
June	2.73	0.78	0.20	1.32	0.80
July	2.41	2.02	3.13	2.82	2.58
August	6.75	8.91	1.92	5.76	5.58
September	3.89	2.09	4.45	3.31	3.34
October	2.71	0.37	1.77	1.77	1.30
November	5.99	4.91	1.96	4.68	3.81
December	1.73	1.18	3.14	2.04	2.10
Total	37.65	31.08	27.39	32.86	30.43

TABLE No. 8—*Continued.*

Month.	1861.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Bellport.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January........	3.88	4.45	5.39	2.91	4.61
February......	2.95	2.16	2.82	1.76	2.46
March.........	5.14	4.01	3.86	3.28	3.99
April..........	4.98	2.55	4.87	3.42	3.81
May...........	5.49	2.90	5.86	4.71	4.52
June..........	3.28	1.20	....	2.60	1.59
July...........	2.11	1.06	....	1.92	1.27
August.........	2.99	2.47	....	4.18	2.72
September.....	3.27	4.20	....	3.04	3.97
October.......	4.86	4.87	2.69	3.24	3.83
November.....	6.31	5.55	3.95	4.96	4.93
December.....	0.39	1.80	....	1.15	1.57
Total.....	45.65	37.22	....	37.17	39.27

Month.	1862.				
	Erasmus Hall, Flatbush, Brooklyn.	Union Hall, Jamaica.	Bellport.	Mean of Fort Columbus and Fort Hamilton.	Value Adopted.
January........	2.25	7.45	6.58	5.70	6.41
February......	2.22	4.18	4.05	3.06	3.82
March.........	2.96	3.60	3.25	3.10	3.35
April..........	3.56	0.30	1.54	2.37	1.33
May...........	3.09	1.20	2.46	3.05	2.08
June..........	4.17	6.86	1.68	5.93	4.43
July...........	3.13	3.29	....	4.31	3.38
August.........	3.78	2.74	....	1.67	2.74
September.....	3.06	1.92	....	1.31	1.98
October.......	2.73	7.54	....	4.03	6.62
November.....	4.49	6.15	....	2.99	5.61
December.....	2.58	1.55	....	0.99	1.60
Total.....	38.02	46.78	....	38.51	43.35

TABLE NO. 8—*Continued.*

Month.	1863. Erasmus Hall, Flatbush, Brooklyn.	1863. Union Hall, Jamaica.	1863. Mean Fort Columbus and Fort Hamilton.	1863. Value Adopted.	1864. Erasmus Hall, Flatbush, Brooklyn.	1864. Union Hall, Jamaica.	1864. Mean Fort Columbus and Fort Hamilton.	1864. Value Adopted.
January	2.41	2.10	2.90	2.22	1.50	2.45	2.25	2.32
February	2.36	3.58	3.96	3.49	1.10	4.25	0.62	3.50
March	3.13	2.92	3.89	3.05	2.30	5.25	2.16	4.58
April	3.29	2.20	3.69	2.49	2 35	4.40	1.80	3.88
May	2.15	4.45	3.80	4.12	1.93	3.27	4.73	3.28
June	2.05	1.60	1.31	1.62	4.45	1.60	2.11	1.97
July	5.62	4.30	4.26	4.44	2.40	2.82	1.72	2.65
August	2.58	3.45	2.35	3.23	2.82	1.10	2.61	1.46
September	0.95	2.21	0.62	1.89	4.14	4.10	4.74	4.18
October	1.90	4.25	2.23	3.76	1.44	2.85	4.05	2.83
November	2.12	7.08	1.72	5.93	3.56	4.50	3.63	4.30
December	4.20	5.30	3.12	4.94	4.01	2.92	3 93	3.15
Total	32.76	43.44	33 85	41.18	32.00	39.51	34.35	38.10

Month.	1865. Erasmus Hall, Flatbush, Brooklyn.	1865. Mean Fort Columbus and Fort Hamilton.	1865. Value Adopted.	1866. Mean Fort Columbus and Fort Hamilton.	1866. New York Deaf and Dumb Asylum.	1866. Value Adopted.	1867. Mean of Fort Columbus and Fort Hamilton.
January	3.34	3.23	3.28	1.61	2.56	2.08	1.48
February	3.72	4.09	3.90	5.48	9.30	7.39	4.29
March	3.96	4.51	4.23	1.95	2.28	2.11	3.80
April	4.24	3.00	3.62	....	4.09	4.09	1.46
May	5.63	4.41	5.02	4.13	4.46	4.29	5.28
June	3.45	2.78	3.12	....	4.38	4.38	9.64
July	3.54	3.54	3.54	....	1.67	1.67	4.75
August	2.90	2.22	2.56	....	4.81	4.81	6.93
September	2.21	2.15	2.18	3.33	4.85	4.09	0.81
October	5.75	3.36	4.55	3.80	5.28	4.54	3.41
November	2.87	3.22	3.05	2.44	3.84	3.14	1.80
December	4.53	4.36	4.44	2.47	3.92	3 20	2.15
Total	46.14	40.87	43.49	....	51.44	45.79	45.80

TABLE No. 8—*Continued.*

Month.	1873. Mean of Forts Columbus, Hamilton, Wadsworth, and U. S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Value Adopted.
January	5.29	5.34	4.08	4.57
February	2.93	3.80	2.20	2.67
March	2.04	2.09	1.62	1.80
April	3.63	4.16	2.38	2.99
May	3.70	3.69	2.72	3.11
June	1.17	1.28	2.94	2.25
July	3.75	4.61	2.62	3.24
August	7.11	9.56	5.66	6.73
September	2.43	3.14	2.22	2.45
October	2.08	2.73	4.02	3.37
November	3.79	4.63	3.00	3.48
December	2.51	2.96	2.52	2.61
Total	40.43	47.99	35.98	39.27

Month.	1874. Mean of Forts Columbus, Hamilton, Wadsworth, and U.S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Hempstead, Parsonage Creek Reservoir.	Brookhaven.	Value Adopted.
January	4.10	5.33	5.42	5.09	4.44	4.82
February	2.07	2.04	1.66	2.78	4.60	3.29
March	1.45	2.12	1.88	1.88	1.45	1.71
April	7.92	8.77	8.14	8.35	8.42	8.66
May	2.13	2.24	1.90	2.31	2.52	2.33
June	2.42	2.78	2.50	....	1.79	2.16
July	3.64	5.06	2.70	...	1.46	2.41
August	3.47	2.43	3.68	....	3.38	3.38
September	8.81	8.24	5.66	....	4.97	5.89
October	2.22	1.70	2.32	....	0.71	1.44
November	2.68	2.30	2.46	....	2.60	2.54
December	2.45	2.82	1.70	....	3.61	2.84
Total	43.36	45.83	40.02	....	39.95	41.47

TABLE NO. 8—*Continued.*

Months.	1875. Mean of Forts Columbus, Hamilton, Wadsworth and U. S. Signal Service.	New York Moteorological Observatory.	Willet's Point.	Flushing.	Brookhaven.	Value Adopted.
January	3 79	3.17	3.58	....	3.91	3.72
February	2.69	2.62	1.40	....	3.36	2.63
March	3.46	3.48	3.22	....	6.33	4.82
April	2.35	3 08	2.76	....	3.37	3.06
May	1.23	1.33	1.90	1.94	1.90	1.80
June	3.65	2.72	3.42	2.77	2.34	2.79
July	3.91	4.89	5.72	4.90	6.22	5.68
August	9.37	8.97	6.60	6.90	4.59	6.05
September	2.01	1.89	2.10	1.60	2.51	2.24
October	3.11	2.85	4.20	3.42	4.48	4.07
November	4.16	3 78	4.70	4.22	6.14	5.26
December	2.48	2.12	2.74	2.70	2.04	2.31
Total	42.21	40.90	42.34	....	47.19	44.43

Months.	1876. Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Flushing.	Brookhaven.	Value Adopted.
January	0.77	0.94	1.24	1.29	1.16	1.14
February	5.12	4.81	4.98	5.27	4.48	4.75
March	8.49	8.79	8.90	10.19	7.21	8.12
April	3.35	3.06	4.46	4.24	6.14	5.07
May	3.47	3.03	4.02	4.10	4.05	3.91
June	2.46	2.66	2.14	2.21	1.63	1.96
July	5.56	3.65	6.16	4.87	5.61	5.52
August	2.49	2.28	3.60	4.22	0 51	1.90
September	5.06	5.28	5.12	4.03	3.66	4.31
October	1.21	1.42	1 36	1.76	0.73	1.07
November	3.93	3.31	3.86	4.18	4.97	4.40
December	2.39	2.54	2.30	3.18	4.53	3.52
Total	44.30	41.77	48.14	49.54	44.68	45.67

TABLE No. 8—*Continued.*

Month.	1877. Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Flushing.	Brookhaven.	Value Adopted.
January	2.53	2.62	....	3.91	2.96	3.21
February	1.72	1.24	1.48	1.90	1.60	1.57
March	6.35	5.56	7.34	8.61	7.83	7.46
April	3.45	2.73	2.36	2.96	2.65	2.68
May	0.71	0.95	1.68	0.95	0.86	1.07
June	3.02	2.80	2.68	2.95	3.40	3.10
July	4.00	5.73	3.46	3.95	3.09	3.55
August	2.48	2.77	3.76	3.20	2.16	2.72
September	1.25	1.33	1.14	1.57	1.28	1.27
October	7.78	8.14	8.46	6.73	8.70	8.35
November	5.96	5.62	5.88	4.95	5.45	5.57
December	0.63	0.68	1.00	0.65	0.31	0.57
Total	39.88	40.17	....	42.33	40.29	41.12

Month.	1878. Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Flushing.	Brookhaven.	Value Adopted.
January	4.54	4.46	....	5.53	6.08	5.63
February	2.31	3.75	3.20	2.88	3.35	3.22
March	3.98	3.27	5.56	3.60	3.09	3.84
April	1.80	1.97	1.96	3.14	3.21	2.67
May	3.57	3.19	6.28	3.60	4.51	4.69
June	3.11	3.08	3.42	....	2.64	2.98
July	5.34	4.62	3.84	4.66	3.52	3.94
August	6.46	7.97	8.34	8.77	3.54	5.79
September	2.85	4.05	3.14	3.38	0.57	1.93
October	1.82	2.43	2.84	3.22	1.02	1.84
November	4.56	4.73	3.38	3.87	4.67	4.28
December	5.92	5.14	7.94	6.33	5.33	6.10
Total	46.26	48.66	....	....	41.53	46.91

TABLE NO. 8—*Continued.*

Month.	Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	N. Y. Meteorological Observatory	Willett's Point.	Flushing.	Hempstead Storage Reservoir.	Brookhaven.	Value Adopted.
	1879.						
January	2.79	2.63	....	2.75	3.09	....	2.95
February	2.27	2.02	....	3.11	2.92	....	2.80
March	2.78	3.41	4.68	3.85	3.38	....	3.50
April	4.16	4.33	4.64	4.80	4.85	....	4.70
May	2.69	2.02	2.12	2.32	1.78	....	1.98
June	3.09	3.15	2.86	3.23	2.82	....	2.93
July	3.72	3.58	4.02	4.24	3.57	....	3.70
August	7.74	7.95	7.54	9.29	8.99	....	8.65
September	1.59	2.37	0.88	2.33	1.21	3.11	1.97
October	1.51	0.43	0.92	0.89	1.07	0.97	1.00
November	1 95	2.20	1.39	2.49	1.98	1 19	1.74
December	5.61	4.92	3.73	5.34	3.95	3.65	4.15
Total	39.90	39.01	.....	44.64	39.61	.....	40.07

Month.	Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	N. Y. Meteorological Observatory.	Willett's Point.	Flushing.	Hempstead Storage Reservoir.	Brookhaven.	Value Adopted.
	1880.						
January	2.20	2.14	1.91	2.95	1.28	1.65	1.71
February	1.97	2.12	1.93	2.33	1.89	0.94	1.66
March	4.51	4.66	....	5.03	5.18	3.92	4.65
April	2.37	2.90	2.26	3.30	2.84	1.98	2.54
May	0.77	0.62	....	1.19	0.72	....	0.91
June	1.36	1.14	0.85	1.52	1.27	0.74	1.09
July	7.15	8.52	8.71	10.10	8.18	4.39	7.15
August	4.01	5.23	6.64	5.30	6.56	6.92	6.28
September	2.27	1.90	2 65	3.00	2.50	3.22	2.71
October	2.59	2.70	2.46	3.00	3.55	2.93	3.09
November	2.67	2.46	2.42	2.80	2.52	2.79	2.62
December	3.55	2.27	2.64	2 05	4.27	7.56	4.78
Total	35.42	36.66	.....	42.57	40.76	.....	39.19

TABLE NO. 8—*Continued.*

Month.	1881.					
	Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory	Flushing.	Hempstead Storage Reservoir.	Brookhaven.	Value Adopted.
January	4.94	4.80	6.c8	5.44	6.00	5.59
February	4.88	4.93	5.05	5.68	1.78	4.20
March	6.41	5.81	8.10	6.74	6.51	6.67
April	0.96	0.95	1.43	0.55	2.80	1 44
May	2.06	3.20	2.88	2.86	1.42	2.34
June	6.30	5.35	5.22	6.09	2.87	4.90
July	1.43	1.25	2.45	0.57	0.61	0.87
August	1.96	0.86	0.90	1.62	0.41	1.12
September	1.13	0.97	0.65	2.72	0.24	1.44
October	1.97	1.60	2.38	2.32	1.68	2.02
November	2.80	2.36	3.25	2.66	2.35	2.59
December	4.06	4.18	4.66	2.28	0.98	2.35
Total	38.90	36.26	43.05	39.53	27.65	35.53

Month.	1882.					
	Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Flushing.	Hempstead Storage Reservoir.	Brookhaven.	Value Adopted.
January	5.44	5.05	5.64	4.49	3.20	4.28
February	3.99	3.43	3.87	4.10	3.28	3.74
March	2.16	2.53	3.57	2.82	....	2.80
April	1.99	1.64	1.90	1.62	1.50	1.64
May	4.33	4.20	4.35	4.05	1.85	3.38
June	2.30	2.52	2.77	2.66	....	2.63
July	2.82	3.21	2.48	2.36	....	2.48
August	1.83	1.14	1.94	1.75	....	1.72
September	13.30	16.85	11.71	10.63	....	11.46
October	0.98	1.51	2 09	2.42	....	2.20
November	1.61	1.24	1.34	0.90	....	1.02
December	2.05	1.95	2.30	2.03	....	2.05
Total	42.80	45.27	43.96	39.83	....	39.40

TABLE NO. 8—*Continued.*

Month.	1883. Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Flushing.	Hempstead Storage Reservoir.	Value Adopted.
January	3.52	2.68	3.39	2.81	2.91
February	2.70	4.21	3.92	4.63	4.38
March	1.12	1.49	1.52	1.29	1.31
April	2.37	3.71	3.49	1.67	2.05
May	2.61	2.83	3.20	4.07	3.77
June	3.83	3.32	2.82	3.38	3.37
July	3.06	3.21	3.60	1.76	2.14
August	2.37	1.82	1.95	2.20	2.16
September	3.44	3.25	3.12	3.09	3.13
October	4.75	4.53	5.78	6.69	6.27
November	1.66	1.52	0.85	1.66	1.58
December	3.85	3.20	3.75	3.97	3.88
Total	35.28	35.77	37.39	37.22	36.95

Month.	1884. Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Flushing.	Hempstead Storage Reservoir.	Value Adopted.
January	6.36	5.22	4.80	4.75	4.93
February	5.40	4.92	5.35	5.87	5.71
March	4.36	4.62	....	4.38	4.40
April	2.91	2.82	....	2.52	2.58
May	4.32	3.74	....	3.01	3.18
June	4.78	4.98	....	4.92	4.91
July	5.66	4.74	....	3.93	4.14
August	9.11	7.90	....	4.31	5.01
September	0.28	0.21	....	0.29	0.28
October	3.47	3.75	....	2.58	2.75
November	3.16	3.18	....	3.01	3.04
December	6.17	6.17	....	5.82	5.88
Total	55.98	52.25	....	45.39	46.81

TABLE No. 8—*Continued.*

Month.	1885.				
	Mean of Fort Columbus, Fort Hamilton, and U. S. Signal Service.	New York Meteorological Observatory.	Hempstead Storage Reservoir.	Setauket.	Value Adopted.
January	2.98	3.06	3.21	....	3.18
February	5.38	4.56	3.92	....	4.09
March	1.12	0.90	1.02	....	1.02
April	2 20	2.19	2.53	....	2.47
May	1.85	1.86	2.51	....	2.40
June	1.63	1.32	1.77	....	1.72
July	3.10	3.59	2.35	1.44	2.14
August	6.43	5.67	6.19	6.43	6.27
September	0.71	0.41	0.94	0.93	0.87
October	5.22	5.18	5.36	6.35	5.75
November	4.83	4.17	4.50	8.16	6.03
December	2.59	2.46	2.55	4.00	3.15
Total	38.04	35.37	36.85	....	39.09

Month.	1886.				
	Mean of Fort Columbus and U. S. Signal Service.	New York Meteorological Observatory.	Hempstead Storage Reservoir.	Setauket.	Value Adopted.
January	4.70	3.91	5.79	3.76	4.70
February	5.90	4.89	7.95	7.08	7.16
March	3.43	2.83	3.47	3.18	3.29
April	4.21	3.85	4.05	4.21	4.11
May	5.80	5.40	4.64	3.13	4.17
June	3.14	3.35	3.73	3.68	3.63
July	2.76	2.75	6.78	7.43	6.38
August	1.09	0.95	1.50	3.00	2.05
September	1.80	1.17	2.64	1.03	1.78
October	3.90	3.07	3.93	4.15	3.95
November	4.32	4.42	3.40	3.43	3.57
December	3.73	2.79	3.50	4.43	3.85
Total	44.78	39.38	51.38	48.51	48.64

TABLE No. 8—*Continued.*

Month.	1887. Mean of Fort Columbus and U. S. Signal Service.	New York Meteorological Observatory.	Hempstead Storage Reservoir.	Setauket.	Value Adopted.
January........	4.36	4.42	4.78	5.33	4.94
February......	5.62	5.96	5.60	6.00	5.80
March.	3.68	3.07	4.13	4.96	4.35
April..........	3.67	2.79	2.89	3.95	3.39
May...........	0.83	0.34	0.30	0.10	0.27
June	7.66	7.76	6.71	6.57	6.82
July	7.55	5.29	3.53	5.30	4.75
August........	3.75	3.59	5.56	4.42	4.77
September.....	2.33	1.93	3.27	2.45	2.74
October	2.43	2.43	2.79	3.76	3.13
November......	2.00	2.02	2.54	2.62	2.48
December	4.25	4.39	3.56	3.42	3.63
Total	48.13	43.99	45.66	48.88	47.07

Month.	1888. Mean of Fort Columbus, Fort Hamilton and U. S. Signal Service.	New York Meteorological Observatory.	Hempstead Storage Reservoir.	Setauket.	Value Adopted.
January........	5.09	4.96	4.78	5.49	5.12
February.......	3.96	3.49	2.82	3.27	3.16
March	5.96	4.62	4.43	7.32	5.78
April...... ..	3.50	2.89	3.22	2.88	3.07
May	4.75	5.62	4.47	4.49	4.60
June	1.75	2.60	2.75	1.69	2.21
July...........	1.25	1.53	2.60	1.61	1.99
August........	6.51	7.66	5.02	5.60	5.61
September.....	6.99	8.16	7.75	6.44	7.17
October........	3.96	4.33	3.73	4.76	4.23
November	4.92	4.04	3.91	4.83	4.40
December.. ...	3.27 *3.76	3.42	2.97	3.08	3.14
Total..	51.91	53.32	48.45	51.46	50.48

* Willett's Point.

TABLE NO. 8—*Continued.*

Month.	1889. Mean of Forts Columbus, Hamilton, Wadsworth and U.S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Value Adopted.
January	5.38	4.97	6.08	6.46	6.26	6.15
February	2.71	2.21	2.33	2.06	2.19	2.19
March	3.73	2.64	2.20	2.40	2.74	2.63
April	5.53	5.47	7.15	4.64	3.57	4.64
May	3.20	2.89	2.60	3.15	3.83	3.31
June	3.17	2.39	2.38	3.60	2.91	3.13
July	8.56	11.89	7.13	8.07	6.64	7.87
August	4.49	3.28	4.02	3.92	4.16	4.00
September	6.31	6.92	7.16	8.51	7.22	7.65
October	2.52	2.61	2.82	3.33	4.64	3.60
November	9.12	9.97	10.28	8.59	8.03	8.70
December	2.05	1.92	1.78	1.81	1.68	1.79
Total	56.77	57.16	55.93	56.54	53.87	55.66

Month.	1890. Mean of Forts Columbus, Hamilton, Wadsworth and U.S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Value Adopted.
January	2.88	2.29	2.56	2.95	1.87	2.41
February	3.75	3.41	3.92	2.52	3.00	3.01
March	6.52	5.50	4.32	6.08	6.56	6.12
April	2.53	1.85	5.60	2.69	3.40	3.14
May	3.10	3.45	3.38	3.97	3.50	3.61
June	3.91	4.67	5.30	3.96	2.97	3.71
July	4.89	4.49	5.86	5.52	5.25	5.30
August	4.79	4.37	4.38	4.73	4.27	4.48
September	5.57	4.63	5.43	6.49	6.53	6.19
October	6.71	6.56	6.50	7.39	10.20	8.36
November	0.83	0.71	1.11	1.01	0.74	0.87
December	5.11	3.70	3.44	4.84	5.65	4 99
Total	50.59	45.63	51.80	52.15	53.94	52.19

TABLE NO. 8—*Continued.*

Month.	1891. Mean of Forts Columbus, Wadsworth, Hamilton and U.S. Signal Service.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	• Value Adopted.
January	6.00	6.12	8.13	4.31	6.29	....	5.74
February	4.78	4.12	4.45	3.78	6.26	....	4.98
March	3.93	3.61	3.48	3.39	3.84	4.40	3.83
April	2.16	2.38	2.80	1.85	3.22	4.05	2.92
May	3.38	2.45	2.35	2.00	1.24	3.15	2.20
June	1.43	1.48	1.20	0.95	1.84	1.25	1.39
July	4.85	3.94	5.00	6.60	5.71	7.15	5.99
August	5.46	4.51	4.90	4.09	3.43	5.07	4.31
September	2.77	2.49	3.03	3.04	3.18	3.10	3.03
October	3.13	2.60	3.57	3.47	6.60	7.55	5.29
November	2.12	2.30	2.52	2.02	2.24	2.00	2.15
December	3.92	3.55	3.70	3.68	3.40	4.45	3.78
Total	43.93	39.55	45.13	39.18	47.25	....	45.61

Month.	1892. Mean of Forts Columbus, Hamilton and U.S. Weather Bureau.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value Adopted.
January	4.89	4.69	3.66	5.03	4.79	5.13	4.84
February	1.19	0.94	1.70	1.98	1.40	2.75	1.82
March	4.62	3.49	3.60	4.52	3.73	3.63	3.93
April	2.36	2.02	2.44	2.53	1.82	3.70	2.52
May	4.30	4.22	5.22	5.23	3.65	4.95	4.53
June	2.97	2.78	2.95	2.72	1.79	2.75	2.48
July	2.45	3.21	3.49	3.19	3.12	4.35	3.40
August	3.90	4.16	5.16	2.58	4.76	4.85	4.20
September	0.87	1.06	0.92	1.73	3.67	2.35	2.29
October	0.63	0.59	0.50	0.49	0.90	1.10	0.78
November	8.28	7.14	8.37	6.09	8.22	9.40	7.93
December	1.64	1.30	1.66	1.66	1.56	1.65	1.60
Total	38.10	35.60	39.67	37.75	39.41	46.61	40.32

TABLE No. 8—*Continued.*

Month.	1893. United States Weather Bureau.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value Adopted.
January	3.56	2.33	2.90	1.32	3.09	3.50	2.74
February	7.81	6.14	7.10	5.71	7.11	....	6.62
March	4.47	3.54	4.48	4.53	5.82	4.75	4.89
April	6.36	5.19	5.33	4.70	4.95	3.40	4.69
May	5.06	4.77	4.55	4.19	5.87	5.85	5.23
June	2.56	2.59	1.96	0.81	0.58	0.80	1.10
July	1.26	1.13	1.77	1.24	1.88	1.90	1.62
August	7.18	8.72	7.05	4.67	6.65	7.19	6.55
September	2.27	1.92	2.17	2.02	2.02	2.55	2.17
October	5.28	5.30	4.35	5.33	4.00	....	4.69
November	3.71	3.55	3.06	2.58	3.25	....	3.07
December	3.49	3.08	3.31	2.52	3.43	4.50	3.44
Total	53.01	48.26	48.03	39.62	48.65	....	46.81

Month.	1894. Mean of United States Weather Bureau and Brooklyn Municipal Building.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value Adopted.
January	2.70	2.01	3.03	2.09	3.63	3.91	3.10
February	5.15	3.93	6.00	3.30	4.40	4.22	4.25
March	1.69	1.35	2.03	1.87	1.34	2.75	1.87
April	2.51	2.19	1.90	2.14	3.11	3.70	2.81
May	3.90	3.73	6.47	5.42	4.40	4.75	4.79
June	0.86	0.98	1.58	0.59	1.17	1.70	1.15
July	2.89	2.21	4.66	0.81	0.63	2.30	1.66
August	1.54	1.17	0.21	0.56	2.61	2.00	1.62
September	8.04	8.68	8.90	4.89	5.26	....	5.96
October	5.83	5.96	6.74	7.12	8.86	....	7.61
November	3.82	4.15	5.54	3.33	6.02	6.05	5.06
December	5.03	4.65	5.19	4.76	4.60	3.30	4.42
Total	43.96	41.01	52.25	36.88	46.03	....	44.30

TABLE No. 8—*Continued.*

1895.

Month.	Mean of United States Weather Bureau & Brooklyn Municipal Building.	New York Meteorological Observatory.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value. Adopted.
January	5.26	5.01	5.97	5.08	5.40	6.05	5.48
February	0.79	0.46	0.85	0.65	0.91	1.40	0.91
March	2.88	2.26	2.55	3.18	3.08	2.90	2.94
April	3.11	3.31	4.09	3.45	3.01	4.20	3.50
May	2.06	2.02	2.77	2.29	2.09	3.70	2.55
June	2.67	2.47	3.22	1.05	2.63	1.50	2.04
July	4.52	4.54	4.85	5.37	3.41	6.00	4.74
August	4.00	4.16	4.55	3.79	5.02	3.20	4.14
September	1.10	0.62	1.45	1.73	2.41	1.40	1.71
October	4.30	4.21	3.53	3.37	3.37	....	3.53
November	3.51	3.83	3.16	3.49	5.40	5.20	4.44
December	1.88	2.48	2.31	2.19	2.48	2.45	2.35
Total	36.08	35.37	39.30	35.64	39.21	.....	38.33

1896.

Month.	New York Meteorological Observatory.	Ridgewood Pumping Station.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value Adopted.
January	0.96	0.76	1.10	1.10	1.48	....	1.25
February	6.83	4.18	7.98	7.04	6.46	....	6.64
March	5.28	6.36	7.41	4.62	4.81	2.82	4.57
April	1.27	1.36	1.13	1.42	1.02	0.73	1.09
May	2.51	2.43	2.66	3.04	3.10	2.18	2.77
June	5.72	6.06	6.01	5.90	4.10	5.00	5.06
July	7.41	3.72	5.79	3.25	2.74	4.70	3.83
August	1.53	1.89	1.64	3.29	2.35	4.20	2.89
September	4.74	5.06	5.68	3.55	3.62	....	3.87
October	1.74	1.94	2.43	1.76	2.87	4.10	2.75
November	2.84	2.65	2.62	2.91	3.21	5.10	3.49
December	1.13	0.74	0.90	0.94	1.60	2.70	1.58
Total	41.96	37.15	45.35	38.82	37.36	.....	39.79

TABLE No. 8—*Continued.*

Month.	1897.						
	New York Meteorological Observatory	Ridgewood Reservoir.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value Adopted.
January	3.00	2.04	3.54	2.27	3.85	4.40	3.43
February	2.52	1.91	4.68	2.74	2.56	2.08	2.57
March	2.39	3.02	3.70	3.11	2.80	4.40	3.29
April	2.67	3.09	3.21	3.33	2.03	4.90	3 18
May	5.77	6.26	5.90	4.64	5.38	....	5.22
June	2.95	1.62	2.67	3.17	2.82	3.50	2.99
July	9.56	9.56	9.75	11.68	18.18	10.00	13.22
August	3.77	2.17	2.26	2.62	5.03	2.10	3.37
September	1.81	0.86	1.67	1.51	1.20	2.30	1.58
October	0.72	0.54	0.70	1.51	1.79	1.50	1.46
November	4.52	2.47	4.66	5.00	5.76	4.90	5.05
December	4.87	4.25	5.06	4.83	6.60	5.50	5.59
Total	44.55	37.79	47.80	46.41	58.00	....	50.95

Month.	1898.						
	New York Meteorological Observatory.	Ridgewood Reservoir.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Value Adopted.
January	4.26	3.91	5.13	4.12	4.00	6.10	4.60
February	4.22	4.52	4.02	3.23	4.82	4.30	4.22
March	2.78	3.71	4.14	3.45	3.40	5.25	3.87
April	3.25	3.42	4.42	3.79	4.90	5.90	4.66
May	6.72	7.47	8 20	8.99	8.30	11.50	9.07
June	1.25	1.31	1.13	0.77	0.62	0.70	0.78
July	4.41	4.85	7.85	5.43	7.81	7.40	6.78
August	3.47	4.27	4.94	4.83	6.56	5.50	5.49
September	1.70	1.72	1.40	2.44	1.85	2.20	2.03
October	6.05	5.68	5.91	5.81	7.08	8.20	6.83
November	6.72	5.86	6.18	6.00	6.28	8.90	6.83
December	3.07	2.76	3.87	2.36	2.38	3.25	2.73
Total	47.90	49.48	57.19	51.22	58.00	69.20	57.89

TABLE No. 8—*Continued.*

Month.	1899. New York Meteorological Observatory.	Ridgewood Reservoir.	Willett's Point.	Hempstead Storage Reservoir.	Setauket.	Brentwood.	Cutchogue.	Value Adopted.
January	3.97	3.92	4.59	4.22	4.71	4.10	4.98	4.35
February	3.91	3.36	4.58	5.02	5.48	4.70	5.90	4.92
March	5.77	6.46	7.26	7.79	8.15	8.70	4.74	7.67
April	1.74	1.61	1.97	1.47	1.54	2.20	1.63	1.74
May	1.09	1.25	1.58	1.79	1.95	2.20	4.30	2.00
June	2.26	1.15	3.35	2.21	3.08	1.80	1.12	2.27
July	4.47	4.46	4.75	5.07	3.10	5.90	4.17	4.63
August	3.41	3.91	1.80	3.59	0.97	2.80	6.15	2.79
September	6.12	6.24	4.50	5.17	5.02	6.00	3.79	5.34
October	2.13	1.81	1.85	2.76	2.75	3.70	3.00	2.85
November	1.79	1.88	2.30	2.69	1.21	2.40	5.64	2.30
December	1.91	1.81	2.40	1.82	1.67	3.22	2.84	2.24
Total	38.57	37.86	40.93	43.60	39.63	47.72	48.26	43.10

Month.	1900. New York Meteorological Observatory.	Ridgewood Reservoir.	Hempstead Reservoir.	Setauket.	Brentwood.	Cutchogue.	Value Adopted.
January	4.22	4.59	4.45	4.92	5.15	4.98	4.79
February	5.38	4.42	5.04	5.88	8.10	5.90	6.12
March	3.49	3.87	3.77	4.77	3.95	4.74	4.14
April	2.02	1.88	1.87	1.53	1.80	1.63	1.76
May	3.72	4.62	4.11	5.12	4.90	4.30	4.61
June	2.20	0.98	1.98	1.38	....	1.12	1.62
July	3.21	4.51	4.69	5.05	....	4.17	4.76
August	4.52	3.53	3.76	5.90	....	6.15	4.88
September	2.50	2.71	2.10	2.31	....	3.79	2.36
October	3.56	3.54	3.22	2.97	....	3.00	3.14
November	4.36	3.98	4.16	4.88	....	5.64	4.57
December	2.01	2.06	2.28	2.63	....	2.84	2.44
Total	41.19	40.69	41.43	47.34	....	48.26	45.19

TABLE No. 8—*Continued.*

Month.	1901.					
	New York Meteorological Observatory.	Ridgewood Reservoir.	Hempstead Storage Reservoir.	Setauket.	Mean of Cutchogue and Southampton.	Value Adopted.
January	1.66	2.01	2.21	1.96	2.99	2.12
February	0.55	0.22	0.77	0.69	0.53	0.68
March	5.47	4.68	6.97	5.61	6.79	6.21
April	6.62	6.63	8.05	8.23	7.70	7.92
May	6.43	7.39	7.17	7.25	6.46	7.12
June	1.00	0.98	0.55	1.12	1.17	0.86
July	7.64	7.27	5.93	3.42	3.73	5.04
August	6.55	4.59	4.03	6.02	4.70	5.01
September	2.42	2.71	3.36	3.55	5.07	3.44
October	2.35	2.35	1.95	2.76	2.12	2.31
November	0.99	1.31	1.28	1.94	2.23	1.57
December	7.01	7.01	7.65	9.43	9.25	8.34
Total	48.69	47.15	49.92	51.98	52.74	50.62

Month.	1902.					
	New York Meteorological Observatory.	Ridgewood Reservoir.	Hempstead Storage Reservoir.	Setauket.	Mean of Cutchogue and Southampton.	Value Adopted.
January	2.27	1.78	2.17	1.95	1.63	2.04
February	5.39	4.39	4.99	5.47	5.61	5.20
March	4.84	4.60	5.01	5.85	6.42	5.38
April	3.03	3.33	3.62	3.26	3.77	3.45
May	1.35	1.36	1.01	0.98	0.82	1.03
June	6.48	5.80	6.03	5.09	5.90	5.68
July	5.59	2.68	2.42	2.41	3.02	2.67
August	4.30	2.77	3.34	0.85	1.81	2.33
September	4.31	3.95	5.54	6.63	7.22	5.88
October	7.16	7.60	8.68	7.32	5.77	7.82
November	1.28	1.89	2.13	1.63	1.65	1.84
December	6.77	6.38	7.04	7.46	7.50	7.17
Total	52.77	46.53	51.98	48.90	51.12	50.49

TABLE NO. 8—*Continued.*

Month.	1903.				
	New York Meteorological Observatory.	Ridgewood Reservoir.	Floral Park.	Hempstead Storage Reservoir.	Farmingdale.
January	4.18	3.65	....	3.82	....
February	4.70	3.65	....	4.65	....
March	4.23	5.50	....	5.21	....
April	3.44	3.33	....	3.98	....
May	0.30	0.32	0.30	0.40	0.25
June	9.78	8.70	10.01	9.58	8.91
July	3.92	3.35	3.46	3.16	3.11
August	....	6.55	6.07	7.67	7.70
September	3.67	2.56	2.19	2.05	1.68
October	13.31	9.97	7.56	6.65	4.43
November	....	....	....	....	....
December	....	....	....	....	....

Month.	1903—(Continued).					
	Oyster Bay	Brentwood.	Setauket.	Manor.	Mean of Cutchogue and Southampton.	Value Adopted.
January	....	....	3.83	....	4.28	3.86
February	....	....	4.79	....	4.69	4.65
March	....	....	7.35	....	7.51	6.11
April	....	...	3.61	....	4.26	3.78
May	0.40	0.39	0.47	0.67	1.10	0.44
June	10.20	7.33	7.84	5.70	5.38	8.30
July	3.23	1.91	2.26	2.37	1.78	2.79
August	6.45	8.59	6.28	8.03	7.57	....
September	2.55	1.35	2.61	0.82	1.25	....
October	....	....	....	4.25	.. .	....
November	....	....	....	....	....	...
December	....	....	....	....	....	....

Table No. 8A.

RAINFALL ON LONG ISLAND.

Summary of Mean Monthly Precipitation on Long Island from 1826 to 1903.

Month.	1826.	1827.	1828.	1829.	1830.	1831.	1832.	1833.	1834.
January	1.05	2.97	2.71	5.33	2.39	3.07	4.39	1.89	2.18
February	2.21	4.53	2.93	4.16	1.65	2.13	3.24	1.78	1.81
March	3.96	1.61	4.78	4.09	5.21	2.89	2.07	2.05	1.67
April	2.64	6.68	4.69	4.33	2.05	6.04	3.70	1.15	3.54
May	0.17	3.95	4.35	3.95	3.68	3.52	4.17	4.36	5.75
June	12.01	2.35	3.22	1.80	4.25	1.93	0.74	4.37	5.54
July	3.73	4.67	3.99	2.45	5.55	4.13	4.91	3.65	6.36
August	13.44	5.63	1.61	3.89	1.98	1.52	5.32	2.14	1.24
September	2.62	4.37	7.26	2.74	1.74	5.62	2.08	3.19	4.04
October	8.31	4.62	1.60	4.36	4.29	4.71	1.55	7.16	2.82
November	2.02	6.14	6.39	5.02	5.70	1.85	2.53	2.69	2.55
December	2.15	3.27	0.42	2.95	6.92	1.75	5.67	4.02	1.74
Total	54.31	50.79	43.95	45.07	45.41	39.16	40.37	38.45	39.24

Month.	1835.	1836.	1837.	1838.	1839.	1840.	1841.	1842.	1843.
January	2.91	5.99	1.99	2.36	0.80	2.20	4.80	2.21	0.71
February	0.95	3.59	2.17	1.37	2.08	2.34	0.98	3.22	1.65
March	3.00	2.34	5.38	2.30	2.07	2.38	2.80	1.57	2.47
April	4.66	1.83	3.59	2.32	3.45	5.12	4.93	4.18	3.99
May	1.14	2.16	5.73	2.99	4.10	3.75	3.20	4.27	2.01
June	2.94	6.54	3.39	2.38	4.00	2.77	4.92	4.03	3.82
July	3.61	2.09	3.89	2.49	2.39	2.38	3.42	5.33	1.05
August	2.74	1.95	2.52	1.65	4.86	5.18	4.06	4.58	9.73
September	1.31	1.31	1.63	7.19	4.28	2.03	3.58	2.46	1.62
October	1.94	2.44	1.18	4.18	2.56	3.86	5.69	2.13	3.81
November	2.73	3.57	1.75	4.05	2.98	3.81	3.28	2.39	2.97
December	2.44	3.42	2.07	0.91	5.33	1.52	3.28	3.10	2.86
Total	30.37	37.23	35.29	34.19	38.90	37.34	44.94	39.47	36.69

TABLE No. 8A—*Continued.*

Month.	1844.	1845.	1846.	1847.	1848.	1849	1850.	1851.	1852.
January	3.80	2.57	4.12	2.85	1.82	0.20	2.14	1.56	1.73
February	1.02	3.73	2.22	4.75	1.50	1.74	1.57	4.72	2.56
March	3.46	2.02	3.58	3.61	2.11	3.99	1.75	2.44	3.33
April	0.74	1.23	3.11	1.53	0.96	0.67	2.07	6.30	4.76
May	3.48	1.28	6.13	2.11	6.01	4.68	8.12	3.67	1.92
June	1.26	4.21	1.25	4.92	4.62	0.66	2.25	1.60	1.71
July	6.07	3.16	4.02	4.82	3.40	1.76	3.95	2.98	0.84
August	5.37	3.54	2.79	4.73	0.83	4.19	7.46	2.81	5.56
September	4.74	2.88	0.36	6.65	2.22	1.04	6.13	0.87	1.60
October	5.81	2.56	1.14	1.86	4.12	6.24	2.57	4.09	2.53
November	2.24	3.36	7.94	5.40	1.40	2.07	2.02	5.33	5.34
December	3.03	3.14	1.84	3.54	4.15	3.16	5.36	2.68	5.03
Total	39.02	33.68	38.50	46.77	33.14	30.40	45.39	39.05	36.91

Month.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.
January	2.71	2.55	5.13	4.14	3.32	2.67	5.84	3.35	4.61
February	3.89	4.39	2.94	0.96	0.91	1.99	4.83	1.27	2.46
March	4.21	1.22	1.44	1.88	1.72	1.81	7.44	1.40	3.99
April	3.92	10.77	2.16	2.29	4.93	2.90	4.68	2.29	3.81
May	3.93	5.63	4.58	4.56	4.84	4.37	3.39	2.61	4.52
June	3.91	1.97	4.46	3.35	3.47	4.55	6.83	0.80	1.59
July	6.98	3.07	5.10	3.58	5.03	3.02	3.65	2.58	1.27
August	5.25	1.00	1.93	7.06	4.01	2.72	4.75	5.58	2.72
September	6.15	5.05	2.35	3.19	2.51	4.68	7.55	3.34	3.97
October	0.82	1.63	4.68	0.94	3.24	1.88	1.88	1.30	3.83
November	3.69	6.74	2.75	2.48	2.22	4.08	2.59	3.81	4.93
December	2.42	4.21	5.51	3.83	5.19	4.70	4.86	2.10	1.57
Total	47.88	47.23	43.03	38.26	41.39	39.37	58.29	30.43	39.27

TABLE NO. 8A—*Continued.*

Month.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.
January	6.41	2.22	2.32	3.28	2.08	1.48	3.24	2.22	3.82
February	3.82	3.49	3.50	3.90	7.39	4.29	1.18	5.72	3.84
March	3.35	3.05	4.58	4.23	2.11	3.80	1.73	4.49	3.54
April	1.33	2.49	3.88	3.62	4.09	1.46	3.13	1.33	3.17
May	2.08	4.12	3.28	5.02	4.29	5.28	5.82	4.31	1.74
June	4.43	1.62	1.97	3.12	4.38	9.64	3.63	5.46	2.09
July	3.38	4.44	2.65	3.54	1.67	4.75	6.63	2.92	3.09
August	2.74	3.23	1.46	2.56	4.81	6.93	3.29	1.74	3.73
September	1.98	1.89	4.18	2.18	4.09	0.81	7.78	2.75	1.73
October	6.62	3.76	2.83	4.55	4.54	3.41	2.26	6.76	4.90
November	5.61	5.93	4.30	3.05	3.14	1.80	4.05	2.87	1.80
December	1.60	4.94	3.15	4.44	3.20	2.15	2.27	5.10	1.57
Total	43.35	41.18	38.10	43.49	45.79	45.80	45.01	45.67	35.02

Month.	1871.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.
January	1.81	2.47	4.57	4.82	3.72	1.14	3.21	5.63	2.95
February	1.50	1.86	2.67	3.29	2.63	4.75	1.57	3.22	2.80
March	3.72	3.15	1.80	1.71	4.82	8.12	7.46	3.84	3.50
April	2.41	1.62	2.99	8.66	3.06	5.07	2.68	2.67	4.70
May	3.41	2.81	3.11	2.33	1.80	3.91	1.07	4.69	1.98
June	5.94	3.74	2.25	2.16	2.79	1.96	3.10	2.98	2.93
July	5.30	7.17	3.24	2.41	5.68	5.52	3.55	3.94	3.70
August	6.89	7.35	6.73	3.38	6.05	1.90	2.72	5.79	8.65
September	1.96	3.31	2.45	5.89	2.24	4.31	1.27	1.93	1.97
October	5.16	2.29	3.37	1.44	4.07	1.07	8.35	1.84	1.00
November	3.93	4.09	3.48	2.54	5.26	4.40	5.57	4.28	1.74
December	1.69	2.45	2.61	2.84	2.31	3.52	0.57	6.10	4.15
Totals	43.72	42.31	39.27	41.47	44.43	45.67	41.12	46.91	40.07

TABLE NO. 8A—*Continued.*

Month.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.
January	1.71	5.59	4.28	2.91	4.93	3.18	4.70	4.94	5.12
February	1.66	4.20	3.74	4.38	5.71	4.09	7.16	5.80	3.16
March	4.65	6.67	2.80	1.31	4.40	1.02	3.29	4.35	5.78
April	2.54	1.44	1.64	2.05	2.58	2.47	4.11	3.39	3.07
May	0.91	2.34	3.38	3.77	3.18	2.40	4.17	0.27	4.60
June	1.09	4.90	2.63	3.37	4.91	1.72	3.63	6.82	2.21
July	7.15	0.87	2.48	2.14	4.14	2.14	6.38	4.75	1.99
August	6.28	1.12	1.72	2.16	5.01	6.27	2.05	4.77	5.61
September	2.71	1.44	11.46	3.13	0.28	0.87	1.78	2.74	7.17
October	3.09	2.02	2.20	6.27	2.75	5.75	3.95	3.13	4.23
November	2.62	2.59	1.02	1.58	3.04	6.03	3.57	2.48	4.40
December	4.78	2.35	2.05	3.88	5.88	3.15	3.85	3.63	3.14
Totals	39.19	35.53	39.40	36.95	46.81	39.09	48.64	47.07	50.48

Month.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.
January	6.15	2.41	5.74	4.84	2.74	3.10	5.48	1.25	3.43
February	2.19	3.01	4.98	1.82	6.62	4.25	0.91	6.64	2.57
March	2.63	6.12	3.83	3.93	4.89	1.87	2.94	4.57	3.29
April	4.64	3.14	2.92	2.52	4.69	2.81	3.50	1.09	3.18
May	3.31	3.61	2.20	4.53	5.23	4.79	2.55	2.77	5.22
June	3.13	3.71	1.39	2.48	1.10	1.15	2.04	5.06	2.99
July	7.87	5.30	5.99	3.40	1.62	1.66	4.74	3.83	13.22
August	4.00	4.48	4.31	4.20	6.55	1.62	4.14	2.89	3.37
September	7.65	6.19	3.03	2.29	2.17	5.96	1.71	3.87	1.58
October	3.60	8.36	5.29	0.78	4.69	7.61	3.53	2.75	1.46
November	8.70	0.87	2.15	7.93	3.07	5.06	4.44	3.49	5.05
December	1.79	4.99	3.78	1.60	3.44	4.42	2.35	1.58	5.59
Totals	55.66	52.19	45.61	40.32	46.81	44.30	38.33	39.79	50.95

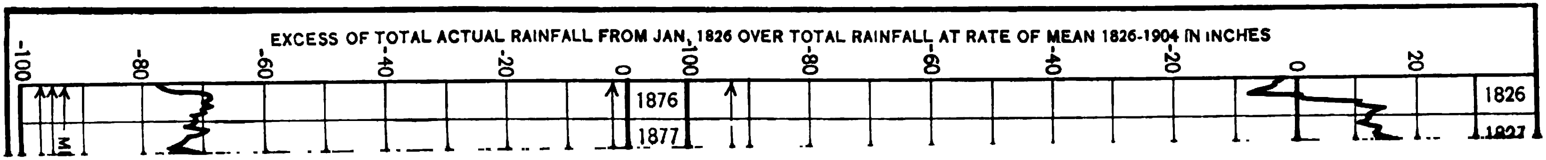
TABLE No. 8A—*Continued.*

Month.	1898.	1899.	1900.	1901.	1902.	1903.	Mean.
January	4.60	4.35	4.79	2.12	2.04	3.86	3.29
February	4.22	4.92	6.12	0.68	5.20	4.65	3 21
March	3.87	7.67	4.14	6.21	5.38	6.11	3.52
April	4.66	1.74	1.76	7.92	3.45	3.78	3.35
May	9.07	2.00	4.61	7.12	1.03	0.44	3.64
June	0.78	2.27	1.62	0.86	5.68	8.30	3.35
July	6.78	4.63	4.77	5.04	2.67	2.79	3.99
August	5.49	2.79	4.88	5.01	2.33	....	4.12
September	2.03	5.34	2.36	3.44	5.88	....	3.40
October	6.83	2.85	3.14	2.31	7.82	....	3.62
November	6.83	2.30	4.57	1.57	1.84	....	3.69
December	2.73	2.24	2.44	8.34	7.17	....	3.38
Totals	57.89	43.10	45.19	50.62	50.49	...	42.56

The few records that were made during these periods have necessarily been assumed, in all cases, to give the average rainfall over the whole territory that was being investigated. It is evident from a comparison of the recent rainfall measurements from the New York, Hempstead, Setauket, New Haven, New London and Block Island stations, from 1879 to 1903 (Table No. 7), that this assumption does not lead to any considerable error. There was very little difference in the rainfall at New York City and at Hempstead and between these and Block Island. Setauket Station, which is in the hills, shows a slightly greater precipitation than Hempstead.

While it was found, in the study of these recent rainfall stations, that during some months the precipitation at one station differed so much from another only ten to twenty miles away as to lead one to suspect an error in the observations, the averages for the twenty-five years from 1879 to 1903 at the above stations show a fairly uniform distribution of rainfall over Long Island and the adjacent shores of New York, Connecticut and Rhode Island. That great differences may occur in the amount of rainfall at two stations but a few miles apart, in a single storm, is well brought out by the heavy storm of October 8 and 9, 1903, during which 11.67 inches fell, in thirty hours, at Central Park; only 5.47 inches was measured at Floral Park during the same time; only 1.50 at Brentwood, and no rain at all occurred at the United States Weather Bureau Station on Block Island.

This storm was an unusual one; still it shows that in comparing the results from several stations it is not always safe to discredit the record from any one station because it differs from that of another station by eight to ten


EXCESS OF TOTAL ACTUAL RAINFALL FROM JAN, 1826 OVER TOTAL RAINFALL AT RATE OF MEAN 1826-1904 IN INCHES
-100
-80
-60
-40
-20
0
1876
1877
-100
-80
-60
-40
-20
0
20
1826
1827
M

inches, unless it is clearly proven from a number of other stations that one is in error.

(3) *Results of Computations—Mean Annual Rainfall,* 1826 *to* 1903—The computations of mean rainfall are shown in Table 8 and the results summarized in Table No. 8A. The mean annual precipitation (rain and melted snow) from 1826 to 1903 was found to be 42.56 inches. This is something like 5 or 6 inches less than the average annual precipitation on the highlands of Connecticut and New York. The reason for this low rainfall on Long Island seems to be that the hills of Long Island are too low to intercept the moisture-laden winds from the sea. As stated in the "Report of the New York State Weather Service, 1894," "Sea winds from the southeast find no obstruction on the immediate coast of New York, but, passing inland, meet the abrupt hill ranges of the southeastern counties and probably give to each a copious rainfall compared to that of intervening valleys."

The Long Island records indicate a general increase in the rainfall since 1832 or 1833; this increase, however, has not been uniform, but three distinct periods may be recognized during each of which the precipitation was fairly constant, as follows:

1832 to 1849, inclusive: 17 years........................	37.39 inches.
1850 to 1885, inclusive: 36 years........................	43.35 inches.
1886 to 1903, inclusive: 18 years........................	44.92 inches.

These periods of high and low rainfall are best seen in the residual mass curve* in Plate II. The greatest deficiency between 1826 and 1903 is seen to have occurred in 1885. The maximum rates of depletion of the accumulated rainfall took place from 1834 to 1839 and from 1847 to 1850; the maximum rates of accumulation in the years from 1888 to 1891 and from 1898 to 1900.

* Since the height of the water table—on which depends the rate of delivery of the ground water on Long Island—represents the cumulative effect of the rainfall for many years, it was appreciated that the ordinary method of considering the minimum delivery of a watershed, to depend upon the rainfall during the dryest season or during the dryest year, would not necessarily give the lowest yield; for, if the season or year of drought followed a period of heavy rainfall, the water table, having been raised during the rainy years, would still deliver, during the period of drought, a large amount of water that had fallen during the previous years. Consequently the residual mass curves were worked up, and are shown in Plates II., IV., VI., IX. and in Fig. 45. The ordinate of any point on these curves represents the excess of the total actual rainfall from the beginning of the period, considered, to the given time over the total that would have fallen during the same period had the precipitation occurred at a rate equal to the mean rainfall from the beginning to the end of the whole period that is considered. On Plate II., for example, the excess in January, 1860, represents the difference between the total rainfall from January, 1826, to January, 1860, and the total that would have fallen if the rate during that time had been equal to the mean rate from January, 1826, to October, 1903. The general agreement between these mass curves and the fluctuations in the elevations of the ground water justify their computations.

The comparison in Fig. 2 of this plate of the mass curve of mean rainfall on Long Island with the mass curve from the independent rainfall record at Newark, N. J., is of interest, for, although the latter is a shorter record, the curve agrees substantially with that of the mean of the Long Island records. The Philadelphia mass curve, for the same period as that of the Long Island record, shows how greatly the distribution of the rainfall may differ at two places only 100 miles apart.

An increase in the annual rainfall on Long Island has certainly occurred since the first observations and it is possible that the present high rate of precipitation may continue for several years, but it is more probable that a period of low rainfall quite as severe as that from 1832 to 1850 may recur during the next twenty years.

Minimum Rainfall—To determine the period and the amount of maximum depletion of the ground water resources—the purpose of these rainfall studies—not the dryest season, nor the dryest year, should be chosen, but the dryest series of years. Five years is probably required to draw the ground water table to its lowest elevation. The lowest five-year period between 1832 and 1850 was that from 1835 to 1839, inclusive, when the average rainfall was only 35.20 inches. As a similarperiod is likely to recur, it is not safe to consider a precipitation of more than 35 inches in estimating the minimum yield of the ground water resources.

II.—EVAPORATION.

A portion of the water that falls to the earth as rain and snow is returned to the atmosphere through evaporation from the surfaces of water and the soil grains and through the transpiration and the other life processes of vegetation.

Evaporation from the soil may be considered to be continuous; the amount, however, during the year, ranges from a comparatively small quantity during the cold winter months to a large proportion of the rainfall in the early summer when the surface of the ground is moist. During periods of drought in the summer and early fall, when the surface of the soil has been well dried out, the loss of water from the earth would be small but for the existence of vegetation.

All plant life requires greater or less amounts of water and, during the growing season, in this climate from May to September, a large proportion of the rainfall is taken up by the plants and returned to the air.

(*A*) *Evaporation from the Soil.*

The rate of evaporation from the soil depends upon (1) the amount of precipitation and the moisture in the surface soil; (2) the temperature of the air and the soil and the force of the wind; (3) the texture of the soil and substrata; (4) the proximity of the surface of saturation to the surface of the ground; and (5) the slope and the smoothness of the ground.

(1) The precipitation is the most important factor, for the amount of moisture in the soil to be evaporated depends upon the amount and the frequency of the rainfall. If the precipitation occurs when the surface of the ground is dry a larger amount is evaporated than when the surface is moist. Under the latter condition the rainfall more quickly passes to the substrata.

(2) The amount of evaporation from the surface of the ground depends, to a great extent, upon the temperature of the air and the temperature of the surface of the soil. The proportion of rainfall that is evaporated is a maximum in July and August when the temperature of the air and of the surface of the ground are the highest, and is a minimum in January and February, the months of lowest temperature. It is a well-known fact that a brisk wind is very effective in drying a soil, and evaporation experiments made by this Commission indicated a large rate of evaporation when the velocity of the wind was high; but so many other factors influenced the observed evaporation from soil that no relation could be determined.

(3) The rate of absorption of the soil and the ability to retain the rainfall that is absorbed depends upon the texture of the soils; a coarse, sandy soil and substrata will allow the rainfall to quickly pass below the reach of capillarity, and, furthermore, in a coarse, sandy soil and substrata, the amount of water that capillarity will raise to the surface will be less than in a fine-grained soil and subsoil.

(4) If the water table is near the surface of the ground, large amounts of water will be drawn to the surface by capillarity and evaporated; if, however, the depth of soil above the ground water is 8 feet or more, in a fine soil, or 3 or 4 feet in a coarse sand, or gravel, the water that reaches the surface of saturation will not return.

(5) A steep slope will give a larger surface run-off and less evaporation than a level area or a moderate slope, and a rough surface will, on the other hand, lessen the surface run-off and increase the amount of evaporation and percolation.

(a) Experiments on Evaporation from Soil.

(1) *English Experiments*—The most complete as well as the best series of observations on the evaporation from the surface of soil are those made by Gilbert and Laws, at Rothamsted, England, from 1870 to 1890. These experiments were made in cast-iron boxes, 43.56 square feet or 0.001 acre in area and 5 feet deep, filled with a somewhat heavy soil, the percolation through which was collected and measured. The results of these experiments are shown in Table No. 9, in which the total evaporation for each month is considered to be the difference between the total rainfall and the total measured percolation.

Table No. 9.

Experiments on Soil Evaporation and Percolation, by Gilbert and Laws, Rothamsted, England.

From "Proc. Inst. C. E." Vol. cv., p. 36.

Month.	Average Monthly Rainfall 1870–'90, Inches Depth.	Evaporation.			Percolation at Depth of 60 Inches.		
		Average Monthly Evaporation, Inches Depth.	Per Cent of Total Evaporation each Month.	Per Cent. Rainfall in each Month.	Average Monthly Percolation, Inches Depth.	Per Cent. of Total Yearly Percolation in each Month.	Per Cent. of Rainfall in each Month.
January	2.51	0.45	2.7	17.9	2.06	15.2	82.1
February	2.04	0.60	3.6	29.4	1.44	10.4	70.6
March	1.74	0.88	5.3	50.6	0.86	6.3	49.4
April	2.21	1.53	9.2	69.2	0.68	5.0	30.8
May	2.28	1.69	10.1	74.2	0.59	4.3	25.9
June	2.52	1.92	11.5	76.2	0.60	4.4	23.8
July	3.03	2.26	13.6	74.6	0.77	5.7	25.4
August	2.45	1.95	11.6	79.6	0.50	3.7	20.4
September	2.86	2.11	12.6	73.8	0.75	5.5	26.2
October	3.20	1.70	10.2	53.2	1.50	11.1	46.9
November	3.03	0.98	5.9	32.3	2.05	15.1	67.7
December	2.42	0.61	3.7	25.2	1.81	13.3	74.8
Total	30.29	16.68	100	55.1	13.61	100	44.9

These results are hardly applicable to conditions in this country and, like all of the experiments that have been made with tanks, the sum of the evaporation and percolation was equal to the rainfall, because the tank confined all the rain that fell and the proportion of the rainfall which, under natural conditions, should have run off on the surface appeared in the results as evaporation and percolation.

Other experiments have been made in England at Bolton Le Moors and at Whitehaven, which are shown in Tables Nos. 10 and 11.

(2) *Massachusetts Experiments*—Experiments on evaporation and percolation through soil were made in 1878 by Prof. Levi Stockbridge at the Massachusetts Agricultural Experiment Station. They were carried on only from May to November, inclusive, and consequently have not the same value as the long series of observations of Gilbert and Laws.

The measurements were apparently taken with considerable care and are of value in showing how little percolation may take place in the warm summer months unless a hard, soaking rain occurs.

Table No. 10.

Mean Evaporation from Earth, at Bolton Le Moors, Lancashire, England, 1844 to 1853, inclusive.

From "Geological Survey of New Jersey, 1894."

Month.	Mean Monthly Rainfall 1844-1853, Inches Depth.	Mean Monthly Evaporation 1844-1853, Inches Depth.	Per Cent. of Mean Annual Evaporation in each Month.
January	4.63	0.64	2.50
February	4.03	0.95	3.70
March	2.25	1.59	6.20
April	2.22	2.59	10.10
May	2.23	4.38	17.08
June	4.07	3.84	14.97
July	4.32	4.02	15.67
August	4.77	3.06	11.93
September	3.79	2.02	7.87
October	5.07	1.28	4.99
November	4.64	0.81	3.16
December	3.94	0.47	1.83
Total	45.96	25.65	100

Table No. 11.

Mean Evaporation from Earth, at Whitehaven, Cumberland, England, 1844 to 1853, inclusive.

Month.	Mean Monthly Rainfall 1844-1853, Inches Depth.	Mean Monthly Evaporation 1844-1853, Inches Depth.	Per Cent. of Mean Annual Evaporation in each Month, 1844-1853.
January	5.1	0.95	3.25
February	3.4	1.01	3.46
March	2.5	1.77	6.06
April	2.2	2.71	9.28
May	1.9	4.11	14.07
June	3.1	4.25	14.56
July	4.3	4.13	14.13
August	4.3	3.29	11.27
September	3.1	2.96	10.13
October	5.3	1.76	6.02
November	4.5	1.25	4.28
December	3.8	1.02	3.49
Total	43.5	29.21	100

The tank was of 2-inch chestnut, lined with copper, 3 feet deep and 12,677 square feet in area, and was filled with a "chocolate-colored sandy loam with many pebbles and small round stones" for the first 10 inches down; with "light yellow gravelly loam" for the next 14 inches; and with "smooth, round stones, from pebbles to 6-inch stones, filled in with sand and gravel," for the last 14 inches. The tank was inclined one inch to lead the water to the percolating tubes which carried it to glass jars. The upper 6 inches of the soil in the tank were turned over repeatedly, but no crop was grown.

(*b*) *Laws of Evaporation from Soil.*

Provided that the amount of moisture in the surface of a soil is always in excess of the evaporation, as on a water surface, there is no reason why the evaporation should not follow the laws that govern evaporation from a water surface, which have been determined by the experiments of Fitzgerald at Chestnut Hill Reservoir, Boston. These showed evaporation from a water surface to be proportional to the difference between the vapor pressure of the water at the temperature of the water and at the temperature of the air, and also to the velocity of the wind. Unless, however, the surface of the soil is within a few inches of the ground water, the moisture in the surface will not be a constant quantity and will vary from a condition of complete saturation to one almost dry.

It would be impossible, then, to secure an expression similar to that obtained by Fitzgerald, without including the factor of saturation of the surface which can only be determined by actual observation each day.

No experiments on a small scale will give more than an approximation of the truth regarding the amount of evaporation from large land surfaces, and such observations as exist on ground water and stream flow, which include all conditions of surface soil and the quantity of water required by the plants, must be depended upon for the true value of evaporation.

(*B*) *Transpiration.*

The amount of water that vegetation draws from the earth and delivers to the atmosphere during the growing season from May to August is a large part of the loss to the atmosphere that is considered as evaporation, for the roots of plants and trees reach down into the subsoil for the water that they require and draw up more moisture than the capillary force in the pore spaces of the soil is able to raise.

(1) *Crops*—Prof. King brought out this fact clearly by a series of observations upon the elevation of the ground water under a piece of ground divided into strips, of which alternate divisions were planted with corn, the others being fallow, and all weeds removed. Very decided depressions of the water table were observed under the corn. These depressions reached a maximum in August, when, as the corn matured, the demand for water was the greatest. In order to prove that these depressions were not due to inequalities in the drainage, the experiment was repeated the next year with corn planted on the strips that had the year before been fallow. The same depression was observed under the corn under those conditions, and in both years the inequalities quite disappeared about twenty days after the corn was cut. The water was from 5 to 8½ feet below the surface, and Prof. King concluded that corn is able to draw water from depths exceeding 7 feet.

The amount of water required by vegetation has been estimated by many experimenters. The best known estimates are, perhaps, those of Risler, in Germany, which are as follows:

TABLE NO. 13.

Crop.	Consumption of Water in inches per day.
Meadow Grass	0.134 to 0.267
Oats	0.140 to 0.193
Indian Corn	0.110 to 0.157
Clover	0.140 to ....
Vineyard	0.035 to 0.031
Wheat	0.106 to 0.110
Rye	0.091 to ....
Potatoes	0.038 to 0.055
Oak Trees	0.038 to 0.035
Fir Trees	0.020 to 0.043

This indicates that anywhere from 10 to 30 inches of rainfall, each season, will be absorbed by vegetation and even greater quantities when supplied.

The experiments of Prof. King at Madison, Wisconsin, on the amounts of water required to produce a pound of dry matter show that when an ample supply of water is furnished some crops will absorb as much as 25 inches of water during the growing season. An abundant supply of water is not, however, always present under field conditions and, on an average, cultivated areas probably dissipate 12 to 15 inches of water between May and September.

(2) *Woodland*—Not more than 25 per cent. of Long Island is under cultivation, while fully 40 per cent. is wooded, so that it is important to know

the relation between the water dissipated from a forest surface by transpiration together with the evaporation from the surface of the ground in the forest and the amount of evaporation from a bare soil or water surface.

The amount of water that is transpired by leaf surfaces has been estimated by Unger to be 33 per cent. of the evaporation from an equivalent water surface (or perhaps 30 per cent. of the rainfall); Sachs found 36 per cent. of evaporation from equivalent water surface for white poplar and 42 per cent. for sunflower.

On page 78, "Bulletin No. 7, United States Department of Agriculture," Mr. M. W. Harrington has collected a number of experiments on transpiration from forests abroad, which fix the amount of transpiration from forests in Central Europe at about one-quarter of the rainfall, or about 6 inches.

In addition to this transpiration there is still to be considered the evaporation of the rainfall in the trees and that from the ground within the forest.

The results of Dr. Ebermayer and others indicate that the annual evaporation from a forest, from May to September, is 75 per cent. of the rainfall, which would correspond, on Long Island, to about 14 inches.

TABLE NO. 14.

"Review of Forest 'Meteorological Observations', A Study Preliminary to the Discussion of the Relation of Forests to Climate," Harrington.

Observer.	Plant.	Transpiration Expressed as Rainfall Equivalent in Inches. Daily.	Annual.	Authority.
Hales	Sunflower	.13	15.2	Ebermayer.
"	Cabbage	.12	14.4	"
"	Grapevine	.03	4.	"
"	Hop	.05	5.6	"
Schleiden	Clover and oats	.11	13.6	"
Vogel	4-year beeches	.003	0.43	"
"	4-year firs	.002	0.28	"
"	Wheat field	.62	4.4	"
"	Barley field	.56	3.9	"
Hartig	24-year mixed forest	.021	3.8	"
Pfaff	Oak	.21	193.2(?)	Austrian Met. Journal.
Höhnel	115-year beeches	.05	9.2	Sachs.
Schubler	Low spear grass	.08	14.	Duchartre.
Haberlandt	Barley	.07	4.9	"
"	Oats	.13	9.1	"

From the experiments of Dr. Ebermayer and those of Schubler, Harrington has deduced the following values (Table 15) for the evaporation from different surfaces compared to the evaporation from a water surface and the precipitation during the warm season (May to September).

TABLE No. 15.

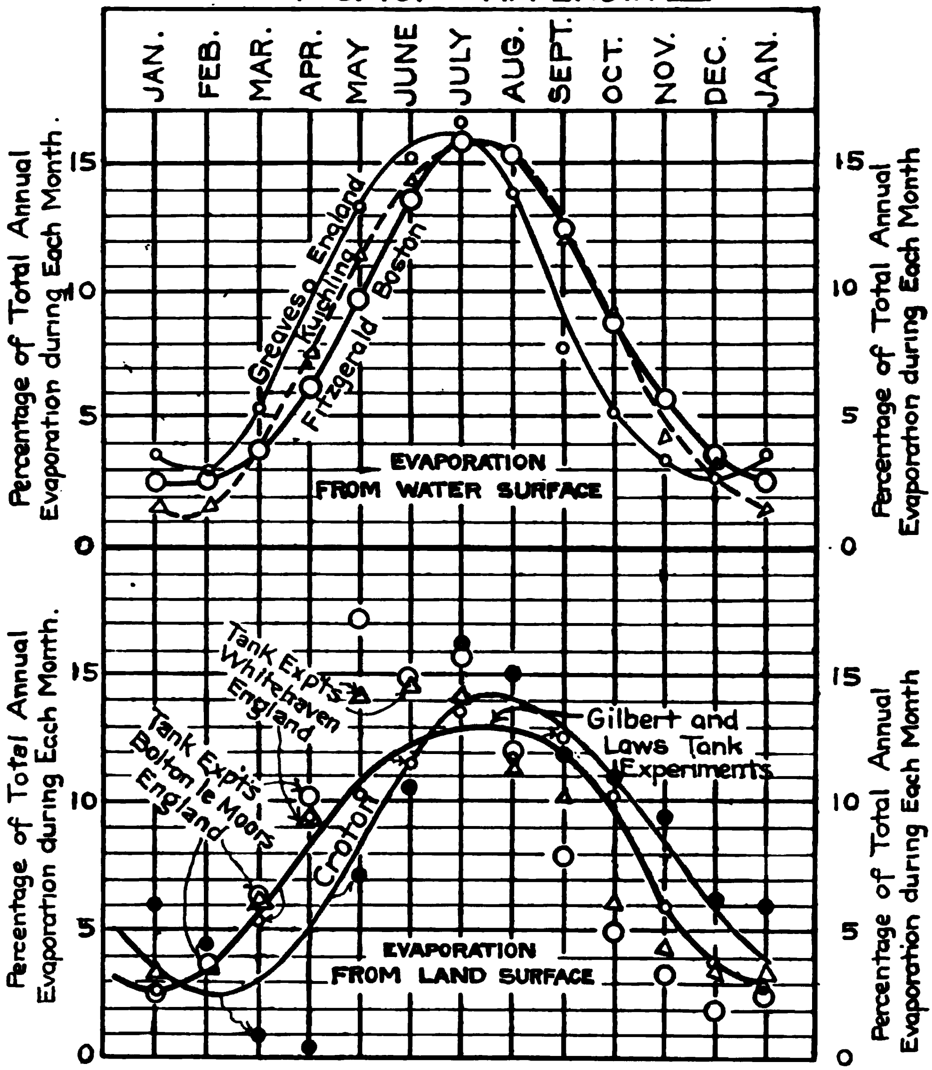
Evaporation from Various Kinds of Vegetation.

Review of Forest 'Meteorological Observations', A Study Preliminary to the Discussion of the Relation of Forests to Climate," Harrington.

	Proportion of	
	Evaporation from Free Water Surface.	Precipitation.
Sod	1.92	.96
Cereals	1.73	.86
Forest	1.51	.75
Mixed, etc.	1.44	.72
Bare soil	.60	.30

This shows that practically all the rainfall is evaporated from a surface of sod and from growing green crops, 75 per cent. from forests and only 30 per cent. from bare soil.

FIG. 40. APPENDIX VII



SEASONAL DISTRIBUTION OF EVAPORATION FROM WATER AND LAND SURFACES.

(*C*) *Seasonal Distribution of Evaporation from the Soil and Vegetation.*

(*a*) *Effect of Temperature, Demands of Plants and Relative Humidity.*

In Fig. 40 the proportion of the total annual evaporation that occurs in each month has been plotted from the evaporation experiments and stream flow; in addition, Fitzgerald's curve of mean monthly evaporation from a water surface and the curve of mean monthly air temperature have been added. Naturally the English experiments do not agree with the curves of evaporation computed from our American streams, because of the difference in the seasons, but the similarity of the curves of evaporation clearly indicate that the monthly evaporation from soil is roughly proportional, like that from a water surface, to the mean monthly temperature of the air.

The tank experiments and the run-off curves show that only 2 to 3 per cent. of the total annual evaporation took place during the winter months of December, January and February, and but little more in November and March. The maximum monthly evaporation, between 10 and 15 per cent. of the whole for each month, occurred in the months of May, June, July, August and September. The Rothamsted experiments, which are the best, show a high evaporation in October and the other two series, which are less reliable, agree on a high rate of evaporation for May.

That a greater proportion of the evaporation should occur in the summer is very natural, for evaporation is due to molecular activity at a water surface, and this activity depends upon the amount of heat energy that exists, which is, of course, measured by the temperature of the air and of the surface soil. The soil temperature follows closely that of the air; this was brought out by a good series of soil temperature observations made at Albany from May, 1847, to December, 1848 (Natural History of New York, 1848), which are shown in Fig. 40A, together with the mean monthly air temperature in New York City for thirty years.

The relative humidity of the air is dependent upon the amount of rainfall and the temperature of the air and may be neglected in considering the annual variation in the amount of evaporation.

(*D*) *Estimates of Evaporation and Transpiration on Long Island.*

An estimate of the evaporation from the surface of Long Island may be made from the evaporation experiments at Floral Park, from the observations on the fluctuations of the surface of the ground water and from the estimates of evaporation made from long term stream flows. In considering the

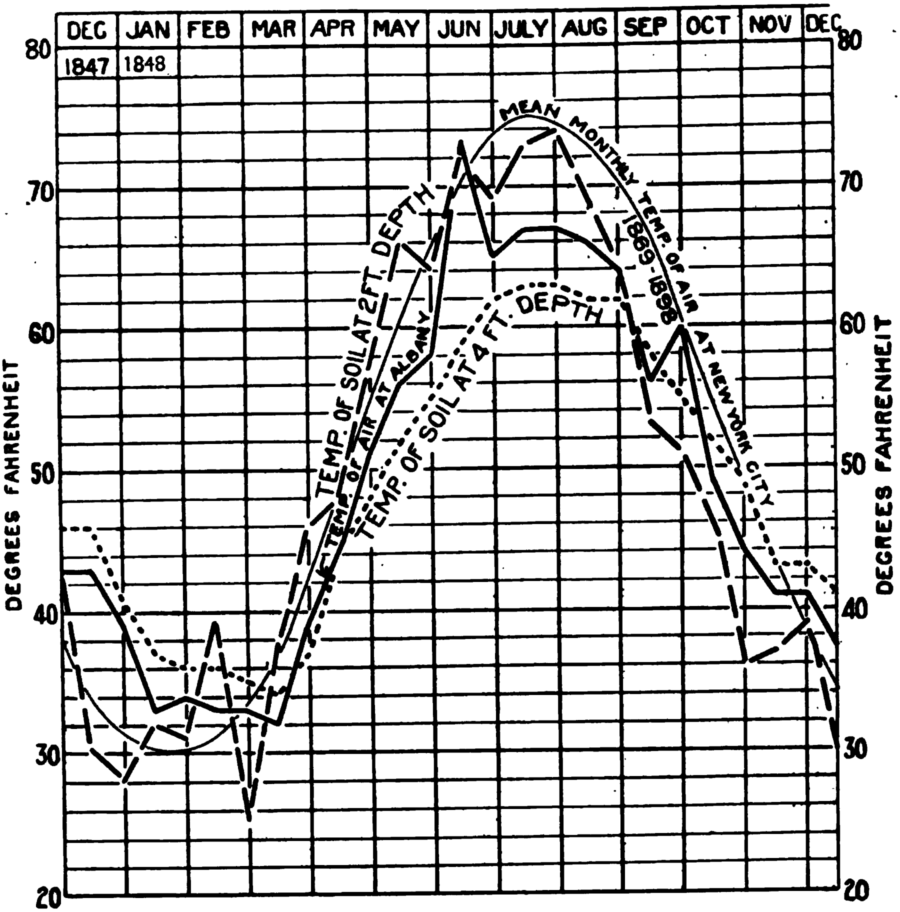


FIG. 40A. APP. VII.

SEMI-MONTHLY OBSERVATIONS ON THE MEAN TEMPERATURE OF THE SOIL AT ALBANY NEW YORK IN 1848.

amount of rainfall that is lost by the earth to the atmosphere, the amount of water that is taken up by plants is usually included under the general term, evaporation.

TABLE No. 16.

Evaporation from Soil Two Feet Above Surface of Saturation in Tank Ten Inches in Diameter, at Floral Park Meteorological Station.

Date, July, 1903.	Number of Hours of Sunshine during this Day.	Mean Velocity of Wind. — Miles per Hour.	Mean Temperature in Degrees Fahrenheit in Shelter 10 Feet above Ground.	Mean Relative Humidity in Shelter 10 Feet above Ground from Hydrograph. — Per cent. of Saturation.	Evaporation from Surface of Soil in Tank in Inches Depth of Water per 24 Hours.	Rainfall in Inches Depth on Surface of Soil from Recording Gauge.	Mean Distance from Surface of Soil to Water in Tank.
1	11.1	7.1	78.6	82.1	0.24	.0	1.830
2	7.8	5.6	76.2	82.6	0.19	1.10	1.842
3	12.3	5.6	74.9	72.0	0.17	0.08	1.790
4	6.9	4.2	69.8	72.3	0.19	0	1.798
5	7.6	10.3	66.6	82.7	0.15	0	1.828
6	8.8	6.0	71.4	85.0	0.22	0.11	1.875
7	15.0	5.4	74.8	68.7	0.12	0	1.901
8	12.4	4.1	77.3	71.3	0.09	0	1.936
9	15.0	5.0	81.1	72.3	0.09	0	1.970
10	10.9	1.0	82.6	73.8	0.06	0	1.988
11	5.2	....	77.8	80.1	0.11	0.27	2.020
12	8.1	2.3	73.8	87.8	0.13	0.08	2.018
13	0	1.7	68.6	91.6	0.08	0.02	2.025
14	7.2	4.3	67.1	80.3	0.16	0.01	2.010
15	6.1	8.1	63.0	68.5	0.20	0	2.028
16	6.0	1.6	65.6	70.4	0.22	0	2.012
17	10.0	1.3	68.2	74.1	0.11	0	2.049
18	0	2.4	63.8	97.7	-0.14	1.00	2.028
19	4.8	2.1	67.1	85.4	0.14	0	1.856
20	6.5	3.6	68.4	92.6	0.19	0	1.785
21	11.2	4.0	65.9	82.6	0.16	0.02	1.903
22	2.7	8.2	69.9	90.6	0.07	0.23	1.852
23	10.4	5.0	71.2	80.2	0.19	0.01	1.961
24	14.6	6.1	72.6	72.2	0.19	0	1.885
25	14.6	5.1	70.7	70.7	0.15	0	1.924
26	16.2	5.3	77.1	71.5	0.14	0	2.066
27	14.5	6.9	62.6	55.5	0.17	0	2.007
28	12.0	4.5	63.9	75.5	0.08	0	2.040
29	1.3	12.0	71.1	93.5	0.11	0.03	1.948
30	9.2	8.5	76.4	87.5	0.04	0.40	1.976
31	3.1	5.5	67.7	80.5	0.16	0	1.957
Sums	280.3	....	....	....	4.18	3.46	....
Means	9.0	4.9	71.1	78.1	0.135	....	1.939

Aug., 1903.							
1	12.8	4.3	64.6	74.0	0.13	0	1.957
2	11.9	3.1	65.1	77.3	0.10	0	1.977
3	10.4	3.4	67.3	79.0	0.11	0	1.915
4	6.2	9.7	66.9	89.9	0.11	2.51	1.922
5	2.9	10.9	63.5	95.9	0.04	0.50	1.403
6	5.6	3.3	66.2	76.3	0.06	0.45	1.322
7	10.2	3.1	67.4	76.3	0.23	0.11	1.068
8	11.3	3.5	59.8	71.6	0.15	0	1.172

TABLE NO. 16—*Continued.*

Date, July, 1903.	Number of Hours of Sunshine during this Day.	Mean Velocity of Wind. — Miles per Hour.	Mean Temperature in Degrees Fahrenheit in Shelter 10 Feet above Ground.	Mean Relative Humidity in Shelter 10 Feet above Ground from Hydrograph. — Per Cent. of Saturation.	Evaporation from Surface of Soil in Tank in Inches. Depth of Water per 24 Hours.	Rainfall in Inches Depth on Surface of Soil from Recording Gauge.	Mean Distance from Surface of Soil to Water in Tank.
9	10.0	3.1	64.8	93.7	0.04	0.10	1.197
10	12.1	2.5	68.4	78.7	0.15	0	1.211
11	12.2	4.4	67.9	98.0	0.04	0.01	1.259
12	6.2	5.1	71.7	71.5	0.21	0	1.233
13	12.8	4.3	63.6	73.6	0.15	0	1.344
14	11.5	3.0	63.9	89.7	0.06	0.04	1.399
15	8.7	3.2	63.9	81.5	0.11	0	1.433
16	7.7	1.3	64.1	90.3	0.06	0	1.498
17	11.6	4.5	67.4	82.0	0.12	0	1.518
18	11.8	6.1	68.9	81.6	0.17	0	1.560
19	10.6	5.1	69.9	91.1	0.13	0.01	1.611
20	9.5	5.2	70.2	90.5	0.02	0.05	1.616
21	12.6	5.1	67.4	72.0	0.22	0	1.648
22	11.5	8.5	72.5	79.5	0.15	0.02	1.653
23	10.8	3.1	75.9	79.9	0.06	0	1.688
24	9.4	2.7	69.1	80.0	0.14	0.02	1.710
25	9.2	5.2	71.2	94.9	0.03	0.29	1.731
26	0.0	4.7	68.6	96.5	0.06	0	1.623
27	6.8	2.0	66.4	93.6	−0.02	0.02	1.657
28	0	10.7	59.6	98.9	0.17	1.32	1.423
29	2.9	9.3	57.0	99.0	−0.05	0.60	0.962
30	8.9	11.6	60.5	98.2	0.04	0.02	1.447
31	9.3	4.8	59.7	92.4	0.06	0	1.630
Sums	286.4	....	....	....	3.05	6.07	....
Means	9.2	5.1	66.2	85.4	0.098	....	1.509
Sept., 1903.							
1	4	2.4	64.3	92.2	0.17	0	1.617
2	6	1.5	64.3	93.7	0.08	0	1.685
3	8	7.7	66.5	90.5	0.16	0.01	1.684
4	7	4.6	63.8	95.9	0.11	0	1.720
5	10	5.2	68.6	92.7	−0.02	0.35	1.748
6	11	8.3	61.0	66.1	0.16	0	1.601
7	10	3.8	61.0	73.9	0.22	0	1.670
8	0	5.4	59.9	81.4	0.12	0	1.740
9	0	4.2	62.6	79.1	0.14	0	1.777
10	4	5.5	68.3	91.5	0.08	0	1.785
11	11	5.0	72.5	80.9	0.06	0.02	1.780
12	12	2.5	65.6	78.7	0.14	0	....
13	12	1.9	68.7	92.0	0.11	0	....
14	12	6.1	68.9	94.4	0.14	0	....
15	8	6.2	68.4	87.4	0.11	0	....
16	0	11.2	71.3	94.3	−0.03	0.67	....
17	5	9.0	70.5	95.5	0.04	0.51	1.770
18	11	7.3	60.2	68.8	0.14	0	1.720
19	9	4.9	56.6	71.1	0.11	0	1.790
20	10	6.1	57.0	80.2	0.14	0	1.770

TABLE No. 16—*Continued.*

Date, July, 1903.	Number of Hours of Sunshine during this Day.	Mean Velocity of Wind. — Miles per hour.	Mean Temperature in Degrees Fahrenheit in Shelter 10 Feet above Ground.	Mean Relative Humidity in Shelter 10 Feet above Ground from Hydrograph. — Per Cent. of Saturation.	Evaporation from Surface of Soil in Tank in Inches. Depth of Water per 24 Hours.	Rainfall in Inches Depth on Surface of Soil from Recording Gauge.	Mean Distance from Surface of Soil to Water in Tank.
21............	12	5.8	59.5	66.7	0.13	0	1.790
22............	12	3.4	64.3	69.9	0.15	0	1.838
23............	12	3.1	64.8	75.6	0.15	0	1.890
24............	12	7.4	59.0	71.9	0.13	0	1.798
25............	12	4.0	52.4	69.5	0.10	0	1.670
26............	12	5.1	58.4	78.2	0.11	0	1.782
27............	3	4.1	64.5	92.2	0.04	0.63	....
28............	10	8.6	51.5	69.4	0.18	0	1.659
29............	10	5.8	49.5	65.3	0.16	0	1.689
30............	11	2.7	52.9	75.9	0.10	0	1.719
Sums.........	251	...	....	...	3.43	2.19	....
Means........	8.4	5.3	62.6	81.2	0.118	....	....
Oct., 1903.							
1............	10.1	8.2	61.0	80.5	0.16	0	1.777
2............	7.9	5.0	66.4	84.4	0.06	0.29	....
3............	10.0	8.7	59.0	78.3	0.16	0	1.784
4............	7.2	4.2	58.9	88.7	0.09	0	1.734
5............	7.1	3.7	63.3	92.8	0.07	0	1.744
6............	4.3	2.8	63.4	89.9	0.04	0.02	1.799
7............	0	7.6	62.2	98.8	0.08	0	....
8............	0	15.3	64.5	93.1	....	0.77	....
9............	3.0	13.7	60.9	93.8	....	4.70 (9 and 10)	....
10............	0	16.8	55.2	85.2	....		....
11............	1.0	15.0	52.5	86.6	0.17	0.35	1.214
12............	11.1	9.0	53.9	81.2	0.15	0.05	1.044
13............	8.8	5.6	58.3	77.5	0.19	0	....
14............	3.2	3.4	56.5	75.0	−0.14	0	1.124
15............	6.0	3.2	53.1	80.1	−0.05	0	1.170
16............	5.1	3.5	56.1	90.9	−0.04	0	1.230
17............	8.1	5.1	59.4	93.9	−0.05	1.19	1.220
18............	7.8	11.7	50.6	70.0	+0.10	0	....
19............	7.7	5.9	50.2	70.1	0.13	0	1.190
20............	10.1	5.5	56.1	75.6	0.12	0	1.510
21............	9.2	4.4	52.0	74.4	0.11	0	1.480
22............	....	....	....	....	....	....	....
Sums.........	127.7	....	....	....	....	7.37	....
Means........	6.1	7.5	57.8	83.9	....	....	....

(*a*) *Evaporation Experiments at Floral Park,* 1903.

The Floral Park experiments have already been described on page 626; the results are shown in Table No. 16 and in Plate III., and give a total evaporation during the months of July, August, September and a portion of October of 11.85 inches, or 62 per cent. of the total rainfall during that period at Floral Park, of 19.09 inches. These months included periods of excessive rainfall, so that the results are not representative of normal summer conditions.

The Floral Park experiments do not furnish results that are applicable to the evaporation from large areas on Long Island, as the ground water in those experiments was too near the surface. The results showed that during the summer months in a year of average rainfall the evaporation from a ground water surface that is less than 2 feet below the surface of the soil will exceed the rainfall. In months of heavy precipitation a comparatively small amount of evaporation will take place and the percolation and run-off will be correspondingly large.

(b) Estimates of Evaporation from the Fluctuations of the Ground Water Surface.

The variations in the elevation of the surface of the ground water promised, at first, to give an idea of the amount of percolation and, by making an allowance for the surface run-off, a fair estimate of the evaporation. These percolation studies are discussed on page 584. Allowing from these studies 21 inches, or 50 per cent. of the mean rainfall, as the percolation and 7 inches, or 16 per cent. of the rainfall, for the surface flow of the streams, the evaporation is 14 inches, or 33 per cent. of rainfall. In dry years the decrease in the rate of capillary flow would allow a smaller quantity to reach the plane of saturation, so that the evaporation for a period of low rainfall is likely to be, on an average, as much as 38 per cent. of rainfall, or 16 inches depth per year.

(E) Evaporation as Determined from Stream Flow.

The method o festimating the evaporation, by taking the difference between the rainfall on the watershed of a stream and the run-off of the stream, is by far the most reliable one when the underflow at the point of measurement of the surface flow is negligible and the ground water storage on the stream is a small proportion of the total run-off.

Such conditions do not exist on the south shore of Long Island and the difference between the monthly rainfall and the monthly run-off ot the streams does not represent the evaporation, for both the underflow and the ground water storage are large; a large amount of the rainfall escapes to the sea through the coarse sands and gravels at great depths; and a large percentage of the summer flow of these streams is seepage from the ground water storage of previous rains.

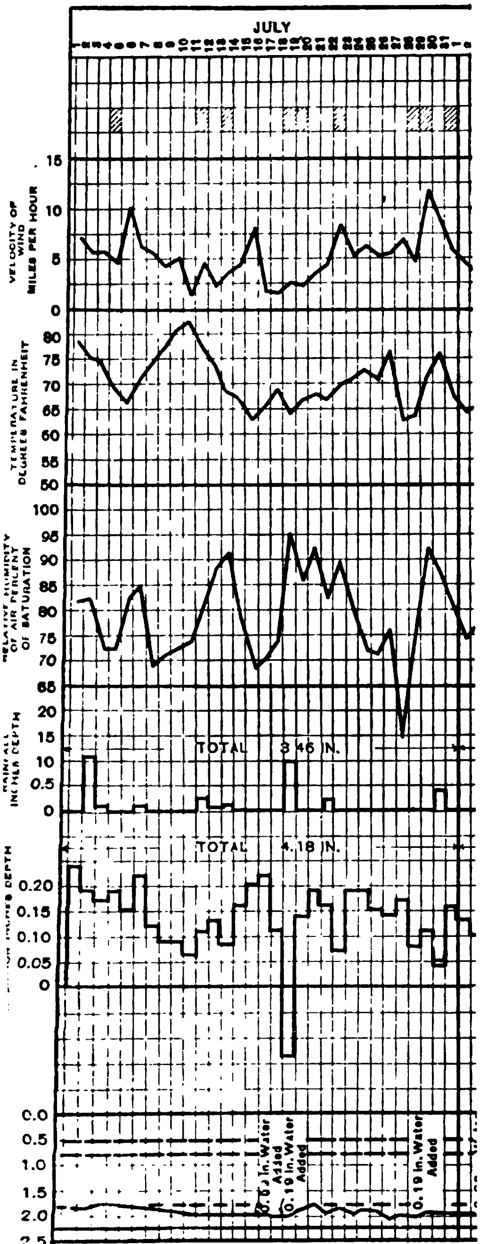
(*a*) *Run-off of the Croton and Sudbury Rivers.*

The long period gaugings of the Croton and Sudbury Rivers afford data, however, from which to estimate the evaporation from a large area under natural conditions and, by comparing these watersheds with those on Long Island, to make an approximate estimate of the Long Island evaporation.

TABLE No. 17.

Seasonal Distribution of Run-off and Evaporation on the Croton Watershed, 1868 to 1899.

		Average Rainfall, 32 Years.	Average Run-off, Depth Inches.	Corresponding Evaporation, Depth Inches.	Percentage of Total Evaporation during Given Months.	Percentage of Rainfall Evaporated
Winter	December	3.71	2.09	1.62	6.3	43.7
	January	4.20	2.66	1.54	6.0	36.7
	February	4.13	2.97	1.16	4.5	28.1
	Total	12.04	7.72	4.32	16.8	35.9
Spring	March	4.03	3.81	0.22	0.9	5.5
	April	3.18	3.04	0.14	0.5	4.4
	May	3.78	1.92	1.86	7.2	49.2
	Total	10.99	8.77	2 22	8.6	20.2
Summer	June	3.36	0.60	2.76	10.7	82.2
	July	4.87	0.64	4.23	16.4	86.9
	August	4.87	1.02	3.85	15.0	79.1
	Total	13.10	2.26	10.84	42.1	82.8
Autumn	September	4.02	0.92	3.10	12.1	77.2
	October	3.80	0.96	2.84	11.0	74.7
	November	4.12	1.70	2.42	9.4	58.8
	Total	11.94	3.58	8.36	32.5	70.0
	Total for year	48.07	22.33	25.74	100.0	53.5



DEPT

COMMIS

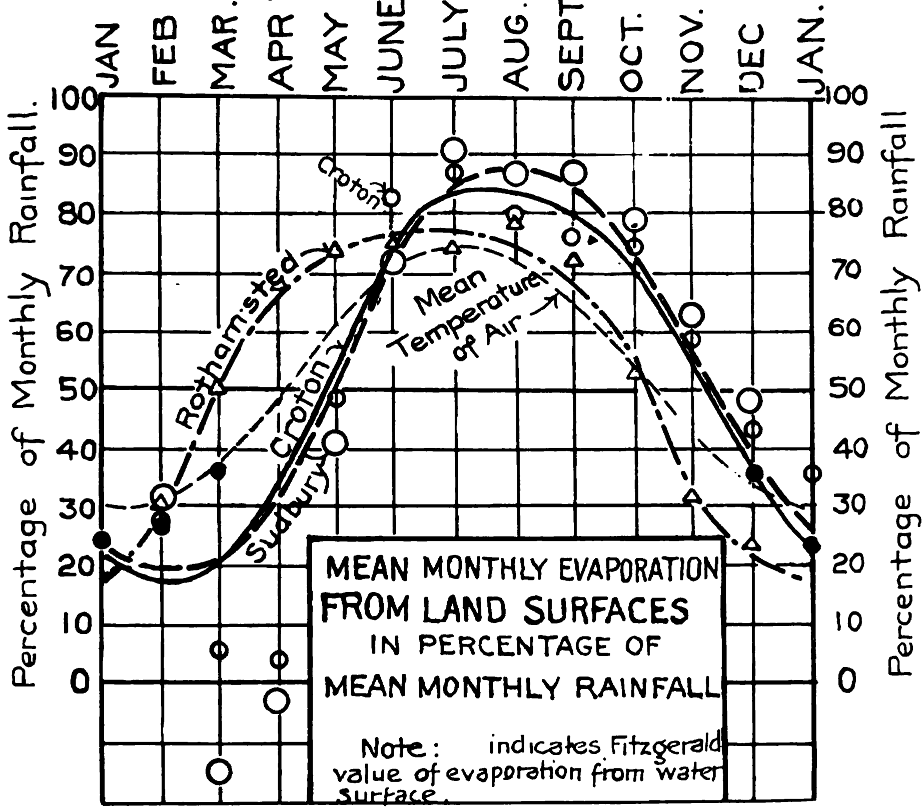
TANK

Note:

NOVEMBER 30, 1903

The average natural flows at the Old Croton Dam have been used for this estimate and are shown in Table No. 17. These flows were computed by Mr. John R. Freeman, and are given in his "Report on New York's Water Supply." From the mean monthly run-offs for thirty-two years the evaporation has been computed by subtracting these quantities in inches depth from the mean monthly rainfall for the same period. This method eliminates the negative evaporations and gives results that agree very well with the distributions determined from the tank experiments, when allowance is made for the small run-off during the months of snowfall and the large surface flows of the spring months. It is clear, however, that the evaporation from a large watershed well covered with vegetation must be greater in the summer than that from a bare soil in a tank. The Croton curves and the English experiments are not strictly comparable, yet it is, perhaps, significant that the percentage of evaporation

FIG. 41 APPENDIX VII



from the Croton run-offs exceeds that from the Rothamsted experiments. This difference would probably be greater but for the exaggeration of the evaporation in the tank experiments through suppression of the run-off factor and the reduction of the apparent evaporation from stream flow by the summer ground water flow in the streams. The average evaporations in percentage of monthly rainfall is shown in Fig. 41 for the Croton and Sudbury watersheds, together with similar quantities from the Rothamsted experiments.

The run-off of the Croton River for 32 years shows a mean annual evaporation of 25.74 inches, or 53.5 per cent., of mean annual rainfall of 48.07 inches, during that period. During a succession of years of low rainfall the evaporation was about 60 per cent. of the rainfall.

The Sudbury River run-off for twenty-eight years gives a mean evaporation of 23.63 inches, or 51.0 per cent. of the mean rainfall of 46.38 inches.

The evaporation from the Croton and Sudbury watersheds, together with that of another Massachusetts stream, are shown in Table No. 17A.

TABLE NO. 17A.

Relation of Run-off and Evaporation to Rainfall, assuming Underflow Negligible.

Stream.	Date of Gauging.		Number of Years.	Average Yearly Rainfall. Inches Depth.	Average Yearly Run-off. Inches Depth.	Corresponding Average Evaporation. Inches Depth.	Per Cent. of Evaporation to Rainfall.
	From	To					
Croton	1868	1899	32	48.07	22.33	25.74	53.5
Sudbury	1875	1902	28	46.38	22.75	23.63	51.0
Nashua, South Branch	1897	1902	6	51.32	27.56	23 76	46.3

The Croton Watershed above the Old Croton Dam has an area of 338.8 square miles, of which the proportion of water surface varies from 1.7 per cent. to 3.6 per cent. The surface is hilly and the bed rock in part exposed, but generally covered with glacial earths and gravels which, as stated by Mr. George W. Birdsall, provides an impervious layer 18 inches below the surface; the valleys are flat and in small areas bordered by swamps. Less than 30 per cent. of the area is wooded, the remainder being pasture or cultivated land. The ground water storage on the Croton is said to be very small.

Table No. 18.

Comparisons of the Watersheds of East Meadow Brook, West Newbridge Stream (Cedar Creek), East Newbridge Stream, Wantagh Streams, Seaford Creek and Massapequa Stream, above the Gauging Stations Established by this Commission.

Classes of Surfaces Into Which Water Sheds Are Divided.	Water-sheds.											
	East Meadow Brook.		West Newbridge Stream.		East Newbridge Stream.		Wantagh Streams.		Seaford Creek.		Massapequa Stream	
	Total Area in this Class in Square Miles.	Percentage of the Whole Area.	Total Area in this Class in Square Miles.	Percentage of the Whole Area.	Total Area in this Class in Square Miles	Percentage of the Whole Area	Total Area in this Class in Square Miles.	Percentage of the Whole Area.	Total Area in this Class in Square Miles.	Percentage of the Whole Area.	Total Area in this Class in Square Miles.	Percentage of the Whole Area.
Woodland	8.69	28.2	0.61	64.9	1.22	51.4	2.48	14.1	1.29	48.0	24.59	61.4
Grassland	3.10	10.0	0.11	11.7	0.31	13.1	1.68	9.6	0.02	0.7	4.78	12.0
Pasture land....	10.40	33.5	0.00	0.0	0.31	13.1	5.71	32.5	0.16	6.0	2.78	6.9
Cultivated land	8.30	26.8	0.20	21.3	0.50	21.1	7.47	42.3	1.18	43.9	7.69	19.2
Impervious surfaces, roads and houses ..	0.35	1.1	0.02	2.1	0.02	0.9	0.19	1.1	0.02	0.7	0.19	0.5
Water surface............	0.13	0.4	0.00	0.0	0.01	0.4	0.06	0.4	0.02	0.7	......	......
Total	30.97	100.0	0.94	100.0	2.37	100.0	17.59	100.0	2.69	100.0	40.03	100.0
Total number of houses in each watershed.		605		60		38		442		54		585
Total estimated population in each watershed assuming five to a house.		3,025		300		190		2,210		270		3,325
Estimated population, per square mile		99		319		80		126		100		84

The watershed of the Sudbury river is 78 square miles in area, generally hilly and with extensive swamps. One-sixth to one-eighth of the area is wooded, the remainder covered by villages and agricultural lands.

(F) Character of the Long Island Watersheds.

In Table No. 18 the character of the watersheds of several Long Island streams that may be considered typical of the southerly portion of the island are shown. The total surface area of these watersheds above the gauging stations established by this Commission amounts to 96.9 square miles, of which 37.59 square miles, or 40.9 per cent., is covered with wood land; 9.98 square miles, or 10.9 per cent., grass land; 19.2 square miles, or 20.9 per cent., pasture land; 24.16 square miles, or 26.3 per cent., cultivated land; 0.77 square miles, or 0.84 per cent., an impervious surface; .02 square miles, or 0.22 per cent., water surface.

The East Meadow Brook watershed is fairly typical of the highly cultivated areas of the watersheds in the westerly portion of the island; the Massapequa Stream watershed represents the more wooded areas of Suffolk County, and the mean of the values from these areas with those from the smaller watersheds of the Wantagh and Newbridge streams give results which are fairly representative of the general character of the surface of Long Island.

Typical views of the several classes of surface into which the southerly portion of the island is divided are shown in the photographs opposite this page.

It will be seen that the area of the water surface above our gauging stations is a negligible quantity, and that the proportion of area in woodland on the island will, in general, exceed that for either the Croton or Sudbury. From the surface conditions, then, the evaporation on Long Island should be less than from either the Croton or Sudbury watersheds. Furthermore, the exceedingly porous substrata and the absence in many large areas of a semi-impervious soil-cover permit the rain to quickly escape below the surface beyond the reach of evaporation; moreover, the greater depth of the ground water on Long Island compared with that on the Croton and Sudbury watersheds prevents the Long Island ground water from being drawn to the surface and evaporated to a greater extent than on the latter watersheds.

The differences between the rainfall and the run-off on such watersheds as the Nashua river, in Massachusetts, and the Pequannock, in New Jersey, are smaller than on the Croton and Sudbury, due in part to the greater elevation of and, consequently, the larger rainfall on the former watersheds and, in a great measure, to the more porous character of the surfaces.

CULTIVATED LAND.

UNCULTIVATED LAND—PASTURE.

WOODLAND OR SPROUTLAND.

WOODLAND AND POND IN SWAMPY AREA NEAR THE SOUTH SHORE.

TYPICAL SURFACES OF OUTWASH PLAINS ON WATERSHEDS BETWEEN EAST MEADOW BROOK AND MASSAPEQUA STREAM.

On the other hand, the rainfall is, on an average, less on Long Island than on the higher watersheds of the Sudbury and Croton and, consequently, the percentage of evaporation should be greater, since we have seen from a study of the percolation that the larger and more frequent the rainfall, the greater the percolation.

(G) Conclusions.

From the annual percolation at Millburn, the demands of vegetation and the stream flows of the Croton and Sudbury rivers, 40 per cent. of the rain, or 17 inches, would seem to be a fair value of the average annual evaporation on Long Island, and fully as much, or, say, 17 inches, or 49 per cent. of the minimum rainfall of 35 inches, during a dry period.

It is possible that the coarse, leachy soils of the uncultivated areas of the outwash plain allow a greater percolation and cause less evaporation than the above estimates, but such uncultivated areas do not cover a large portion of the surface, particularly in Nassau County, and a decrease in the evaporation on such surfaces is probably offset by large evaporations from the more highly cultivated areas. The texture of some of the soils, through years of cultivation, has beocme very fine and compact and differs little from the soils in many localities that are not considered to be as pervious as the surfaces of the Long Island watersheds.

III.—STREAM FLOW.

No accurate gaugings, for a greater period than a few months, have been made of the flow of the Long Island streams and such periods have never included the seasons of maximum flow, winter and early spring, so that it is impossible to closely estimate the relation between the total annual stream flow and the annual rainfall. The records of pumpage and waste that have been made by the Brooklyn Water Department on the Long Island watersheds furnish the best means of making an estimate of the total annual run-off, particularly of the winter and spring flows.

(*A*) *Estimate of Run-off from the Brooklyn Records.*

Beginning in January, 1895, records were kept of the depths wasting over the spillways of the supply ponds of the Brooklyn Water Works, between Baiseley's Pond and Massapequa, from which the total amounts of water that wasted each month were determined. With the amounts of waste that the Brooklyn Water Department has computed from these records and the total amounts pumped each month at the Millburn and the Ridgewood pumping stations and at all the driven well stations, the records at which begin in 1897, estimates of the run-off from the old and the new Brooklyn watersheds have been made from 1897 to 1903.

(*a*) *New Watershed.*

The records east of the Millburn Pumping Station give the best estimate of run-off, because the ground water pumpage at each driven well station is accurately measured, and the amount of ground water can therefore be separated from the total surface and ground water flow in the pumpage at the Millburn Station. Having eliminated the ground water pumpage of the driven well stations, the addition of the waste at the ponds from Millburn to Massapequa gives the total run-off of the streams that are tributary to the supply ponds.

The average monthly run-off of the streams in million gallons per day and in inches depth on the ground water catchment areas of the streams, together with the monthly rainfall at Hempstead Storage Reservoir, are shown in Table No. 19. The ratios of annual run-off to rainfall vary from 24 to 39 per cent.; the average for the five complete years, from 1897 to 1902, inclusive, was 13.5 inches depth, or 29.2 per cent. of the mean rainfall during this period, 44.88 inches.

TABLE No. 19.

Run-off of Watersheds Between Millburn and Massapequa.

From Records of Brooklyn Water Department.

DATE.	Total Amount Pumped at Millburn Pumping Station Each Month, Million Gallons.	Total Delivery of Driven Well Stations East of Millburn Each Month, Million Gallons.	Total Flow of Surface Streams in Conduit East of Millburn and the Amount from Millburn Stream.	Total Amount Wasted Over Spillways of Supply Ponds from Massapequa to Millburn. Million Gallons	Total Flow of Surface Streams that enter Conduit from Massapequa to Millburn, Million Gallons.	Corresponding Inches Depth on Ground Water Catchment, Area of 64.92 Square Miles.	Total Rainfall During Each Month, Inches.	Mean Annual Ratio of Run-off to Rainfall, Per Cent.	Mean Ratio of Run-off to Rainfall for December, January, February and March, Per Cent.
1897.									
January........	1,330.040	*........	....	3.717	....	......	2.26	......	......
February......	1,205.596	....	....	134.900	....	......	2.55	......	......
March	1,339.371	....	....	24.129	....	......	3.11	......	......
April..........	1,297.989	....	....	36.717	....	......	1.73	......	......
May.	1,337.385	236.365	1,101.015	0.0	1,101.015	0.976	4.64	21.0	......
June...........	1,282.438	383.129	899.309	14.630	913.939	0.810	3.17	25.6	......
July...........	1,311.858	227.968	1,083.890	441.452	1,525.342	1.351	11.68	11.6	......
August........	1,358.856	0.0	1,358.856	128.765	1,487.621	1.319	2.62	50.3	......
September.....	1,319.633	296.949	1,022.684	0.0	1,022.684	0.907	1.51	60.1	......
October........	1,307.842	454.901	852.941	0.0	852.941	0.756	1.51	50.1	......
November.....	1,322.436	475.405	847.031	0.412	847.443	0.751	5.01	15.0	......
December......	1,339.745	225.963	1,113.782	31.202	1,144.984	1.015	4.83	21.0	......
Total...							46.41	......	......
1898.									
January.......	1,440.341	0.0	1,440.341	0.0	1,440.341	1.276	4.12	31.0	......
February......	1,218.083	0.0	1,218.083	229.062	1,148.145	1.284	3.23	39.7	......
March.........	1,367.572	0.0	1,367.572	294.562	1,662.134	1.473	3.45	42.7	32.32
April..........	1,281.281	0.0	1,281.281	156.708	1,437.989	1.275	3.79	33.6	......
May....	1,331.785	0.0	1,331.785	810.553	2,142.338	1.346	8.99	11.9	......
June...........	1,269.759	0.0	1,269.759	436.947	1,706.706	1.513	0.77	196.4	......
July...........	1,317.809	0.0	1,317.809	49.164	1,366.973	1.212	5.43	22.3	......
August........	1,249.785	0.0	1,249.785	0.0	1,249.785	1.108	4.83	22.0	......
September....	1,161.785	204.270	957.510	0.0	957.510	0.849	2.44	34.8	......

*No record of delivery of driven well stations from January to April.

[illegible]

TABLE No. 19.

Run-off of Watersheds Between Millburn and Massapequa.

From Records of Brooklyn Water Department.

Date.	Total Amount Pumped at Millburn Pumping Station Each Month, Million Gallons.	Total Delivery of Driven Well Stations East of Millburn Each Month, Million Gallons.	Total Flow of Surface Streams in Conduit East of Millburn and the Amount from Millburn Stream.	Total Amount Wasted Over Spillways of Supply Ponds from Massapequa to Millburn, Million Gallons	Total Flow of Surface Streams that enter Conduit from Massapequa to Millburn, Million Gallons.	Corresponding Inches Depth on Ground Water Catchment, Area of 64.92 Square Miles.	Total Rainfall During Each Month, Inches.	Mean Annual Ratio of Run-off to Rainfall, Per Cent.	Mean Ratio of Run-off to Rainfall for December, January, February and March, Per Cent.
1897.									
January........	1,330.040	*........	....	3.717	....	......	2.26	......	......
February......	1,205.596	....	....	134.900	....	......	2.55	......	......
March........	1,339.371	....	....	24.129	....	......	3.11	......	......
April..........	1,297.989	....	....	36.717	....	......	1.73	......	......
May..........	1,337.383	236.365	1,101.015	0.0	1,101.015	0.976	4.64	21.0	......
June..........	1,282.438	383.129	899.309	14.630	913.939	0.810	3.17	25.6	......
July..........	1,311.858	227.968	1,083.890	441.452	1,525.342	1.351	11.68	11.6	......
August........	1,358.856	0.0	1,358.856	128.765	1,487.621	1.319	2.62	50.3	......
September.....	1,319.633	296.949	1,022.684	0.0	1,022.684	0.907	1.51	60.1	......
October........	1,307.842	454.901	852.941	0.0	852.941	0.756	1.51	50.1	......
November.....	1,322.436	475.405	847.031	0.412	847.443	0.751	5.01	15.0	......
December......	1,339.745	225.963	1,113.782	31.202	1,144.984	1.015	4.83	21.0	......
Total....							46.41	......	......
1898.									
January.......	1,440.341	0.0	1,440.341	0.0	1,440.341	1.276	4.12	31.0	......
February......	1,218.083	0.0	1,218.083	229.062	1,448.145	1.284	3.23	39.7	......
March.........	1,367.572	0.0	1,367.572	294.562	1,662.134	1.473	3.45	42.7	32.32
April..........	1,281.281	0.0	1,281.281	156.708	1,437.989	1.275	3.79	33.6	......
May..........	1,331.785	0.0	1,331.785	810.553	2,142.338	1.346	8.99	11.9	......
June..........	1,269.759	0.0	1,269.759	436.947	1,706.706	1.513	0.77	196.4	......
July..........	1,317.8 9	0.0	1,317.809	49.164	1,366.973	1.212	5.43	22.3	......
August........	1,249.785	0.0	1,249.785	0.0	1,249.785	1.108	4.83	22.9	......
September....	1,161.780	204.270	957.510	0.0	957.510	0.849	2.44	34.8	......

*No record of delivery of driven well stations from January to April.

October.......	1,175.315	309.496	865.819	2.500	868.319	0.769	5.81	13.2	......
November.....	991.894	112.228	879.666	353.499	1,233.165	1.093	6.00	18.2	......
December	871.236	0.0	871.236	991.217	1,802.453	1.650	2.36	69.9	.....
Total.....						14.848	51.22	28.99	......
1899.									
January........	1,172.247	0.0	1,172.247	813.449	1,985.696	1.760	4.22	41.7	......
February.......	1,119.762	0.0	1,119.762	864.669	1,984.431	1.758	5.02	35.0	42.10
March.........	1,265.446	0.0	1,265.446	2,114.435	3,379.881	2.996	7.79	38.4	......
April..........	1,145.951	0.0	1,145.951	1,413.063	2,559.014	2.268	1.47	154.4	......
May...........	1,138.712	0.0	1,138.712	590.263	1,728.975	1.532	1.79	85.7	......
June...........	1,243.582	0.0	1,243.582	16.815	1,260.397	1.117	2.21	50.5	......
July...........	1,270.130	0.0	1,270.130	0.0	1,270.130	1.125	5.07	22.2	......
August	1,228.487	29.305	1,199.182	0.0	1,199.182	1.063	3.59	29.6	......
September.....	1,232.866	206.079	1,026.787	0.0	1,026.787	0.910	5.17	17.6	......
October	1,257.146	253.836	1,003.310	0.0	1,003.310	0.889	2.76	32.2	......
November.....	1,217.312	314.319	933.003	0.0	933.003	0.827	2.69	30.7	......
December	1,310.920	333.911	977.009	0.0	977.009	0.866	1.82	47.5	......
Total.....						17.111	43.60	39.25	......
1900.									
January.......	1,272.559	218.277	1,054.282	0.0	1,054.282	0.934	4.45	21.0	......
February......	1,135.288	28.424	1,106.864	165.025	1,271.889	1.127	5.04	22.3	28.34
March.........	1,253.224	0.0	1,253.224	266.630	1,519.854	1.347	3.77	35.7	......
April..........	1,220.026	0.0	1,220.026	174.506	1,394.532	1.237	1.87	66.2	......
May...........	1,255.883	0.0	1,255.883	25.962	1,281.845	1.136	4.11	27.7	......
June...........	1,196.729	0.0	1,196.729	0.0	1,196.729	1.061	1.98	53.7	......
July..........	1,132.456	202.737	929.719	0.0	929.719	0.825	4.69	17.6	......
August.......	1,244.916	528.687	716.229	0.0	716.229	0.634	3.70	16.9	......
September.....	1,102.100	513.283	588.817	0.0	588.817	0.522	2.10	24.9	......
October.......	1,102.519	528.679	573.840	0.0	573.840	0.509	3.22	15.8	......
November.....	1,065.815	510.914	554.901	0.0	554.901	0.492	4.16	11.8	......
December	1,266.470	901.696	364.774	0.0	364.774	0.323	2.28	14.2	......
Total.....						10.147	41.43	24.49	......

The results of these computations of run-offs are subject to the errors in the estimate of waste at the ponds, in the computation of the pumpage by plunger displacement, to errors occasioned by the loss of surface water by seepage through the bottom of the supply ponds or through the walls of the conduit, by the entrance of ground water into the conduit when the water within is below the water table, and by the seepage of ground water into the supply ponds when they are drawn down.

Mr. W. W. Brush, the Assistant Engineer of the Brooklyn Water Department, states that the error in the quantities wasting at the supply ponds is not greater than 10 to 15 per cent., and that 2.7 per cent. is the slip of the engines at Millburn Pumping Stations. Considering that further errors may be introduced by leakage of ponds and the conduit, the run-off quantities have probably not a greater accuracy than 20 per cent. The seepage from the bottom of ponds is in part balanced by the leakage into the conduit of large amounts of ground or surface water, as at Seaford Creek; otherwise, this percentage of error would be still larger. It was noted that the estimated run-offs were small when the driven well stations were in operation, that is, the pumping increased the seepage through the bottom of the supply ponds. It is believed that the percentage 29.2 is an underestimate.

(*b*) *Old Watershed.*

Similar computations have been made of the monthly run-off of the streams between Ridgewood and Smith's Pond, from the records of pumpage and waste for the years from 1897 to 1903. The results, however, are not as reliable as those from the new watershed, as the surface and ground water pumpage at some stations can only be approximately separated.

The total run-off and the mean rainfall on the old watershed (mean of rainfall at Ridgewood Reservoir and Hempstead Storage Reservoir), for each month, are shown in Table No. 20. The average ratios of mean annual run-off to the mean rainfall was 23 per cent. for the five years in which records of waste and pumpage were complete.

(*B*) *Comparison With Other Streams.*

The run-off of other streams on the Atlantic Coast that have been accurately gauged for a long term of years can only be used with great caution, because, unlike other streams in this vicinity, the flow of the Long Island streams includes only a portion of the total delivery of the watersheds; the remainder of the run-off reaches the sea as underflow.

The total flow of the Long Island streams will, then, as the Brooklyn estimates indicate, be much less than the 50 per cent. of the rainfall that has been found on the Croton and Sudbury rivers. Only during the winter months, when the ground on Long Island is frozen, may the run-off of the streams here be considered comparable with that of other streams. The months of frost are those from December to March, inclusive, but before applying to the conditions here the results from other streams, the character of the Long Island winters must be considered.

(*a*) *Winter Run-off: December to March.*

The winters are comparatively mild for this latitude and the snowfall is light. During the most severe winters the ground seldom freezes before the middle of December and the frost rarely remains after the first of March: it often happens that the frost does not enter the ground for more than two or three days at a time during an open winter.

The average snowfall on Long Island is stated to be 20 inches, in the report of the New York State Weather Service for 1894; the records at Hempstead Storage Reservoir show about the same amount, but the most reliable record, that of Dr. Daniel Draper, at Central Park, New York City, gives an average fall of 33.19 inches for thirty years.

If 30 inches of snow be accepted as the average fall on Long Island, certainly not more than 20 inches of snow, or, say, 2 inches of melted snow, are likely to be so rapidly melted in a thaw as to run off over the surface of the ground and enter the streams. Even then, during the months of December to March, the run-off of the Long Island watersheds is probably much less than those of the Croton and Sudbury rivers. The Croton Watershed gives a total mean run-off of 78 per cent. of the total rainfall for these months, and the Sudbury 73 per cent. during the same period. The winters on both watersheds are more severe; the average annual snowfall on the Croton is about 50 inches, that on the Sudbury about 46 inches.

Considering that the Long Island watersheds have less snow and less frost and that the soil and substrata are more pervious than on these two watersheds, the total run-off on the Croton and Sudbury basis, during the four months of December, January, February and March, in a year of normal rainfall, is not probably over 50 per cent. of the average rainfall of 13.4 inches for those months, or about 7 inches, and is, perhaps, not over 4.5 inches during a long period of low rainfall.

From the run-offs of the Croton and Sudbury rivers only an approximate estimate of the winter flow of the Long Island streams can be made; the Brooklyn gaugings, as already stated, give only dry weather flows during a few months of extreme drought, so that the best data from

TABLE No. 20.

Run-off of Watersheds Between Ridgewood and Millburn.

From Records of Brooklyn Water Department.

1897.	Total Amount Pumped at Ridgewood Pumping Station Each Month, Million Gallons.	Total Amount Pumped at Millburn Pumping Station Each Month, Million Gallons.	Total Amount Supplied By Old Watershed.	Total Delivery of Driven Well Stations on Old Watersheds.	Total Flow of Surface Streams that Enters Conduit from Old Watersheds.	Total Amount Wasting Over Spillways of Supply Ponds on Old Watershed.	Total Flow of Surface Streams on Old Watershed.	Corresponding Inches Depth on Ground Water Catchment Area of 52.10 Square Miles.	Total Rainfall During Each Month, Inches.	Ratio of Run-off to Rainfall, Per Cent.	Mean Ratio of Run-off to Rainfall for December, January, February and March, Per Cent.
January....	2,638.903	1,330.040	1,308.869	959.219	349.650	245.785	595.435	0.658	2.27	28.0	......
February...	2,382.677	1,205.596	1,177.081	857.326	319.755	295.447	615.202	0.679	2.74	24.8	......
March......	2,608.664	1,339.371	1,269.293	899.915	369.378	165.581	534.959	0.591	3.11	19.0	......
April.......	2,524.205	1,297.989	1,226.216	856.276	369.940	243.723	613.663	0.678	3.33	20.3	......
May........	2,617.261	1,337.380	1,279.881	963.510	316.371	249.682	566.053	0.625	4.64	13.5	......
June........	2,611.081	1,282.438	1,328.643	1,027.379	301.264	203.093	504.357	0.557	3.17	17.6	.....
July........	2,770.417	1,311.858	1,458.559	927.228	531.331	225.903	757.234	0.836	11.68	7.2	......
August.....	2,713.295	1,358.856	1,354.439	886.274	468.165	136.558	604.723	0.668	2.62	25.2	......
September..	2,750.421	1,319.633	1,430.788	853.205	577.582	65.419	643.001	0.710	1.51	47.1	......
October....	2,834.005	1,307.842	1,525.163	909.148	617.015	35.971	652.986	0.721	1.51	47.8	......
November..	2,583.112	1,322.436	1,260.676	815.605	445.070	81.807	526.877	0.582	5.00	11.6	......
December...	2,653.410	1,339.745	1,313.665	751.675	561.990	148.327	710.317	0.784	4.83	16.2	......
Totals....								8.089	46.41	17.43	
1898.											
January....	2,821.794	1,440.341	1,381.453	843.533	537.920	160.950	698.870	0.772	4.12	18.7	......
February...	2,512.835	1,218.083	1,294.752	728.312	566.440	217.683	784.123	0.866	3.23	26.8	......
March......	2,785.524	1,367.572	1,418.952	960.165	458.787	180.570	639.357	0.706	3.45	20.5	24.70
April.......	2,614.522	1,281.281	1,333.241	858.292	474.919	266.805	741.754	0.819	3.79	21.6	......
May.......	2,719.792	1,331.785	1,388.007	860.921	527.086	395.987	923.073	1.019	8.99	11.3	......
June.......	2,719.774	1,269.759	1,450.015	679.746	770.269	322.664	1,092.933	1.207	0.77	156.9	......
July.......	2,800.026	1,317.809	1,482.217	845.571	636.646	218.730	855.376	0.945	5.43	17.4	......
August....	2,838.170	1,249.785	1,589.385	956.510	621.875	189.152	811.027	0.896	4.83	18.5	......
September..	2,818.130	1,161.780	1,656.350	970.606	685.744	73.441	759.185	0.838	2.44	34.4	.....

October	2,755.529	1,175.315	1,580.194	882.412	607.782	138.929	836.711	0.924	5.81	15.9	......
November..	2,616.111	991.894	1,624.217	705.350	918.867	241.305	1,160.172	1.281	6.00	21.4	......
December ..	2,831.653	871.236	1,960.417	763.005	1,197.412	486.237	1,683.649	1.859	2.36	78.7	......
Totals....								12.132	51.22	23.69	
1899.											
January....	2,930.304	1,172.247	1,758.057	903.893	854.164	639 618	1,493.782	1.650	4.22	39.1	......
February...	2,730.710	1,119.762	1,610.948	883.663	727.285	462.878	1,190.163	1.314	5.02	26.2	......
March	2,893.663	1,265.446	1,628.217	822.566	605.651	959.824	1,765 475	1.950	7.79	25.0	39.88
April	2,786.621	1,145.951	1,640.670	821.726	818.944	741.239	1,550.243	1.712	1.47	116.5	......
May	2,917.337	1,138.712	1,778.625	808.019	970.606	365.409	1,336.015	1.475	1.79	82.4	......
June	2,830.439	1,243.582	1,586.857	866.129	720.728	231.650	952.378	1.052	2.21	47.7	......
July........	2,921.158	1,270.130	1,651 028	852.858	798.170	191.382	989.552	1.093	5.07	21.6	......
August.....	2,839.819	1,228 487	1,611.332	887.030	724.302	188.106	912 408	1.008	3.59	28.1	......
September..	2,776.242	1,232.865	1,543.376	868.714	674.652	199.045	873.707	0.965	5.17	18 7	......
October	2,763.840	1,257.146	1,506.694	868.908	637.786	153.416	791.202	0.874	2.75	31.6	......
November..	2,640.915	1,247.312	1,393.603	805.315	588.283	0.0	588 288	0.650	2.69	24 2	......
December ..	2,673.926	1,310.920	1,363.006	868.016	494.960	151.043	646.003	0 713	1.82	39.2	......
Totals....								14.456	43.60	33.16	
1900.											
January....	2,681.095	1,272.559	1,408.537	874.964	523.573	244.270	767.843	0.848	4.45	19 1	......
February...	2,512.951	1,135.288	1,377.663	816.052	561.621	379.754	941.375	1.040	5.04	20.6	......
March	2,817.149	1,253.224	1,503.925	882.525	681.400	425.046	1,106.446	1 222	3.77	32.5	25.29
April	2,662.0 0	1,220 026	1,441.974	818 818	623.156	304.981	928.137	1.025	1.87	51.8	......
May	2,747.480	1,255.883	1,491.597	855.515	636.081	336.374	972.456	1.074	4.11	26.1	......
June	2,680.105	1,196.729	1,483.377	823.995	659.382	197.023	856.405	0.946	1.98	47.8	......
July........	2,735.894	1,132.456	1,603.438	869 922	733.516	163.488	897.004	0.991	4.69	21.1	......
August	2,780.003	1,244.916	1,535.087	893.624	641.463	110.664	752.127	0.831	3.76	22.1	......
September..	2,493 062	1,102.099	1,390.963	865.989	524.974	84.851	609.825	0.673	2.10	32.1	......
October	2,461,468	1,102 519	1,358.949	908.724	450.225	79 301	529.526	0.585	3.22	18.2	......
November..	2,414.968	1,065.815	1,349.153	860.086	489.067	95.660	584 727	0.646	4.16	15.5	......
December ..	2,687.628	1,265.470	1,421.158	912.648	508.510	145.220	653.730	0.722	2.28	31.7	......
Totals....								10.603	41.43	25.56	

TABLE No. 20—*Continued.*

1897.	Total Amount Pumped at Ridgewood Pumping Station Each Month, Million Gallons.	Total Amount Pumped at Millburn Pumping Station Each Month, Million Gallons.	Total Amount Supplied By Old Watershed.	Total Delivery of Driven Well Stations on Old Watersheds.	Total Flow of Surface Streams that Enters Conduit from Old Watersheds.	Total Amount Wasting Over Spillways of Supply Ponds on Old Watershed.	Total Flow of Surface Streams on Old Watershed.	Corresponding Inches Depth on Ground Water Catchment Area of 52.10 Square Miles.	Total Rainfall During Each Month, Inches.	Ratio of Run-off to Rainfall, Per Cent.	Mean Ratio of Run-off to Rainfall for December, January, February and March, Per Cent.
1901.											
January ...	2,675.212	1,275.741	1,399.471	901.105	498.366	147.570	645.936	0.713	2.21	32.3	......
February...	2,345.667	1,144.587	1,201.080	820.092	380.088	94.378	474.466	0.524	0.77	68.1	......
March	2,707.533	1,260.561	1,446.972	914.853	532.119	176.877	708.996	0.783	6.97	11.2	22.42
April	2,557.133	1,242.316	1,314.817	906.218	408.599	42.984	451.583	0.499	8.05	6.2	......
May	2,769.342	1,305.199	1,464.143	952.543	511.600	80.729	592.329	0.654	7.17	9.1	......
June	2,730.960	1,241.204	1,489.756	921.111	568.645	17.691	586.336	0.648	0.55	117.8	......
July	2,792.772	1,298.342	1,494.430	935.126	559.304	13.043	572.347	0.632	5.93	10.6	......
August.....	2,702.854	1,297.101	1,405.753	922.755	482.998	17.842	500.840	0.553	4.03	13.7	......
September..	2,688.521	1,241.059	1,447.462	874.629	572.833	59.874	632.707	0.699	3.36	20.8	......
October ...	2,822.632	1,234.047	1,588.585	905.099	683.486	37.293	720.779	0.796	1.95	40.8	......
November..	2,606.421	1,247.255	1,359.166	822.420	536.746	58.384	595.130	0.657	1.28	51.3	......
December ..	2,789.912	1,315.327	1,474.585	923.575	551.010	134.997	686.007	0.758	7.65	9.9	......
Totals....								7.916	49.92	15.86	
1902.											
January ...	2,840.474	1,466.664	1,373.810	847.871	525.939	99.871	625.810	0.691	2.17	31.8	......
February...	2,600.443	1,338.038	1,262.405	713.436	548.969	812.060	1,361.029	1.503	4.99	30.1	......
March	2,903.043	1,497.560	1,405.483	891.987	513.496	961.505	1,475.002	1.629	5.01	32.5	23.09
April.......	2,803.113	Records of Pumpage Missing for these Months.	....	....	....	....	....	......	......	......	......
May	2,874.259		....	....	....	....	....	......	......	......	......
June	2,785.111		....	....	....	....	....	......	......	......	......
July........	2,836.439		....	....	....	....	....	......	......	......	......
August.....	2,721.731		....	....	....	....	....	......	......	......	......
September..	2,770.968		....	....	....	....	....	......	......	......	......
October ...	2,835.222		....	....	....	....	....	......	......	......	......
November..	2,693.754		....	....	....	....	....	......	......	......	......
December..	2,905.113		....	....	....	....	....	......	......	......	......

which to check up the approximate estimate of run-off from the Brooklyn records of waste and pumpage are the stream measurements that were made by this Department during the months from July to October. These, with the ground water data, and the estimated winter flows, give an approximate estimate of the total run-off of the streams, a fair idea of the proportion of this total run-off that is surface flow, and the proportion that is ground water flow.

TABLE NO. 21.

Flow of the East Meadow Brook at the Weir Station Established by the Commission on Additional Water Supply from June to October, Inclusive, 1903.

Day of Month.	June.		July.		August.		September.		October.	
	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.
1	18.04	11.66	24.38	15.75	14.41	9.32	15.49	10.01	13.56	8.76
2	18.13	11.72	21.82	14.10	13.38	8.65	16.07	10.38	12.71	8.22
3	17.89	11.57	24.30	15.71	15.43	9.98	16.02	10.35	13.72	8.87
4	17.48	11.30	23.14	14.96	14.94	9.66	15.20	9.83	16.30	10.53
5	17.48	11.30	22.00	14.22	63.95	41.33	16.88	10.91	14.30	0.24
6	18.15	11.73	21.41	13.83	23.87	21.89	17.27	11.16	13.07	8.45
7	24.95	16.13	20.80	13.44	29.32	18.95	15.56	10.05	12.77	8.25
8	31.59	20.42	19.16	12 38	18.50	11.96	13.32	8.61	13.68	8 84
9	26.92	17.40	17.50	11.31	18.79	12.14	14.02	9.06	35.93	23.22
10	19.35	12.50	19.21	12.42	16.09	10.40	13.72	8.88	29.70	19.19
11	19.87	12 84	18.86	12.18	18.70	12.08	13.49	8.73	14.91	9.64
12	41.89	27.08	19.97	12.90	19.73	12.75	13.32	8.61	19.93	10.29
13	40.37	26.08	24 20	15.64	17.19	11.11	13.45	8.70	15.30	9 90
14	22.59	14.60	21.20	13.71	16.72	10.81	14.38	9.20	14.49	9.36
15	38.42	24.83	18.31	11.83	15.58	10.07	15.06	9.74	13.88	8.97
16	32.24	20.84	17 95	11.60	15.55	10.05	19.85	12.82	12.90	8.33
17	24.82	16.04	19.32	12.48	16.79	11.85	15.12	9.78	21.30	13.77
18	20.22	13.07	24.05	15.54	15.36	9.93	16.81	10.87	32.22	20.81
19	22.97	14.84	29.07	18.78	14.12	9.13	16.07	10.38	22.45	14.50
20	23.84	15.41	20.36	13.16	15.28	9.88	14.72	9.52	16.00	10.34
21	25.98	16.78	20.29	13.11	16.09	10.40	13.35	8.63	16.49	10.65
22	24.28	15.69	18.79	12.15	15.41	9.97	13.44	8.69	16.23	10.49
23	24.31	15.72	23.68	15.30	14.89	9 63	13.02	8.42	16.12	10.41
24	28.37	18.33	17.26	11.15	18 36	11.87	13.21	8.54	15.80	10.22
25	25.21	16.29	17.65	11.42	14.18	9.17	13 09	8.46	15.90	10.28
26	21.95	14.18	16.08	10.39	15.65	10.12	13.25	8.57	16.09	10.40
27	21.37	13.81	16.20	10.47	17.21	11.12	13.76	8.90	15.71	10.16
28	20.56	13.28	15.58	10.07	22.69	14.66	16.17	10.45	15.59	10.08
29	28.85	18.64	15.62	10.10	32.55	21 03	13.41	9.67	15.80	10.22
30	36.92	23.87	16.38	10.58	25.99	16.79	13.84	8.95	15.68	10.13
31	.....	.....	16.08	10.39	17.65	11.41	.....	.....	15.88	10.26
Total	.....	487.93	......	401.05	......	408.10	. ...	286.94	......	342.78
Average per month	25.17	16.26	20.02	12.94	20.36	13.16	14.78	9.56	17.11	11.06

TABLE NO. 21—*Continued.*

Flow of the Newbridge Streams at the Weir Stations Established by the Commission on Additional Water Supply from August to October, Inclusive, 1903.

DAY OF MONTH.	JUNE.		JULY.		AUGUST.		SEPTEMBER.		OCTOBER.	
	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.
1	....	......	....	......	4.07	2.62	3.76	2.43	2.65	1.71
2	....	......	....	......	4.02	2.60	3.59	2.32	2.55	1.65
3	....	......	....	......	3.92	2.54	3.54	2.29	2.79	1.80
4	....	......	....	......	4.66	3.01	3.47	2.24	2.47	1.60
5	....	......	....	......	12.40	7.88	3.69	2.38	2.57	1.66
6	....	......	....	......	6.34	4.09	3.18	2.05	2.66	1.72
7	....	......	....	......	5.65	3.65	3.26	2.11	2.55	1.65
8	....	......	...	......	4.94	3.19	3.27	2.12	2.55	1.65
9	....	......	....	......	4.81	3.11	3.27	2.12	5.25	3.39
10	....	......	....	......	4.73	3.06	3.28	2.12	3.66	2.36
11	....	......	....	......	5.29	3.42	3.23	2.09	3.33	2.15
12	....	......	....	......	4.91	3.17	3.10	2.00	3.00	1.94
13	....	......	....	......	4.37	2.82	3.16	2.04	3.00	1.94
14	....	......	....	......	4.22	2.73	3.03	1.96	2.99	1.93
15	....	......	....	......	4.30	2.78	3.00	1.94	2.94	1.90
16	....	......	....	......	4.23	2.73	4.42	2.21	2.90	1.87
17	....	......	....	......	4.11	2.66	3.45	2.23	4.01	2.59
18	....	......	....	......	3.78	2.45	3.39	2.19	4.63	2.99
19	....	......	....	......	3.61	2.34	3.01	1.94	3.75	2.42
20	....	......	....	......	3.71	2.40	2.94	1.90	3.61	2.33
21	....	......	....	......	3.42	2.21	2.93	1.90	3.51	2.27
22	...	......	....	......	3.38	2.18	2.87	1.86	3.47	2.24
23	....	......	....	......	3.33	2.15	2.83	1.83	3.42	2.21
24	....	......	....	......	3.44	2.22	2.78	1.80	3.36	2.17
25	....	......	....	......	3.34	2.16	2.73	1.76	3.37	2.18
26	....	......	....	......	3.57	2.31	2.74	1.77	3.43	2.22
27	....	......	....	......	3.26	2.11	2.69	1.74	3.36	2.17
28	....	......	....	......	4.41	2.85	2.99	1.93	3.43	2.22
29	....	......	....	......	4.05	2.62	2.72	1.76	3.43	2.22
30	....	......	....	......	4.63	2.99	2.84	1.83	3.38	2.10
31	....	......	....	......	4.02	2.60	....	....	3.37	2.18
Total	....	......	....	......	....	89.65	....	60.85	....	65.52
Average per month	....	......	....	......	4.47	2.89	3.15	2.03	3.27	.211

TABLE NO. 21—*Continued.*

Flow of the Wantagh Streams at the Weir Stations Established by the Commission on Additional Water Supply from July to October, Inclusive, 1903.

Day of Month.	June. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	June. Total Flow in Million Gallons Per 24 Hours.	July. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	July. Total Flow in Million Gallons Per 24 Hours.	August. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	August. Total Flow in Million Gallons Per 24 Hours.	September. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	September. Total Flow in Million Gallons Per 24 Hours.	October. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	October. Total Flow in Million Gallons Per 24 Hours.
1	....	......	....	......	11.63	7.52	14.05	9.08	11.20	7.24
2	....	......	....	......	12.21	7.89	11.84	7.65	10.52	6.80
3	....	......	....	......	12.07	7.80	12.92	8.35	11.51	7.44
4	....	......	....	......	13.10	8.47	14.91	9.63	9.85	6.37
5	....	......	....	......	48.30	31.21	14.67	9.48	13.07	8.45
6	....	......	....	......	21.19	13.70	14.11	9.12	9.81	6.34
7	....	......	....	......	17.31	11.19	12.61	8.15	10.33	6.68
8	....	......	....	......	16.00	10.34	10.85	7.01	10.23	6.61
9	....	......	....	......	15.67	10.13	13.21	8.54	29.81	19.27
10	....	......	....	......	16.23	10.49	12.79	8.27	14.99	9.67
11	....	......	....	......	18.46	11.93	10.78	6.97	13.59	8.78
12	....	......	....	......	16.73	10.81	12.52	8.09	14.02	9.06
13	....	......	....	......	13.18	8.52	11.33	7.33	12.51	8.08
14	....	......	....	......	14.89	9.62	9.93	6.42	10.11	6.54
15	....	......	....	......	13.62	8.81	11.90	7.69	12.60	8.15
16	....	......	....	......	13.66	8.83	14.22	9.19	11.30	7.30
17	....	......	....	......	14.19	9.17	13.76	8.89	19.28	12.46
18	....	......	....	......	10.88	7.03	13.09	8.46	19.90	12.86
19	....	......	....	......	13.35	8.63	10.71	6.92	14.06	9.08
20	....	......	....	......	13.72	8.87	12.75	8.24	12.86	8.31
21	....	......	13.55	8.76	12.26	7.93	9.68	6.26	11.17	7.22
22	....	......	14.34	9.27	12.36	7.99	11.10	7.18	13.12	8.48
23	....	......	16.62	10.74	12.24	7.91	12.19	7.88	12.80	8.27
24	....	......	13.12	8.48	11.93	7.71	10.18	6.58	12.12	7.84
25	...	......	12.75	8.24	10.73	6.93	11.03	7.13	12.13	7.85
26	....	......	8.53	5.51	13.86	8.96	10.52	6.80	11.40	7.37
27	....	......	9.82	6.35	12.56	8.12	11.27	7.28	12.30	7.95
28	....	......	11.36	7.34	18.70	12.09	12.68	8.20	12.67	8.19
29	....	......	12.52	8.09	25.65	16.57	10.06	6.50	12.67	8.19
30	....	......	12.19	7.88	19.92	12.87	13.75	8.89	12.56	8.13
31	....	......	12.30	7.95	10.07	6.51	......	......	12.06	7.81
Total	....	......	......	......	.....	314.53	....	236.17	....	262.76
Average per month	....	......	......	......	15.68	10.15	12.17	7.87	13.13	8.48

TABLE NO. 21—*Continued.*

Flow of the Upper Massapequa Stream Near Farmingdale at the Gauging Station of the United States Geological Survey from June to October, Inclusive, 1903.

Day of Month.	May. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	May. Total Flow in Million Gallons Per 24 Hours.	June. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	June. Total Flow in Million Gallons Per 24 Hours.	July. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	July. Total Flow in Million Gallons Per 24 Hours.	August. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	August. Total Flow in Million Gallons Per 24 Hours.	September. Average Flow in Cubic Feet Per Sec. Per 24 Hours.	September. Total Flow in Million Gallons Per 24 Hours.
1	....	....	0.94	0.61	0.43	0.28	0.43	0.28	0.43	0.28
2	....	....	0.94	0.61	0.43	0.28	0.43	0.28	0.35	0.23
3	....	....	0.87	0.56	0.43	0.28	0.43	0.28	0.32	0.21
4	....	....	0.79	0.51	0.43	0.28	0.28	0.18	0.32	0.21
5	....	....	....	....	0.43	0.28	1.68	1.08	0.30	0.10
6	2.06	1.33	0.63	0.41	0.43	0.28	0.89	0.58	0.25	0.16
7	2.06	1.33	1.41	0.91	0.43	0.28	0.81	0.52	0.21	0.14
8	2.06	1.33	1.00	0.65	0.43	0.28	0.63	0.41	0.18	0.12
9	2.06	1.33	0.63	0.41	0.43	0.28	0.62	0.40	0.20	0.13
10	2.06	1.33	0.63	0.41	0.43	0.28	0.53	0.34	0.22	0.14
11	2.06	1.33	0.63	0.41	0.78	0.50	0.62	0.40	0.22	0.14
12	2.06	1.33	1.72	1.11	0.63	0.41	0.52	0.34	0.17	0.11
13	2.06	1.33	1.00	0.64	0.63	0.41	0.47	0.30	0.14	0.09
14	2.06	1.33	1.12	0.72	0.53	0.34	0.46	0.30	0.18	0.12
15	1.66	1.07	0.88	0.57	0.43	0.28	0.43	0.28	0.16	0.10
16	1.28	0.83	0.63	0.41	0.43*	0.28	0.43	0.28	0.32	0.21
17	1.28	0.83	0.63	0.41	....	....	0.42	0.27	0.31	0.20
18	1.28	0.83	0.63	0.41	....	....	0.39	0.25	0.25	0.16
19	1.28	0.83	0.63	0.41	....	....	0.35	0.23	0.17	0.11
20	1.28	0.83	0.88	0.57	....	....	0.43	0.28	0.18	0.12
21	1.28	0.83	0.88	0.57	....	....	0.35	0.23	0.17	0.11
22	1.28	0.83	0.63	0.41	....	....	0.31	0.20	0.17	0.11
23	1.28	0.83	0.63	0.41	....	....	0.35	0.23	0.11	0.07
24	1.28	0.83	0.53	0.34	....	....	0.31	0.20	0.12	0.08
25	1.28	0.83	0.43	0.28	....	....	0.43	0.28	0.11	0.07
26	1.28	0.83	0.34	0.22	....	....	0.42	0.27	0.21	0.14
27	1.28	0.83	0.26	0.17	....	....	0.33	0.21	0.15	0.10
28	1.28	0.83	0.26	0.17	....	....	0.88	0.57	0.19	0.12
29	1.11	0.72	2.02	1.30	....	....	1.06	0.68	0.07	0.05
30	0.94	0.61	0.78	0.50	....	....	0.62	0.40	0.10	0.07
31	0.94	0.61	....	....	0.46	0.29	0.50	0.32	....	.....
Total....	...	....	....	...	....	....	....	10.07	....	4.06
Average per month...	....	....	....	....	....	....	0.49	0.32	0.20	0.13

*Gaugings from May 6th to July 16th, inclusive, by the U. S. Geological Survey.

TABLE NO. 21—*Continued.*

Flow of the Massapequa Stream at the Weir Station Established by the Commission on Additional Water Supply from June to October, Inclusive, 1903.

DAY OF MONTH.	JUNE.		JULY.		AUGUST.		SEPTEMBER.		OCTOBER.	
	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours	Average Flow in Cubic Feet Per Sec. Per 24 Hours.	Total Flow in Million Gallons Per 24 Hours.
1	....	......	20.51	13 25	10.77	6.96	13.59	8.78	8.92	5.77
2	....	......	18.07	11.68	10.27	6.64	12.08	7.81	8.75	5.66
3	....	......	17.55	11.34	9.61	6.21	11.25	7.27	9.21	5.95
4	....	......	16.88	10 91	10.47	6.77	11.10	7.18	8.90	5.75
5	....	......	16.16	10.44	29.50	19.07	11.65	7.53	8.71	5.63
6	....	......	16.37	10.58	24.54	15 86	11.47	7.41	8.70	5.62
7	....	......	16.06	10.38	20.76	13.41	10.69	6.91	8.64	5.58
8	....	......	15.16	9.80	15.69	10.14	10.37	6.70	8.50	5.49
9	....	......	14.83	9 59	14.39	9.30	10.34	6.68	19.72	12.74
10	...	......	14.28	9.23	13.70	8.85	10.33	6.68	18.98	12.26
11	....	......	15.39	9.95	14 63	9.46	10.13	6.55	13.86	8.96
12	....	......	14.86	9.61	14.91	9.64	9.81	6.34	12.23	7.91
13	....	......	16.01	10.35	11.59	7.49	9.60	6.20	10.99	7.10
14	....	......	15.29	9.88	12.21	7.89	9.51	6.14	10.24	6.62
15	....	......	13.98	9.03	11 70	7.56	9 42	6.09	9.71	6.27
16	....	......	13.62	8.80	11.29	7.30	10.70	6.91	9.53	6 16
17	. .	......	13.11	8.47	11.10	7.18	11.26	7.28	12.72	8.22
18	....	......	12.18	7.87	10.62	6.86	12.31	7.96	16.12	10.41
19	....	......	15.53	10.04	10.32	6.67	10.32	6.67	13.50	8.57
20	17.33	11.20	14.57	9.42	10.85	7.01	9.71	6.28	11.47	7.41
21	20.13	13.01	16.07	10.39	10.42	6.74	9.24	5.97	11.09	7.16
22	15.65	10.12	14.40	9.30	9.87	6.38	9.18	5.93	10.62	6.87
23	18.70	12.08	13.99	9 04	9.82	6.35	9.14	5.91	10.50	6.79
24	23.51	15.19	13.03	8.42	9.91	6.41	9.06	5.85	10.35	6.70
25	18.54	11.98	12 97	8.39	10 69	6.91	8.86	5.73	10.25	6.63
26	17.16	11.09	12.42	8.03	12.02	7.77	8 65	5.50	10.17	6.57
27	16.39	10.59	11.23	7.26	10 82	7.00	9.12	5.90	9.98	6.45
28	15.75	10.18	11.05	7.14	16.28	10 53	11.30	7.30	9.98	6.45
29	21.18	13.69	10.81	6.98	26.54	17.15	9.36	6.05	9.82	6.35
30	28.58	18.47	10.99	7.10	21.62	13.97	8.89	5.75	9.76	6.32
31	....	......	10 99	7.10	15.74	10.17	....	......	9.76	6.32
Total	....	......	....	289.77	....	279.62	....	199 35	....	220.66
Average per month....	....	......	14.47	9.35	13.96	9.02	10.29	6.65	11.02	7.12

TABLE No. 22.

Monthly Flows of Long Island Streams.

Ground Water and Surface Flows of Streams from Gaugings of the Commission on Additional Water Supply, 1903.

Month of 1903.	Total Average Monthly Flow in Million Gallons per 24 Hours.	Corresponding Monthly Run-off in Inches Depth on Ground Water Catchment Area.	Total Monthly Rainfall in Inches Depth on Watershed.	Ratio of Monthly Run-off to Monthly Rainfall.	Approximate Ground Water Flow in Inches Depth on Ground Water Catchment Area.	Approximate Flood or Surface Flow in Inches Depth on Area of Surface Watershed.
1	2	3	4	5	6	7
EAST MEADOW BROOK.						
June	16.26	1.54	9.56	0.57	1.28	0.18
July	12.94	1.27	3.17	0.40	1.17	0.08
August	13.16	1.29	7.27	0.18	1.02	0.18
September	9.56	[illegible]	2.09	0.44	0.88	0.04
October	11.06	1.09	5.21	0.21	0.93	0.11
NEWBRIDGE STREAMS.						
June	....	....	....	....	....	....
July	....	....	....	....	....	....
August	2.89	1.78	7.27	0.25	1.52	0.22
September	2.03	1.21	2.09	0.58	1.18	0.02
October	2.11	1.30	5.21	0.25	1.18	0.10
WANTAGH STREAMS.						
June	....	....	....	....	....	....
July	....	....	....	....	....	....
August	10.15	0.86	7.27	0.12	0.66	0.24
September	7.87	0.64	2.09	0.31	0.56	0.10
October	8.48	0.71	5.21	0.14	0.60	0.14
MASSAPEQUA STREAM.						
June	....	....	....	....	....	....
July	9.35	1.03	3.17	0.33	0.96	0.03
August	9.02	1.01	7.27	0.14	0.76	0.10
September	6.65	0.72	2.09	0.34	0.68	0.02
October	7.12	0.79	5.21	0.15	0.69	0.04
MEAN OF ABOVE STREAMS.						
	Total.	Mean.	Mean.	Mean.	Mean.	Mean.
June	....	....	....	....	....	....
July	....	....	....	....	....	....
August	35.22	1.09	7.27	0.15	0.84	0.16
September	26.11	0.79	2.09	0.38	0.72	0.04
October	28.77	0.89	5.21	0.17	0.75	0.09

(C) Run-off from April to November.

The results of the gaugings by the Long Island Department are shown in Table No. 21, in which the flow of each stream by days is given, and in Table No. 22, which gives the total monthly flows in inches depth with the mean monthly rainfall. The total run-off in million galons per twenty-four hours of each of the four important streams that were gauged are shown in Plate IV.

A study of this diagram makes clear that the portion of the rain that flows over the surface into the ponds and streams, or the flood flow, is comparatively small and the percolation correspondingly large. In other words, the flood flow during the summer, in the Long Island streams, is a relatively small proportion of the total run-off; this is made up, for the most part, of rainfall that first percolates through the ground to the surface of saturation and thence reaches the streams as ground water.

From the ground water elevations and the diagrams from the recording depth gauge of our weir stations, it was possible to draw a line on the "hydrograph" of each section which represented, approximately, the ground water flow of that stream; the distance between this line and the total flow of the stream is, then, the flood flow, or the water that entered the stream from the surface. The results of these analyses are shown in Table No. 23.

During the five months from July to October, inclusive, the total average run-off from the watersheds of the East Meadow Brook, Wantagh Streams, Newbridge Streams and Massapequa Stream, was 90.3 cubic feet per second, or 139.7 million gallons per day. This corresponds to a depth of 5.54 inches on the approximate ground water catchment area of the above watersheds, 57.7 square miles; this depth is 20.3 per cent. of the total rainfall of 27.30 inches for the five months, from July to October. The area of the surface watershed of these streams, a total of 91.9 square miles (see Plate V.), was not used in the computation of inches depth, because the surface flow during these months made up only a small proportion of the total run-off and the upper portions of the surface watershed, beyond the ground water divides, contribute but little or no ground water to these streams, as indicated by the ground water contours and confirmed by an inspection of the surface of the watersheds and the flow of the streams. The flow at the upper Massapequa gauging station near Farmingdale (see Table No. 21) shows that the flow there was little affected by heavy rains, and was comparatively insignificant compared to the corresponding flow per square mile farther down the stream.

Considering that this summer has been a season of heavy rainfall and the evaporation has been less than the normal, it is probable that, for the same period, in a year of average rainfall, *the total run-off would be about*

TABLE No. 23.

Flood Flows on Long Island Streams, June-October, 1903.

Month, 1903.	Rainfall per Month. Mean of Hempstead Storage, Oyster Bay and Farmingdale, Inches.	East Meadow Brook. 30.97 Square Miles.		Newbridge Streams. 3.31 Square Miles.		Wantagh Streams. 17.59 Square Miles.		Massapequa Streams. 40.03 Square Miles.		Mean.	
		Flood Flow, Inches Depth Surface Watershed.	Per Cent. of Monthly Rainfall.	Flood Flow, Inches Depth Surface Watershed.	Per Cent. of Monthly Rainfall.	Flood Flow, Inches Depth Surface Watershed.	Per Cent. of Monthly Rainfall.	Flood Flow, Inches Depth Surface Watershed.	Per Cent. of Monthly Rainfall.	Flood Flow, Inches Depth Surface Watershed.	Per Cent. of Monthly Rainfall.
June	9.56	0.18	1.88	....	....	....	....	....	....	0.18	1.83
July	3.17	0.08	2.49	....	....	....	....	0.03	1.01	0.06	1.80
August	7.27	0.18	2.46	0.22	3.05	0.24	3.25	0.10	1.32	0.16	2.13
September	2.09	0.04	1.67	0.02	1.15	0.10	4.74	0.02	0.77	0.04	1.87
October	5.21	0.11	2.05	0.10	1.98	0.14	2.59	0.04	0.83	0.09	1.63
Total	27.30	0.58	....	0.34	....	0.48	....	0.19	....	0.53	9.31
Mean	....	....	2.12	....	2.14	....	3.23	....	1.05	....	1.86

15 *per cent. of the mean rainfall of* 18.49 *inches for the period, or* 3 *inches, and, during a dry year, about* 2 *inches.* It would be fair to assume the same rates of run-off for the months of May and November, and a somewhat larger flow for April, say, 7 *inches, during a year of average rainfall and* 3.5 *inches* for a year of minimum rainfall.

(D) Total Annual Run-off.

If we add these results to the assumed run-offs for the months from December to March (7 inches in an average year, 4.5 inches during a period of drought) the total average stream flow in a normal year is 14 inches, or 33 per cent. of the average rainfall, and, in a year of low rainfall, about 8 inches, or 20 per cent. of a rainfall of 35 inches.

These values are somewhat larger than those obtained from the Brooklyn records, but, considering the possibilities of error in such computations, it is believed that the larger values are nearer the truth.

(E) Annual Ground Water Flow.

It has been noted that the greater portion of the flow of the Long Island brooks during the period of the gaugings during the past season was the seepage from the saturated soils near the surface streams. The amount of this seepage and, consequently, the flow of ground water in a stream, depends upon the difference in elevation of the surface of the stream and the surface of the adjacent water table. A comparison of the elevations of ground water in Wells Nos. 34 and 380, with the approximate ground water run-off curves in Plate IV. shows that this relation is, in general, true, so that if the relative heights of the ground water above the streams throughout the year are known, a measure of the relative amount of flow of the ground water for the whole twelve months may be obtained.

Unfortunately, no measurements for a period greater than a few months have been made of the elevations of the ground water near the streams that were accurately gauged and, therefore, the records of the elevation of the ground water at Millburn Reservoir must be used. The mean monthly elevations of the ground water at Millburn Well No. 34, above the surface stream just east of the reservoir, are given in Table No. 24 below, and are shown graphically in Fig. 2 of Plate IX., page 812.

Assuming that these represent the relative heads on the ground water that enters the streams between East Meadow Brook and Massapequa, the average monthly ground water flows for these streams have been computed from the assumed ground water run-off for September, the dryest month of our gaugings. The September run-off is unquestionably larger than that

TABLE NO. 24.

Mean Monthly Elevation of Water Table and Computed Ground Water Flow.

Month.	Mean Elevation of Ground Water Above Surface Stream.	Ratio of Heads Each Month to that in September.	Actual Measured Depth of Ground Water Flow in Inches during 1903.	Computed Ground Water Monthly Run-off in Inches Depth.
January......... ...	2.60	0.97	....	0.70
February.......... ...	2.88	1.07	....	0.77
March................	3.62	1.35	....	0.97
April................	3.85	1.43	....	1.03
May..................	3.84	1.43	....	1.03
June.................	3.61	1.34	1.28	0.97
July.................	3.22	1.20	1.07	0.86
August	3.03	1.13	0.84	0.81
September......... . .	2.69	1.00	0.72	0.72
October..........	2.25	0.84	0.75	0.61
November......	2.15	0.80	....	0.58
December	2.44	0.91	....	0.66
Total............	....	....	....	9.71

of a normal year because of the heavy summer rains; during a year of extremely low rainfall, a minimum September flow of only half this amount has been measured. Considering that in a normal year the spring flows are likely to be larger than those computed, because of greater fluctuations in the surface of the ground water near the heads of the streams than those of Millburn Reservoir, and that in dry years the annual ground water flow may not exceed 5 inches, *a value of 8 inches, or 19 per cent. of the total mean rainfall seems to be a fair estimate for the average annual ground water flow of the streams, and 5 inches, or 14 per cent. of the minimum rainfall, a probable minimum ground water flow.*

(F) Annual Flood Flow.

The difference in million gallons between the total run-off of the streams from Freeport to Massapequa and the estimated ground water flow is the flood flow of the streams, which are shown in Table No. 23. These flood flows have been reduced to inches depth on the surface watershed, on the asumption that the whole surface of each watershed delivers some surface water to the streams, although we know that the amount that is delivered from the upper portions of some of these watersheds is much less than that from the lower portions.

(*a*) *Summer Flood Flow.*

For the five months from June to October of 1903, the gaugings of the Commission on the streams from Freeport to Massapequa showed that the flood flow was little more than ½ inch, or less than 1.9 per cent. of the mean annual rainfall. This percentage of the rainfall that appears as flood flow is seen to be fairly constant for months of high and low rainfall, during the months from June to October, so that we may assume that the watersheds deliver surface water at the same rate for the months of May and November, allowing a greater percentage for April and somewhat larger quantities for May and November. This assumption gives a total flood flow of, say, 5 per cent. of the total mean rainfall of 22.18 inches, for the months from April to November, inclusive, or, say, 1.5 inches.

(*b*) *Winter Flood Flow.*

During the remaining four months from December to March, more or less snow is on the ground, the surface is frozen a portion of the time, and, consequently, the percentage of rainfall that appears as surface run-off is much larger.

(*c*) *Total Annual Flood Flow.*

The difference between the estimated total run-off and the ground water flow gives, for an average year, a total flood flow of 6 inches, which corresponds to a flood flow, from December to March, of 4.5 inches, or 33 per cent. of the mean rainfall for those months.

During a year of minimum rainfall, the flood flow, during the months from December to March, does not probably exceed that for the other eight months, or the total annual flood flow is not greater than 3 inches.

The total flood flow for a year of average rainfall is, then, 6 inches, or 16 per cent. of the rainfall, and only, perhaps, 3 inches, or 14 per cent., for a year of the minimum rainfall.

IV.—PERCOLATION.

That portion of the rainfall which is not immediately evaporated at the surface of the ground, or does not at once flow into the surface streams or ponds, enters the ground and percolates downward through the pores of the soil to the surface of saturation. A portion of this water in the soil is drawn to the surface by capillarity and evaporated either before or after reaching the water table; another part flows laterally through the saturated soil to a surface stream; and a third portion penetrates still deeper into the earth and finally escapes directly into the sea. The general movement of the water in the capillary spaces of the earth from the surface of the ground to the surface streams or the sea has been termed "seepage."

The downward movement of the water from the surface of the ground to the surface of saturation is, in this report, distinguished from the general movement or "seepage" by the term "percolation." Besides the downward movement, or percolation, the water in the pore spaces above the water table may move upward or laterally.

The direction of the flow of water above the plane of saturation is upward or downward according as the upward force exerted by the surface tension of the films of water in the capillary spaces is greater or less than the force that is exerted on the mass of the film by gravity.* When the soil becomes saturated, this capillary force is zero and any movement in the saturated strata is purely gravitational.

(*A*) *Downward Capillary Flow, or Percolation.*

The fact has been established by our observations and those of Prof. F. H. King, Mr. W. S. Auchincloss† and others, that the effect of a rain at the surface of saturation is not coincident with its fall when the water table is not immediately below the surface of the ground; the rain may not reach the water table for months after the precipitation occurs, if the water table is far below the surface.

> "It is a great mistake to imagine that rainfall penetrates rapidly to the lake (water table). This is rarely the case, and in many soils it takes months to accomplish the journey. Instances have occurred at Hill Crest (Bryn Mawr, Pa.) wherein the ground water steadily *lessened* in months of *heavy* rainfall; also instances in which the water steadily *rose* in times of severe *drought*" ("Waters Within the Earth and Laws of Rainflow," page 37).

* See "Mechanics of Soil Moisture," by Lyman J. Briggs, Bulletin No. 10, U. S. Department of Agriculture, Bureau of Soils.

† "Waters Within the Earth and Laws of Rainflow," by W. S. Auchincloss.

How slowly the rain may penetrate into the ground, under some conditions, can be judged from some observations of Prof. F. H. King, which were published in the seventh Annual Report of the Wisconsin Agricultural Experiment Station. On page 145, Prof. King gives the results of some observations following a rainfall of 1.14 inches on a very dry soil. This rain occurred during the night; the next morning the water had penetrated only three or four inches into the soil of the corn field; twenty-four hours later the depth that was wet was 4.5 to 5.5 inches in the corn and 4.5 inches in the clover; sixty-two hours from the beginning of the storm the rainwater had only penetrated 5.5 inches to 6 inches in the corn ground and 5 inches in the clover. To quote Prof. King:

> "Here, then, we see that when the ground becomes very dry, capillary action downward, aided by the force of gravity, is so slow that even a very heavy rain penetrates to so slight a depth that it may be nearly all quickly lost by surface evaporation."

This rate of motion, observered by Prof. King, averages about 0.1 foot per day which we shall see is, under average conditions, about the same as the velocity of the upward and lateral capillary movement.

The velocity of downward capillary movement is, in general, however, much greater than in this distance; for had the soil in the Wisconsin experiment been moist, the rainfall of 1.14 inches would have penetrated several feet during the time required to go as many inches.

The great range of depths at which the ground water is found on Long Island offers an exceptional opportunity for the study of the rate of downward capillary movement of percolation, and the observations of this Department on the fluctuations of the surface of the ground water give the means to compute the rate of this movement as well as the data to approximate the amount of this percolation.

(*a*) *Long Island Observations.*

On Plate VI. the results of many of the daily observations on the elevation of the water in the Long Island wells are shown, together with the rainfall and temperature of the air.

An inspection of this diagram shows that, when the ground water is only 1 or 2 feet below the surface of the ground, the greater part of the rain that does not immediately evaporate or flow over the surface into the streams, after a rainfall at once reaches the surface water. As the depth to the ground water increases, the time required for the water from a given rain to reach the surface of saturation becomes correspondingly greater; the amount of water from a rain that reaches the ground water during a given time is smaller; and the period of effect from a rainfall proportionally longer.

The inclination of the lines that have been drawn through the points of maximum and initial effect from the large storms of 1903, indicate that the velocity of percolation was greater in the summer than in the winter and early spring.

(1) *Winter and Spring Rains*—It will be seen from Plate VI. that when the surface of saturation was 3 or 4 feet below the surface of the ground, the peak of the rise of the water table occurred a day or two after the rainfall and that soon after the rain the surface of the ground water rapidly returned to its original level, through loss by capillary rise and lateral flow into adjacent streams; when the ground water was 40 or 50 feet below the surface, the bulk of the percolation from the March and April rains did not reach the surface of saturation for forty to sixty days after the precipitation, and the downward percolation still continued to affect the surface of the ground water for thirty days longer.

When the depth of the ground water was from eighty to ninety feet, the peak of the rise or time of maximum effect of the winter and spring rains occurred three to four months after the April rains and about six months from the beginning of the winter rains; and the water from these early rains still continued to sensibly affect the surface of saturation for thirty or forty days after the maximum had occurred.

(2) *Summer Rains*—Percolation from the rains of June, July and August reached the ground water with much less delay than that from the spring rains, and the effect of the heavy storm of the 1st of August was noticeable even at a depth of 30 to 40 feet within a few days. At still greater depths, the effect of the summer rains was not marked by any pronounced rise, but it is clear that the percolation from these storms held the ground water for several weeks at the maximum that had been reached through the percolation from earlier rains.

(3) *Computation of Velocity of Percolation*—Through the maximum and minimum points on the plotted curve of each well, lines have been drawn from the surface of the ground, at the time of the occurrence of the rainfall, which show the average length of time required for each large addition to the ground water to pass from the surface of the ground to the given depth. Considering that the wells on which the observations were made are scattered over the southerly part of Nassau County and a few are in the westerly part of Suffolk County and that the material of the substrata at each well ranges from gravel to fine sand, the agreement between the many observations is, on the whole, very good. The strata through which this percolation took place consists of 12 to 18 inches of brown loam and 18 to 24 inches of yellow subsoil, which overlie the so-called "yellow gravels" of the glacial outwash

plain. This material is made up, in general, of yellow to reddish sands, ranging from coarse to fine, occasionally mixed with coarse and fine gravel, and very fine sand. On an average, the effective size of the material is 0.25 and the uniformity coefficient from 2 to 6, as shown in the classification and sizing of typical wells on Plates VI. and VII.

From these curves the velocities of percolation have been computed for each 10 feet in depth from the surface to a depth of 90 feet, and are shown in Table No. 25.

Table No. 25.

VELOCITY OF PERCOLATION ON LONG ISLAND.

Rate of Downward Flow of Capillary Water in Southerly Outwash Plain.

Depth of Surface of Saturation below Surface of Ground.	Date of Maximum Effect of this Rain When Most of Percolation had Reached Water Table.	Time in Days Between This and Date of Rain.	Time in Days For Each Ten Feet.	Velocity of Percolation in Feet Per Day.
Storm of March 8 and 9, 1903.				
10	Mar. 16	8	8	1.25
20	Mar. 29	21	13	0.77
30	Apr. 22	35	14	0.71
40	Apr. 27	50	15	0.67
50	May 14	67	17	0.59
60	June 1	85	18	0.56
70	June 20	104	19	0.53
Storm of April 14 and 15, 1903, preceded by succession of small storms and, excepting two small showers, followed by 53 days of drought.				
10	Apr. 20	5	5	2.00
20	Apr. 30	15	10	1.00
30	May 13	28	13	0.77
40	May 28	43	15	0.67
50	June 13	59	16	0.63
60	June 29	75	16	0.63
70	July 15	92	17	0.59
80	Aug. 1	109	17	0.59
90	Aug. 18	126	17	0.59

Depth of Surface of Saturation below Surface of Ground.	Date of Maximum Effect of this Rain When Most of Percolation had Reached Water Table.	Time in Days Between This and Date of Rain.	Time in Days For Each Ten Feet.	Velocity of Percolation in Feet Per Day.
Storm of June 7 and 8, 1903, preceded by 53 days of drought.				
10	June 10*	3	3	3.33
20	June 18	11	8	1.25
30	June 28	21	10	1.00
40	July 9	33	12	0.83
50	July 23	47	14	0.71
60	Aug. 6	61	14	0.71
70	Aug. 20	75	14	0.71
80	Sept. 3	89	14	0.71
Storm of June 29 and July 2, 1903.				
10	July 5	3	3	3.33
20	July 11	9	6	1.67
30	July 20	18	9	1.11
40	July 30	28	10	1.00
50	Aug. 9	38	10	1.00
60	Aug. 19	48	10	1.00
Storm of August 5, 1903.				
10	Aug. 7	2	2	5.00
20	Aug. 10	5	3	3.33
30	Aug. 17	12	7	1.43

* The dates of this storm are those of initial effect.

(4) *Seasonal Change in Velocity of Percolation*—The velocities at all depths increased during the period of the observation, from March to November; those at the surface from 1.25 feet per day to 5.0 feet per day; those at depths of 80 to 90 feet, from 0.5 to 0.7 foot per day.

This increase in velocity may be attributed, in a measure, to the increasing temperature of the upper strata during the summer months, which decreased the surface tension of the capillary films; but it is to be explained, for the most part, by the greater amounts of moisture contained in the capillary spaces after the passage of the early spring rains.

TABLE NO. 26.

Date of Maximum Effect from Spring Rains at Depths from 10 *to* 90 *Feet in Years from* 1898 *to* 1903, *Inclusive.*

Depth of Surface of Saturation below Surface of Ground.	Date of Last Heavy Spring Rain after Frost Left Ground.	Date of Summit of Ground Water.	Time Between Rain and Summit of Ground Water. Days.	Date of Last Heavy Spring Rain after Frost Left Ground.	Date of Summit of Ground Water.	Time Between Rain and Summit of Ground Water. Days.	Date of Last Heavy Spring Rain after Frost left Ground.	Date of Summit of Ground Water.	Time Between Rain and Summit of Ground Water. Days.
	1898.			1899.			1900.		
	Average Temperature of Air May 26—54°.			Average Temperature of Air Mar. 19–29—55°.			Average Temperature of Air Mar. 16–20—34°.		
2	May 26	May 27	1	Mar. 19-24	Mar. 23	....	Mar. 16-20	Mar. 21	1
5	....	May 28	2	....	Mar. 24	....	....	Mar. 22	2
10	....	May 31	5	....	Mar. 31	7	....	Mar. 30	10
	1901.			1902.			1903.		
	Average Temperature of Air April 20, 21—45°.			Average Temperature of Air Mar. 5–9—35°.			Average Temperature of Air Apr. 14, 15—42°.		
2	Apr. 20, 21	Apr. 22	1	Mar. 5–9	Mar. 10	1	Mar. 14, 15	Mar. 16	1
5	....	Apr. 24	3	....	Mar. 11	2	....	Mar. 17	2
10	....	May 4	14	....	Mar. 14	5	....	Mar. 20	5
20	....	....	....	....	....	....	....	Mar. 30	15
30	....	....	....	....	....	....	....	May 13	28
40	....	....	....	....	....	....	....	May 28	43
50	....	....	....	....	....	....	....	June 13	59
60	....	....	....	....	....	....	....	June 29	75
70	....	....	....	....	....	....	....	July 15	92
80	....	....	....	....	....	....	....	Aug. 1	109
90	....	....	....	....	....	....	....	Aug. 18	126

The Temperature Factor—The temperature of the surface soil follows very closely that of the air, but the annual variation in the temperature of the earth decreases rapidly with the depth; at depths of 40 to 60 feet, the change is not over three or four degrees, and at greater depths the temperature of the earth is sensibly constant. This difference in the temperature of the earth at different depths accounts for the greater velocities at the surface than below, and the higher temperatures during the summer months may, in part, explain the greater velocities of percolation observed in the summer in depths from the surface to perhaps 20 or 30 feet. Changes in the temperature, however, do not account for the changes in velocity at depths of 60 to 80 feet, where the temperature is almost constant.

The effect of temperature on the adjustment of water in soils is discussed by Professor Briggs, in "The Mechanics of Soil Moisture." On page 21 he states:

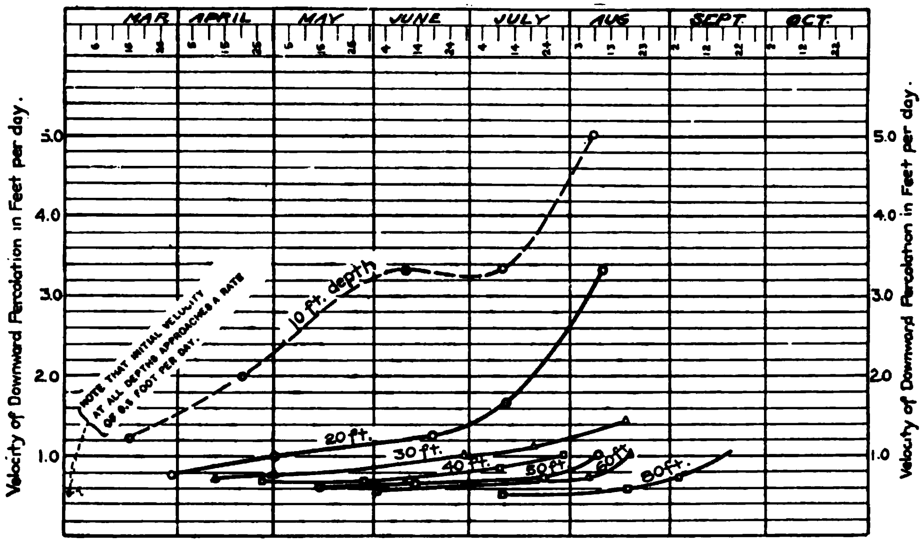
"The influence of temperature on the rate of flow of water in saturated soils is very great. This is due to a change in the viscosity of water with temperature, as has been pointed out in the section on viscosity. This property is not only of interest in considering saturated soils, but is also an important factor in determining the rate of adjustment of water in soils in which saturation is not complete."

Effect of the Saturation of the Soil—The observations of the Brooklyn Water Department as well as those of this Commission show clearly the effect of saturation upon the rate of percolation.

It is evident from Plate IX. that the heavy rainfall of April 20 and 21, 1901, was preceded by a winter in which the precipitation had been very small; the residual mass curve indicates that the greatest deficiency in rainfall, during the period from 1897 to 1903, occurred in March, 1901, at which time, and in the November of the preceding year, the Millburn well showed the greatest depletion in the ground water for the seven years of which there is a record. The result of this low precipitation, during the winter and spring months, when the evaporation was small and the ground water reserves should ordinarily have been replenished, was to lower the ground water and drain out the water in the soil above, so that the April rains fell on a comparatively dry soil; the substrata absorbed the rainfall; the amount that reached the surface of saturation was consequently less than in other years; and the velocity of percolation was correspondingly low. The percolation from the rain of March 19 and 20, 1899, which required ten days to reach the surface of saturation, occurred under somewhat similar but less severe conditions of low winter precipitation.

The increasing velocities that were observed in the deep wells (Plate VI.) during the months from March to November of 1903, are entirely due to the increased saturation of the sands in the summer through the passage of water from the winter and spring rains.

FIG. 42. APP. VII.



RATE OF PERCOLATION
VELOCITIES AT DEPTHS OF 10 TO 80 FEET BELOW SURFACE OF GROUND
MARCH TO OCTOBER, 1903

The velocities at each depth have been plotted in Fig. 42, and it appears that the initial rate of percolation at all depths from the early winter rains was very nearly 0.5 foot per day and that the water from later rains traveled at a greater velocity because of the greater saturation of the soil. In August and September, this velocity was about 1 foot per day at 80 or 90 feet in depth; about 2 feet at a depth of 30 or 40 feet; and approached the rate of saturated flow under hydrostatic head near the surface, because of the high degree of saturation. The slow downward movement of the rain to the surface of saturation is a very important factor in a consideration of the purity of a ground water supply. Even at a downward velocity of 2 feet per day, the highest velocity found at a depth of 30 or 40 feet, it is evident that the time required for the rain to pass from the surface of the ground to the surface of the deep ground water is sufficiently long to cause a sterilization of the waters through the starvation and death of the bacteria that are carried down from the surface.

Other observers have noted the slow downward movement of the capillary waters and have also shown that the rate of movement is dependent upon the degree of saturation of the soil and substrata.

" Close observation shows that a copious rainfall can make its journey to the sublake in twenty-five days, provided the soil has been *saturated* by frequent storms. But when the ground is moderately dry, it takes sixty days to cover the same distance. A period of drought prolongs the time to at least ninety days. Just in proportion, then, as the dryness of the soil increases will the time of descent be prolonged." (" Waters Within the Earth, and Laws of Rainflow," page 10.)

" If the soil is nearly saturated, so that the films connecting the capillary spaces are short and thick, and the capillary spaces themselves are not active, but little resistance is offered to the movement of water, and the addition of water at the surface is quickly felt farther down. If, on the other hand, the soil contains but little water, the same amount of water added to the surface, while producing marked changes in the upper layers, will not be felt so quickly at the lower depths on account of the activity of the upper capillary spaces and the length and small cross section of the connecting films. But an adjustment of the water between the upper and lower capillary spaces takes place in this case also until equilibrium is gradually reached." (" The Mechanics of Soil Moisture," page 20.)

Increase in Velocity Not Increase in Quantity—The increase in the rate of percolation to the shallow and deep ground waters that was observed by this Department did not mean that the amount of percolation on Long Island was increased during the past summer, for the sharp rise of the ground water surfaces in March, April and May indicated that the quantity of water reaching the water table or the surface of saturation was a maximum when the velocity of percolation was the least.

(*B*) *Upward Capillary Flow.*

Unlike the downward movement in the pore spaces of the soil, the upward movement which has been termed by Professor King the " translocation of moisture," takes place against gravity, and the rate of motion is slow compared with that of percolation through moist earth.

The velocity of this upward movement of moisture has been determined by Professor King at the Wisconsin State University. In the sixth and seventh Annual Reports of the Wisconsin State Agricultural Experiment Station, he described his experiments on evaporation and upward flow through fine sand and clay loam.

Tanks 4 feet long and 1 foot in diameter were placed where a current of air from a ventilator passed across the tops. Measured amounts of water were added at the bottom of the tanks each day to maintain the surfaces of saturation at constant levels. During the series of experiments, the water was maintained at the surface and at depths from 1 to 4 feet below, and but for a crust of salt that formed on top of the soil, the loss with the water at the several depths would have been very nearly the same.

Assuming the area through which the motion took place to be 33 per cent. of total section, the result indicated a velocity of 0.10 to 0.13 foot per day, which is confirmed by other experiments of Prof. King in which he observed the time required for moisture to rise through eleven inches of dry soils. The velocities by these experiments ranged from 0.04 to 0.18 foot per day.

(*C*) *Lateral Capillary Flow.*

The same conditions that cause a movement of soil moisture upward may give rise to a lateral transfer of moisture, the mechanics of which are explained by Prof. Briggs in "The Mechanics of Soil Moisture," page 19.

Prof. King's experiments showed the velocity of this flow to be very small—not over 0.1 foot per day. The lateral transfer of soil moisture, however, cannot be considered as important in these studies as the motion in a vertical direction.

(*D*) *Amount of Percolation.*

The amount of rainfall that is permanently added to the ground water resources is a maximum under the conditions that give the least evaporation and surface run-off; that is, when the precipitation is high and the soil moist, the surface of the ground and the substrata loose and porous, the surface of saturation beyond the limit of capillary, the air movement small and the surface of soil approximately level and fairly rough.

The percolation is a maximum in the spring, but, in general, is large during the months from November to May and small during the remainder of the year.

The total amount of percolation on Long Island may be estimated from the fluctuations in the elevation of the ground water surface, from such tank experiments as may have been made on Long Island and elsewhere, and from the rainfall, evaporation and stream flow.

(*a*) *Fluctuations of the Surface of the Ground Water.*

At first sight, the rise in the ground water after a rainfall seems to be the best possible measure of the amount of percolation, providing the pore spaces of the material at the water surface is known. Several difficulties, however, at once appear; all the seepage from a given area does not at once reach the ground water but works slowly down for several days after the rain, during which time the water table has fallen an unknown distance through loss by seepage into lower strata or lateral flow to surface streams. Besides this uncertainty in the total rise of the water table, a still greater difficulty is found in obtaining the actual amount of pore space that exists above the surface of saturation. The total rise of the water table, due to a given rain, can be determined within reasonable limits, but the actual amount of space available in the sands at the time of each rain cannot be obtained except by very frequent moisture observations at the surface of saturation.

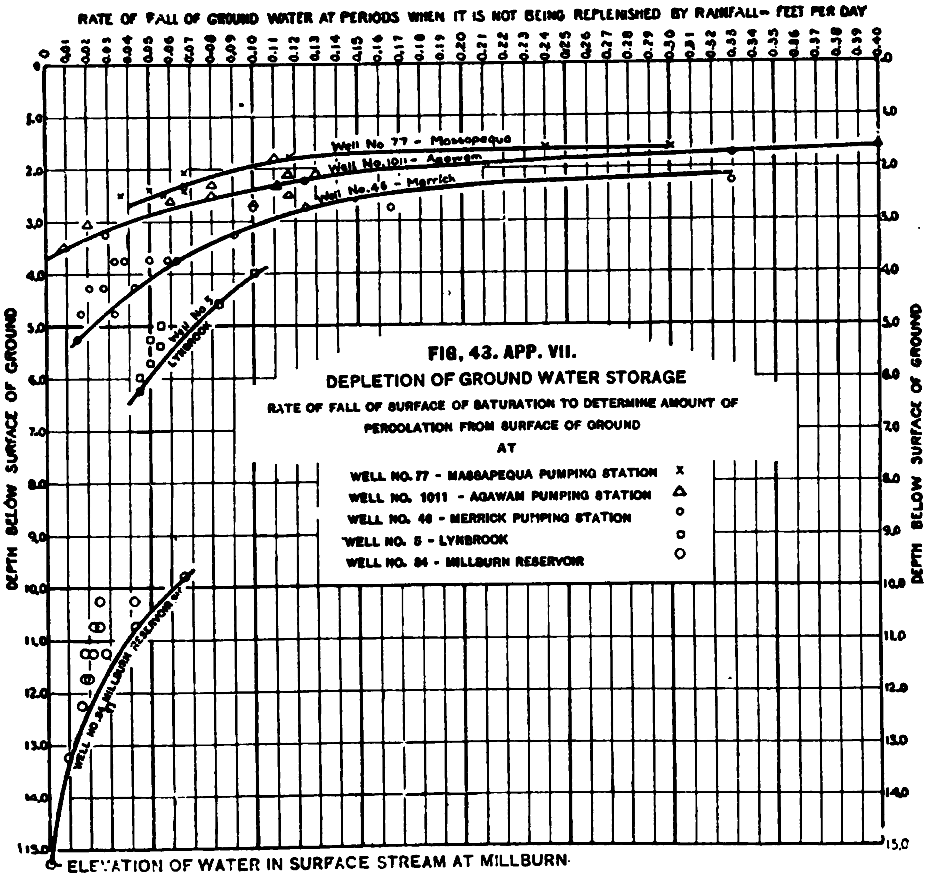


FIG. 43. APP. VII.
DEPLETION OF GROUND WATER STORAGE
RATE OF FALL OF SURFACE OF SATURATION TO DETERMINE AMOUNT OF PERCOLATION FROM SURFACE OF GROUND AT

An attempt has been made to approximate the amount of percolation on Long Island from the observations of the Brooklyn Water Department on the ground water at Millburn Reservoir from 1897 to 1903. The ground water there is 12 to 15 feet below the surface of the ground, and, therefore, out of reach of evaporation. A depletion curve was worked up for Well No. 34 by computing from the depth curve in Plate IX. the rate of fall of the water table during periods of no rain. These rates, with the corresponding mean elevation of the water table, were plotted in Fig. 43 and the line drawn by aid of these points gave the rate at which the surface of the ground water fell from any elevation when no water was being received at its surface. The amount of fall of the water table was first worked up from this curve for each calendar month for a condition of no rain, and the difference between this amount and the actual amount of fall represented the height of water in the soil corresponding to the rainfall for that month. This actual rise was then converted into depth of water in inches by considering the space available as equal to the total pore space, less the average amount of moisture present at a distance of about 12 to 24 inches above the surface of saturation. The curve

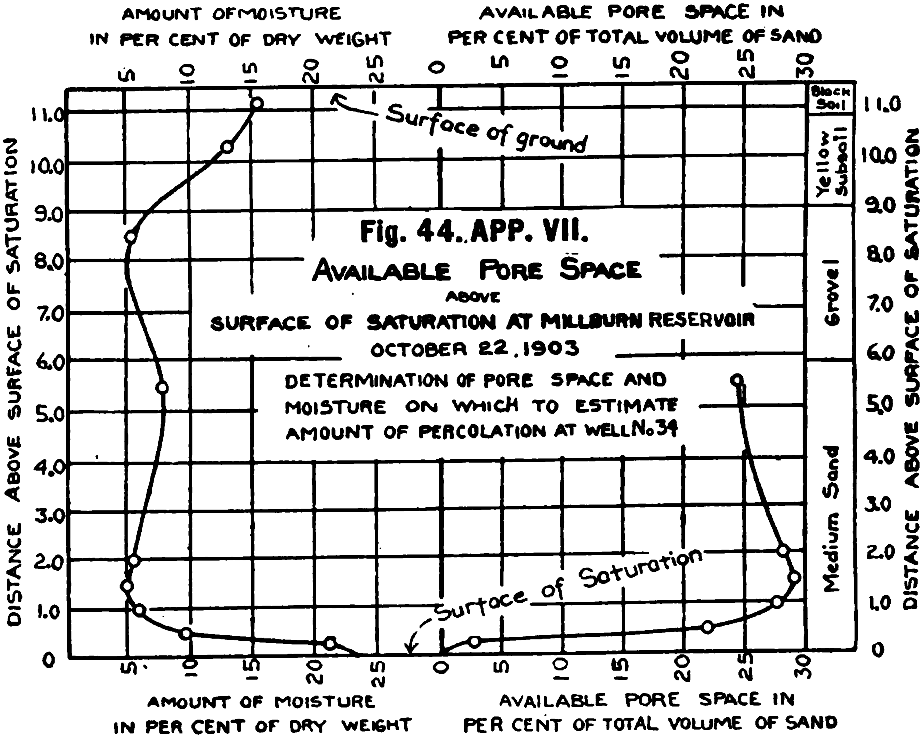


Fig. 44. APP. VII.

of saturation (Fig. 44) on which the value of pore space required by this assumption was based, was made up from moisture determinations on the sands at Millburn Well No. 34. A little study shows that if the amount of moisture immediately above the surface of saturation is constant, it is the available pore space above the highly saturated stratum that must be considered filled by percolating waters.

The extensive work of the Chemical and Biological Department on soil physics showed that, in general, the amount of moisture, 2 to 3 feet above the water table, varied within comparatively small limits.

The method, in general, gave reasonable results, but an occasional value for the amount of percolation during a month, which was several hundred per cent. larger than the rainfall, showed that the amount of moisture in the sands above the water table was not always as constant as had been assumed, and that a great many moisture observations would be required to secure consistent values for percolation.

The totals for each year from the Millburn well, with the corresponding rainfall, are given in Table No. 27.

TABLE NO. 27.

Approximate Amount of Percolation at Millburn Reservoir from the Fluctuations in Brooklyn Well No. 34.

Year.	Total Rainfall each Year at Hempstead Storage Reservoir.	Total Estimated Percolation.	
	Inches Depth.	Inches Depth.	Per cent. Total Rainfall.
1898	51.12	28.74	56.2*
1899	43.60	29.91	68.6†
1900	42.03	14.23	33.9**
1901	49.92	22.21	44.5**
1902	51.98	29.98	57.7
Average	47.77	25.01	52.4

The surface in the vicinity of the Millburn well No. 34, at which the observations on the ground water were made, is covered with sod, from which character of surface the evaporation is known to be large, so that, on the basis of the fluctuations at this well, the mean percolation over Long Island, during the years from 1897 to 1903, was probably close to 60 per cent. of the mean rainfall. The rainfall during that period was above the normal (see Mass Curve of Rainfall, Plate II.), so that, from these studies, the total perco-

* Heavy rains from May to November.
† Rainy spring and summer.
** Years of maximum ground water depletion, 1897-1903.

lation for the Long Island watersheds, during a year of average rainfall, is not probably over 50 per cent. of the mean annual rainfall, or 22 inches. For a dry period, the amount of percolation would be still less, and probably not greater than 17 or 18 inches, or 50 per cent. of an annual rainfall of 35 inches.

(*b*) *Percolation Experiments at Floral Park,* 1903.

The experiments at Floral Park indicate a total percolation, during the the months from July to October, inclusive, of 7.24 inches, or 38 per cent. of the total rainfall for these months. This includes, let us assume, the total amount of surface run-off, say 1 inch (stream gauging), which leaves 6.24 inches, or 33 per cent., of the rainfall for percolation.

In these experiments the soil in the tank was only 2 feet above the water and the evaporation was naturally large, so that 50 per cent. of the rainfall may have percolated through a similar soil where the ground water was 10 feet or more below the surface of the soil.

As the surface of the tank was uncropped, this percentage also includes the water which is absorbed during the growing season by vegetation. Prof. King's experiments indicate this amount to be, perhaps, 8 inches, or say 20 per cent. of the rainfall. The above considerations serve to check the amounts of percolation that must be computed from the estimates of evaporation and stream flow.

The amounts of percolation that were found in the English experiments on evaporation and percolation, which are given in Tables 9, 10 and 11, are of interest in showing the seasonal distribution of percolation, but the results are not applicable to Long Island conditions.

The carefully conducted experiments on the percolation of water that were made by Walling, in Munich, show the effect of a sod in reducing the percolation through sand, peat and clay soils.

TABLE NO. 27A.

Percolation Experiments of Walling, Munich.

Rainfall	100.	per cent.
Percolation through—		
Sand:		
Fallow	65.	"
Grass	14.	"
Peat:		
Fallow	44.	"
Grass	8.7	"
Clay:		
Fallow	33.	"
Grass	1.3	"

(*C*) *Final Estimate of Percolation from Rainfall Evaporation and Stream Flow.*

If the mean evaporation from the Long Island watersheds is 40 per cent. of the rainfall, or 17 inches, and 17 inches the evaporation during a dry period, 49 per cent. of a minimum rainfall of 35 inches, the percolation and the surface run-off or flood flow is 25.5 inches for an average year and 18 inches during a period of dry years. The average surface run-off was estimated (page) at 6 inches and the minimum, for a period of low rainfall, at 3 inches. The total annual percolation on the Long Island watersheds is then (25.5—6=) 19.5 inches, or 44 per cent. of the rainfall for an average year, and (18—3=) 15 inches, or 42 per cent. for the rainfall during a period of dry years.

V.—Ground Water.

(*A*) *Configuration of the Long Island Water Table.*

The contours of the surface of saturation which are drawn as blue dash and blue dotted lines on Plate VIII.,* show the approximate form, on July 1, 1903, of the surface of the mass of the saturated strata on Long Island, exclusive of that in the Borough of Brooklyn, that in the easterly end of Suffolk County and of those masses in such unimportant areas as the peninsulas on the north shore. Where these contours are shown as a succession of long dashes, the surface of the ground water is well established; where shown as dotted lines, as on some of the areas covered by the moraine and the thick layers of till on the northerly portion of the Island, the location of the surface of the water table is somewhat conjectural, because few existing wells were found there of sufficient depth to reach the true water table and the cost of the necessary test wells, some of which would have had to be fully 150 feet in depth, was prohibitive. The surface of the ground water, which is held by the fine compact material forming the moraines and the layers of till that partially cover the northerly portion of the Island, are not shown on this contour map, since, in general, it appears that the water from these elevated strata is slowly percolating into the sands and gravels

* It is of interest to compare the contours of the ground water on this map with those given by Mr. Kirkwood in his "Map Showing Drainage Extent of Supply Streams" in the "Report on Brooklyn Water Works" of 1867. The general agreement between the contours on the two maps is very good, although, with more points of observation, the lines determined by the Commission are not as regular as those of Mr. Kirkwood and the ground water is somewhat higher now than when the Kirkwood surveys were made.

that, as the geologists have shown, underlie the mantle of till, to what might be termed the lower water table, which is the surface shown by the contours on Plate VIII.

The strata between these two saturated layers are, in some localities, completely saturated, the difference between the elevations of the two water tables representing the loss of head through vertical seepage; but in many localities the intervening sands were found to be only partially saturated.

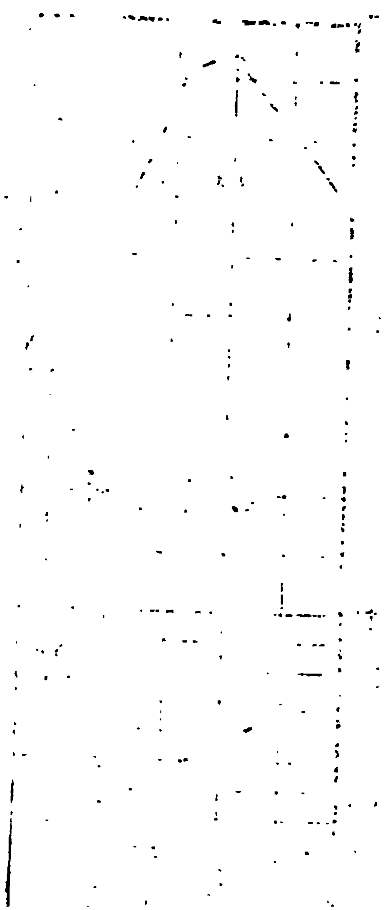
Farmers on the Island have stated several instances of wells being dug through the upper water-bearing strata, in an effort to get more water than the fine material there afforded, and of not finding any water until the lower water table, the "main vein," as they termed it, was reached.

Neglecting, however, these elevated water tables and the pockets that are found where disturbed strata of fine material exist, the shape of the ground water conforms to the general topography of the Island. The position of the summit of the water table, at some points, is coincident with the surface summit, but, in general, differs greatly from it.

The flow of water in the pore spaces of the soil resembles in character that of a viscous liquid like molasses. If, then, we imagine a thick and uniform layer of molasses applied to a figure similar to that of the outline of Long Island—just as a uniform layer of rain is applied to the Island—and allowed to run off over the edges, we would find that the shape of the resulting surface would resemble that of the Long Island water table. Like the mass of the ground water, the molasses would be higher in the centre than on the edges and the highest point would be in the centre of the widest part of the figure.

The actual form of the water surtace would conform more closely to that formed by the molasses and the summit of the water table would, consequently, be nearer the center of the island, if the valleys did not exist in the surface of the island on the north and south shóres and if the material of the saturated strata were everywhere uniform. The valleys that are occupied by surface streams remove a large proportion of the ground water from the upper saturated strata and make the form of the water table irregular; where these valleys do not exist, the ground water contours are parallel with the shore line. In consequence of the deeper valleys and the finer and more compact material of the saturated strata on the northerly side of the island, the water table there is more irregular and the slopes much steeper than on the south shore.

While the amount of data is not so complete on the north as on the south side of the island, there is enough information to show clearly that the character of the surface of the water tables and the material of the substrata differ greatly on the two slopes.



(*B*) *Difference Between Surface Watersheds and Ground Water Catchment Areas.*

(*a*) *Effect on Stream Flow and Underflow on the South Shore.*

The position of the ground water divide materially affects the run-off of the streams on both shores of the island and the amount of underflow beneath the streams. From Jamaica to Brentwood the ground water divide is, on an average, 2 miles south of the surface divide and 9.5 miles from the south shore; from Brentwood east to a line between Port Jefferson and Patchogue, the ground water divide is about 3 miles north of the surface divide and 10 miles from the south shore. The Brooklyn gaugings show that the dry weather flow per square mile of surface watershed of the large streams on the south side, that are within the first section, are less than the flow per square mile of surface watershed of the large streams east of Brentwood and Smithtown.

It is evident, then, from the position of the ground water divide and the stream flow, that, the material of the substrata being the same, somewhat larger quantities of water, for a given length of conduit line, should be obtained along the south shore in Suffolk County between Islip and Moriches than in the present Brooklyn Watershed from Ridgewood to Massapequa.

(*b*) *Effect of Stream Flow on North Shore.*

No gaugings of the streams on the north shore have been made. The only large stream there, the Nessequogen River, however, occupies a deep valley near Smithtown, at which point the ground water divide is much nearer the south shore than at any other point between Ridgewood and Moriches.

(*C*) *Cross Sections of the Island.*

The cross sections of the island in Plate VII. show more clearly than the contour map the different character of the slopes on the north and south shores.

(*a*) *Southerly Slopes.*

The southerly slopes of the water table are, in general, well established and are consistent with the known laws of flow in porous media. The sections show that where the lateral flow is approximately in the direction of the section lines and a portion of the water is not diverted laterally by surface drainage, the general character of the curves of the upper surface of the ground water approximates the theoretical curve of the flow in a uniform material above an impervious floor before entrance to a surface stream: that is, a parabola with its axis horizontal and its vertex outside the limits of the land surface.

The irregularities in the slopes can readily be explained by the presence of strata of fine material; none of these strata are, however, continuous, as the blue clays of what the United States Geological Survey calls the "Sankaty Deposits" were once believed to be, so that they have less influence on the flow than if they formed an impervious floor under the island.

The slopes of the southerly surface of the Long Island water table have been determined from the plotted sections and are given in Table No. 28.

TABLE NO. 28.

Slope of Surface of Ground Water on Long Island.

From Summit of Water Table to South Shore.

Distance from Summit, in Miles.	Slope of Ground Water, in Feet, Per Mile.											
	Section Numbers.											
	1	2	3	4	5	6	7	8	9	10	11	12
1	4.5	11	4.0	7.0	(2.0)	(1.8)	(2.5)	(4)	(3.8)	13.0	1.0	1.5
2	6.5	..	4.3	8.8	8.5	2.0	5.0	5.5	5.2	16.5	3.0	3.5
3	7.0	..	6.5	10.5	14.5	4.3	5.8	5.0	6.7	20	3.8	5.0
4	...	..	11	11.8	....	9.5	4.2*	5.0	14.3	....	9.0	7.5
4.5	...	..	15	....	....	....	....	....	....	....	...	....
5	...	.	....	18.5	....	11.0	12.0	4.0	....	....	6.3	10.5
6	...	..	....	....	....	13.0	12.0	6.0	....	....	5.5	15.5
7	...	..	....	....	....	13.5	14.5	10.0	....	....	5.5	10.0
8	...	..	....	....	....	13.2	13.0	11.5	....	....	...	11.0
9	...	..	....	....	....	....	15.5	11.5	....	....	..	....
10	...	..	....	....	....	....	....	13.5	....	....	...	....

The slopes range from 2 to 20 feet per mile; the maximum slopes on each section from 7 to 20, an average of 14 feet per mile. From observations of the water table south of Jamaica, Mr. Kirkwood stated, in 1867, that the water table "has a pretty uniform inclination toward the southern shore or 12 feet per mile" ("Report on Brooklyn Water Works, 1867," page 60), which is very near the mean maximum that was found, although somewhat greater than the present maximum slope of the water

NOTE.—The figures in parentheses indicate that the ground water surfaces at those points are not fully established.

* This marked flattening of the curve at a distance of four miles from summit of the water table is apparently caused by the stratum of fine sand shown at a depth of three feet below the surface of the ground water in Test Well No. 908, and for the same reason the gradient rapidly increases to 12.0 feet at a distance of five miles from the summit.

table in the easterly and westerly portions of the island and less than the present maximum slopes in the centre of the island where the height of the summit of the water table is greatest. The maximum gradient on the sections, on July 1, 1903, was that on Section 10, at a distance of three miles from the summit of the water table.

The maximum slopes and, in general, the maximum velocities corresponding, are near the south shore, where the volume of flow is greatest, and a large amount of ground water is rapidly withdrawn by the surface streams.

(*b*) *Northerly Slopes.*

It has been noted that the slopes of the surface of saturation on the north shore are much steeper than the southerly slopes, because of the presence there, in general, of finer and more compact material than in the outwash plains and the underlying strata on the south shore of the island. The northerly slopes are not well determined, but vary from 30 to 100 feet per mile.

(*c*) *Artesian Wells.*

When even a comparatively shallow well is driven into the saturated sands below the surface till on the north shore of the island, particularly at the heads of the deep bays where the slope of the ground water surface is a maximum, a marked artesian condition is found, because of less resistance to the upward flow of the ground water through the pipe than to its escape through the earth. Deep wells on the south shore also reveal a slightly greater pressure at the bottom than that due to the height from the bottom of the well to the surface of the water table. In general, in a homogeneous material this pressure is that corresponding to the height of the summit of the water table above the bottom of the well minus the loss of head due to the frictional resistance to the passage of the water between these two points. The difference between the surface of the water in an artesian well and the elevation of the sea is the head that is required at the depth of the bottom of the well to overcome the frictional resistance of the flow between that point and the point where the water enters the sea.

The proximity to the north shore of the summit of the water table explains the greater artesian effect observed there in wells of all depths, for the distance from the summit of the water table to any well on the north shore is much less than the distance from the summit to the south shore and the loss of head is, therefore, less, although, in general, the material on the north shore is finer and, consequently, offers more resistance to flow.

While thick clay beds exist on the north shore, as well as on the south shore, overlying fairly coarse water-bearing sands, there is no evidence that the deep clay beds on the north shore are more continuous than the strata of blue clay under the south shore were found to be and, therefore, it is very reasonable to suppose that the water found in the deep wells on the north shore represents seepage from the summit of the water table near the centre of the island.

(*D*) *Fluctuations in the Elevation of the Surface of the Ground Water.*

The ground water observations made by this Department showed that the surface of saturation is never at rest but constantly rises and falls, as the accession of rainwater to this surface from above is greater or less than the loss or efflux of water from the saturated strata through vertical or lateral flow. These changes in the elevation of the water table may be divided into long period fluctuations and annual fluctuations.

(*a*) *Long Period Fluctuations.*

(1) *Long Island Ground Water Observations*—The long period fluctuations in the elevation of the water table are occasioned by the variation in the amount of rainfall from year to year. To properly study such changes requires, of necessity, a long series of ground water observations which, unfortunately, have not been made on Long Island.

The observations of the Brooklyn Department of Water at Millburn Reservoir furnish the only adequate data that we have for the study of the long period fluctuations and these cover only six years and were made on shallow wells only 10 to 15 feet deep not far from a surface stream.

Shallow Ground Waters—During a greater portion of the six years, 1897 to 1903, covered by the Millburn observations, daily readings of the elevation of the water in the test wells about the Millburn Reservoir were made, and, for the remaining time, the measurements were made once a week. The results of these measurements, with such observations as were made by this Department at Millburn, are plotted with those on several much shallower wells on Plate IX., together with the residual mass curve of rainfall for the years from 1897 to 1903. It is evident, from a study of this diagram, that the greatest elevation of the water table occurred during periods of maximum rainfall; the maximum elevation of the surface of the Millburn well was in 1899, when the residual mass curve shows the greatest excess in the rainfall; the next highest elevation was in 1903, when the mass curve again indicates an excess in the total rainfall, but not so great as that in 1899. The minimum elevation of the ground water at Millburn Reservoir occurred in the winter of 1900-1901, when the greatest depletion in the rainfall is found. The maximum change in the elevation of the ground water was 4.9 feet, from a depth of 9.6 feet to a depth of 14.5 feet.

Deep Ground Waters—If the elevation of the ground water near the surface of the ground changes from year to year with the variation in the amount of total rainfall, it is more than likely that the deep waters, which are beyond the influence of loss from evaporation and farther from surface streams than shallow waters generally are on Long Island, will show the same fluctuation, during a given period of years, as those in the shallow wells, and the amount of such fluctuations in the deep waters will probably be greater than those that were found at Millburn Reservoir, where the height of the ground water is controlled by a surface stream. While no measurements on deep ground waters have been made, the evidence that has been collected on the heights of certain Long Island ponds and upon the depths of water in old domestic wells permits a fair estimate to be made of the maximum fluctuations that have occurred during the past seventy years.

Evidence from Lake Ronkonkoma—The fluctuations of the surfaces of the ponds in Suffolk County that occupy the deep kettle holes that extend below the general surface of the water table would, if known, give a good idea of the corresponding fluctuations in the ground water, for these ponds of this description that have no surface outlet are simply immense natural wells. Lake Ronkonkoma is the largest and best known of these ponds and the rise and fall of its waters have been an object of speculation for many years in the easterly part of Long Island.*

This lake is a few miles north of the station of the same name on the Long Island Railroad; it is in the centre of a hollow in the hills that is without surface outlet, has an area of about 230 acres and at present is said to have a maximum depth of about 60 feet; as its surface is about Elev. 55, the bottom of the lake is somewhat below sea level. It can readily be appreciated that, with this great depth, the waters of the lake must follow very closely the rise and fall of the ground water.

Mr. William H. Warner, of Ronkonkoma, has occasionally made some notes on the height of water in the lake and from these he stated that: "In 1857 the lake was low; in 1891 it was higher than any one living re-

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* A curious theory is current near Ronkonkoma and elsewhere on the island that the surface of the lake and the ground water surface throughout the island rises and falls once in seven years. The idea, however, is not credited by close observers and all the evidence that has been gathered disproves it.

A very similar notion is held by the river men along the St. Lawrence River, but the United States Engineers' gaugings on the lakes prove the idea to be as mistaken as the Long Island story seems to be.

The identity of the two ideas that were advanced to explain a simple phenomenon that is caused by the variation in the rainfall is of interest, for it calls our attention to the similarity in the cause of the fluctuations here and there.

members it (at least three feet higher than it is now) ; between these dates there were several periods of high and low water, but cannot remember the dates. From 1891 to 1898 the lake was falling; since 1898 it has been rising."

Mr. J. F. Browne, gauge reader employed by the Commission at Lake Ronkonkoma, recalled that the lake was "very low during the years from 1880 to 1885" and lowest in 1885, after which it rose to a maximum in 1893 (this date from memory, probably 1891). In the summer of 1893 (1891) "the lake had never been so high, to the recollection of the oldest inhabitants; the water carried off a great part of the banks and trees that were 60 and 70 years of age; since 1893 (?) it has receded considerably, but during the past three years it has been rising."

The statements of Mr. Warner and Mr. Browne indicate that the lake is now about 15 feet higher that at its lowest stage in 1885 and about 3 feet lower than in 1891, which would make the maximum difference in height, between 1885 and 1891, fully 18 feet.

It is interesting to compare these data with the residual mass curve of rainfall in Plate II., for the relation between the high and low stages of the lake and the corresponding periods of high and low rainfall makes clear the general law that the fluctuation of the surface of the ground water depends upon the excess or deficiency of the amount of rainfall that reaches the surface of saturation over the rate of depletion or efflux from the saturated strata.

The low period which Mr. Warner recalls, in 1857, is seen to have occurred after a long period of low rainfall from 1831 to 1853, and the lowest stage, in 1885, the year of the greatest depletion in the mass curve. The highest known stage of the lake, for 60 to 70 years, occurred in 1891, after five years of heavy rainfall that exceeded in amount any similar period of which we have a record. It is evident that the rate of rainfall of about 43 inches, which occurred from 1891 to 1898, was not sufficient to maintain the lake at the high stage that was then reached. The reason is apparent from a study of the ground water contour map, on which it is seen that at its present stage Lake Ronkonkoma is losing water on three sides through the saturated sands. The surface of the lake is now probably 3 feet higher than the normal ground water surface east and west. This brings us to the relation between the fluctuation in the lake and the normal fluctuation of the ground water surface.

The lake receives the surface drainage of an area of about 4.18 square miles, inclusive of the lake surface, and this, in addition to the ground water that enters from the water table north, gives the lake a larger increment from the rainfall than the general water table receives through percolation, and, therefore, during years of heavy rainfall the lake rises higher than the ground water on either side at equal distances from the summit of the water table .

Evaporation from the surface of the lake is probably somewhere near 40 inches each year, but the amount of surface drainage ordinarily much exceeds this, except, perhaps, in a very dry period when this loss must lower the waters of the lake somewhat below the surrounding ground water.

The maximum fluctuation that has occurred in the surface of the lake is 18 feet or more and, as has been noted above, is greater than that of the normal ground water surface which has not probably fluctuated much over 10 or 12 feet during the last sixty or seventy years.

Evidence from Domestic Wells—Many old wells that were observed were said to have never gone dry and the general testimony was that the ground water was higher this summer than ever before, so that the ground water observations furnish some idea of the upper and lower limits of the past fluctuations of the ground water.

In 1903 the maximum depths of water in the wells on the lines of the cross-sections of the island that were selected ranged from 2 to 12 feet, as shown on Plate VII. and as tabulated in Table No. 29. Unless it were established that a well had filled, it would be fair to assume that the ground water had never fallen below the present elevation of the bottom; but it is somewhat probable that all of these wells have filled a little, many of them, perhaps, several feet.

Still, from the Ronkonkoma records, the lowest stage for, perhaps, 70 years, occurred between 1880 and 1885, which is corroborated by the statements of several owners of wells, so that it is doubtful if filling will account for all the somewhat shallow wells.

Without actual measurements, the statement of the "oldest inhabitant" that the wells have never been higher than this summer would be given the same credence as the tales of the old-fashioned snow storms from the same sources, but the rainfall records indicate that the rainfall for the past six years has been much above the normal.

The depth of most of the wells varies from 4 to 9 feet and, considering the filling that may have taken place by the entrance of fine sand through the dry rubble or brickwork and the factor of safety against failure of their water supply that the owners of the deeper wells provided, the maximum range of saturation, during the last 25 years, was probably about 5 feet in the deep ground waters on Long Island which is equivalent to 15 inches of water.

During a period of extreme drought, it is very probable that the summit of the ground water will fall even a greater distance below the maximum than the evidence that has been gathered would, in general, indicate; ten feet

TABLE NO. 29.

Maximum Depths of Water in Long Island Wells—1903.

Elevation of Surface of Ground Water.	Section No. 1. No. of Well	Section No. 1. Max. Depth of Water	Section No. 2. No. of Well.	Section No. 2. Max. Depth of Water	Section No. 3. No. of Well	Section No. 3. Max. Depth of Water	Section No. 4. No. of Well	Section No. 4. Max. Depth of Water	Section No. 5. No. of Well	Section No. 5. Max. Depth of Water	Section No. 6. No. of Well.	Section No. 6. Max. Depth of Water
		Feet.		Feet.		Feet.		Feet.		Feet.		Feet.
0–10	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
10–20	..	..	620	4.6	..	..	511	4.2	..	..	..	..
	..	..	213	6.7	..	..	719	3.5	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
20–30	299	6.8	100	5.4	329	4.8	512	3.5	143	9.8	..	..
	300	6.8	101	7.7	..	..	..	..	..	..	..	..
	..	..	1230	9.0	..	..	..	..	..	..	..	..
	..	..	231	9.8	..	..	..	..	..	..	..	..
30–40	..	.	165	7.8	103	7.7	513	4.7	..	..	..	..
	..	..	156	8.0	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
40–50	..	..	..	..	166	11.8	106	4.5	..	..	139	5.9
	..	..	..	..	163	11.4	328	5.3	..	..	..	..
	..	..	..	..	162	10.8	..	..	..	..	..	..
	..	..	..	..	867	7.9	..	..	..	..	..	..
50–60	..	..	..	..	..	..	107	8.4	127	6.5	138	4.3
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
60–70	..	..	..	..	..	..	326	10.3	..	..	235	9.4
	..	..	..	..	..	..	119	15.0	..	..	..	..
	..	..	..	..	..	..	327	6.7	..	..	..	..
70–80	..	..	..	..	..	..	..	..	128	15.7	236	8.9
	..	..	..	..	..	..	..	..	129	14.3	609	1.8
	..	..	..	..	..	..	..	..	130	9.1	608	1.4
	..	..	..	..	..	..	..	..	131	10.2	..	..
80–90	..	..	..	..	..	..	..	..	..	..	136	9.0
	..	..	..	..	..	..	..	..	..	..	305	4.4
	..	..	..	..	..	..	..	..	..	..	1085	7.8

Elevation of Surface of Ground Water.	Section No. 7. No. of Well	Section No. 7. Max. Depth of Water	Section No. 8. No. of Well	Section No. 8. Max. Depth of Water	Section No. 9. No. of Well	Section No. 9. Max. Depth of Water	Section No. 10. No. of Well	Section No. 10. Max. Depth of Water	Section No. 11. No. of Well	Section No. 11. Max. Depth of Water	Section No. 12. No. of Well	Section No. 12. Max. Depth of Water
		Feet.		Feet.		Feet.		Feet.		Feet.		Feet.
0–10	..	..	..	..	274	3.3	468	2.91	456	15.5	..	..
	..	..	..	..	..	..	..	..	781	3.3	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
10–20	..	..	372	4.4	275	3.4	..	..	..	..	773	1.6
	..	..	..	..	276	9.0	..	..	..	..	..	..
	..	..	..	..	1091	2.0	..	..	..	..	..	..
20–30	182	..	..	..	279	3.7	..	..	530	7.3	..	..
	..	5.7	..	..	..	..	..	..	784	4.9	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
30–40	..	..	374	9.0	280	3.9	..	..	513	4.7	804	5.6
	..	..	..	..	..	..	..	..	913	6.4	..	..
	..	..	..	..	..	..	..	..	785	6.4	..	..
40–50	133	7.6	..	..	281	7.8	392	11.8	517	2.4	..	..
	..	..	..	..	711	9.6	393	6.3	518	1.1	..	..
	..	..	..	..	..	..	394	5.6	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
50–60	184	9.0	..	..	282	9.6	582	8.0	584	6.7	750	7.9
	440	4.9	..	..	283	7.4	..	..	..	..	..	..
	439	4.6	..	..	..	..	..	..	..	..	..	..
	438	6.1	..	..	..	..	..	..	..	..	..	..
60–70	185	10.5	346	11.8	284	7.8	..	..	540	14.7	..	..
	144	8.0	347	10.6	..	..	..	..	789	12.0	..	..
	..	..	348	11.	..	..	..	..	..	..	..	..
70–80	..	..	..	..	958	13.7	..	..	..	..	554	11.9
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..
80–90	171	11.3	366	2.	..	..	..	..	..	..	..	..
	170	8.6	555	7.	..	..	..	..	..	..	..	..
	257	13.3	526	3.9	..	..	..	..	..	..	..	..

will probably cover the maximum fluctuation that is likely to occur, which is equivalent to about 30 inches of water.

Comparison of Ground Water Contours of 1903 with Those of 1867—The contours drawn in the vicinity of Jamaica by Mr. James P. Kirkwood, which are published in his report of 1867, permit, by a comparison with our elevations in that area for this summer, an estimate of change in the elevation of the surface of saturation from 1867 to July, 1903. In general, at an elevation of 40 to 50 feet, the heights of 1903 are 5 feet greater than those in 1867. No record of the month in which the early levels were made could be found at the Brooklyn office and, consequently, the comparison has less value than it would otherwise have. It is clear, though, that the ground water in July of this year was 3 to 5 feet higher than in 1867.

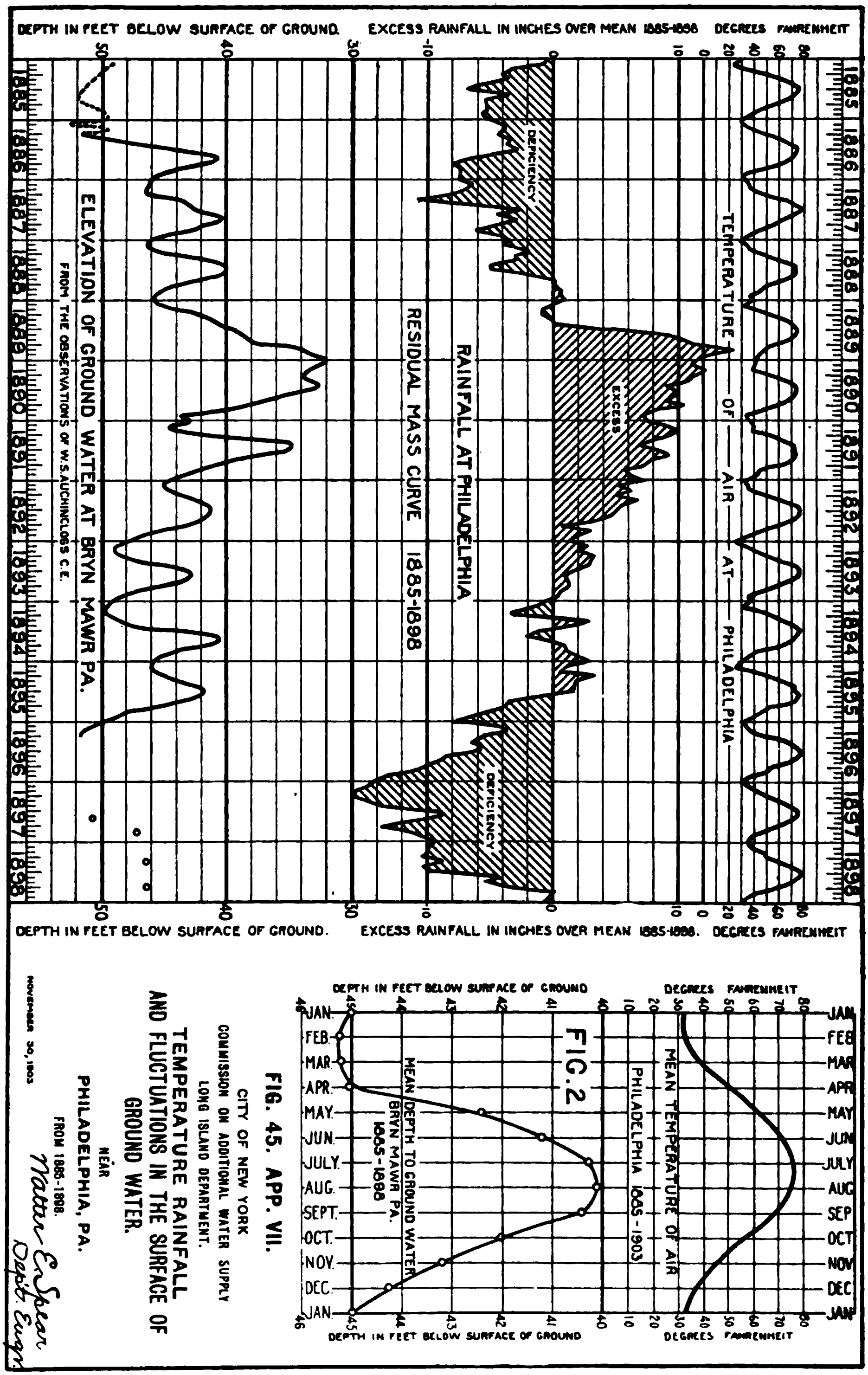
Other Observations on the Fluctuations in the Deep Ground Waters—The observations of Mr. W. S. Auchincloss, whose estimates of the velocity of percolation have already been quoted, were made between 1886 and 1898 on a well at his former residence at Bryn Mawr, Pa. This well is 64 feet deep, the first 14 feet in a soil "of a magnesian or talcose nature only slightly pervious to water," the remaining 50 feet in a "hydro-mica schist, more or less decomposed near the surface, but only removed by blasting at greater depths." "Occasional crevices and fissures were met and at almost all points was so laminated that a penknife could, with ease, be imbedded in the direction of the strata."

The results of Mr. Auchincloss' observations have been plotted with the residual mass curve of rainfall at Philadelphia in Fig. 45, and the resulting curves show very clearly the facts that were brought out by the fluctuations in the surface of Lake Ronkonkoma, that the general elevation of the ground water during a period of years depends upon the total amount of precipitation, and further suggests that this elevation depends, to some extent, upon the seasonal distribution of the rainfall.

The maximum fluctuation in the surface of the ground water from 1885 to 1889, was 20 feet, which agrees well with the rise of 18 feet in the surface of Lake Ronkonkoma, although at Bryn Mawr this large fluctuation was probably due to the small pore space of the rock in which the well was sunk.

(*b*) *Annual Fluctuations.*

(1) *Long Island Observations*—Besides the long period changes in the elevation of the ground water which are proportional to the excess or deficiency in the annual rainfall, other and more regular changes take place annually. The periods in the shallow and deep ground waters are not identical, because, as we have seen, the rate of movement of the rain to the surface of saturation is exceedingly slow.


DEPTH IN FEET BELOW SURFACE OF GROUND.
EXCESS RAINFALL IN INCHES OVER MEAN 1885-1898
DEGREES FAHRENHEIT
TEMPERATURE — OF — AIR — AT — PHILADELPHIA
RAINFALL AT PHILADELPHIA
RESIDUAL MASS CURVE 1885-1898
DEFICIENCY
EXCESS
ELEVATION OF GROUND WATER AT BRYN MAWR PA.
FROM THE OBSERVATIONS OF W.S. AUCHINCLOSS C.E.
FIG. 2
MEAN TEMPERATURE OF AIR
PHILADELPHIA 1885-1903
MEAN DEPTH TO GROUND WATER
BRYN MAWR PA.
1885-1898
JAN. FEB. MAR. APR. MAY. JUN. JULY. AUG. SEPT. OCT. NOV. DEC. JAN.
FIG. 45. APP. VII.
CITY OF NEW YORK
COMMISSION ON ADDITIONAL WATER SUPPLY
LONG ISLAND DEPARTMENT.
TEMPERATURE RAINFALL
AND FLUCTUATIONS IN THE SURFACE OF
GROUND WATER.
NEAR
PHILADELPHIA, PA.
FROM 1885-1898.
NOVEMBER 30, 1903
Walter E. Spear
Dep't. Engr.

Shallow Ground Waters—The measurements of the elevations of the ground water at Millburn Reservoir permit a study of the rise and fall in shallow ground waters where the water table is only 10 to 15 feet below the surface of the ground. From Plate IX. it can be seen that a maximum elevation of the surface of saturation occurred in a normal year, between the middle of March and the last of April, or it immediately followed the last heavy spring rain after the frost left the ground. The one exception noted, during the period of observation, from 1897 to 1903, was in 1901, when the ground water did not reach a maximum until June 1; but the spring of that year was a season of abnormally low rainfall.

From the residual mass curve, the greatest deficiency of the rainfall, during the seven years from 1897 to 1903, is seen to have occurred in March, 1901, in consequence of the low rainfall of the preceding months, and the elevation of the ground water at Millburn reached a minimum from which it did not recover until June 1.

Between the years 1897 and 1902 the minimum elevations of the surface of saturation occurred in the winter months from November to January or, in general, 7 to 9 months after the maxima. In 1902, however, the minimum occurred in September, because of exceptionally heavy rains in October and December that raised the surface of the ground water to such a height that it did not fall again during the winter to the September elevation.

The mean elevations of the ground water for each calendar month, from 1897 to 1903, at Millburn Reservoir, have been found and are shown in Figure No. 2, of Plate IX., as elevations above the surface stream east of the reservoir. This curve indicates that, on an average, the shallow ground waters attain a maximum height during May and fall to a minimum height during the last of October, a little less than six and one-half months after the maximum. The difference between the average maximum Spring elevation and the average maximum in November is a little less than 2 feet.

Deep Ground Waters—Unfortunately, the Brooklyn Water Department has not made many observations on wells in which the depth to ground water exceeded 15 to 20 feet and the measurements made by this Department do not cover a sufficient period to more than suggest the laws which govern the fluctuations of the surface of the deep ground waters.

The observations of this Department on percolation indicate that, with increase of depth, the annual maximum elevation of the surface of saturation becomes more clearly defined than when the ground water is near the surface of the ground and also that, in consequence of the slow rate of downward capillary flow in the winter and spring, these maxima in the deep ground waters occur later than those near the surface, by periods proportional to the depth; for example, in 1903 the maximum in the ground water on Long Island, at a depth of 30 feet, occurred, on an average, 23 days after that at 10 feet, and the maxima at 50, 70 and 90 feet followed that at 10 feet by 54, 67 and 121 days, respectively. Furthermore, the increasing rate of percolation during the summer, as previously explained, allows the percolation from the summer rains to reach the water table shortly after the arrival of the spring and winter rains, so that the percolation from 8 or 9 months' rain is concentrated at the surface of the deep ground water within 3 or 4 months, which results in a high elevation of the water table in summer and a low elevation in winter.

(2) *Other Observations on Deep Ground Waters*—The observations of Mr. Auchincloss, at Bryn Mawr, showed that the surface of saturation, there, at a depth of 50 to 60 feet, fluctuated each year in a regular period, independent of the long term fluctuations of the ground water.

With the exception of seasons of abnormal rainfall, the plotted curve of the Bryn Mawr observations shows a minimum each year, in the winter, from December to March, and a maximum, in the summer, from June to September, which agrees with the indications of our Long Island observations.

The period of storage and the following period of depletion of the ground water are seen to be fairly constant, the former lasting about five months, the latter the remaining seven months, or, as stated by Mr. Auchincloss, the "influx period usually lasts five months from the day it commences. Thus:

"When the influx begins in January it culminates in June.

"When the influx begins in February it culminates in July.

"When the influx begins in March it culminates in August.

"When the influx begins in April it culminates in September."

The monthly averages of the height of ground water eliminate the long period fluctuations due to variations in amount of precipitation; a curve plotted from such averages is shown in Fig. 2 of No. 45.

To quote Mr. Auchincloss, it "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."

The mean rise and fall at Bryn Mawr during a year was about five feet.

The rise and fall of the Great Lakes is merely another example of the fluctuation in the level of the ground water, for these lakes are, for the most part, fed by seepage from the saturated strata of the enclosing land surfaces. The maximum elevation of the lakes occur in summer, the minima in winter.

(3) *Cause of Annual Fluctuations of the Ground Water*—The cause of this annual rise and fall in the ground water, the occurrence of high water in the summer and low water in the winter, is, primarily, that the amount of the rainfall that reaches the plane of saturation varies widely during the year. This variation in the amount of percolation is due, on Long Island and elsewhere, to the change in the rate of evaporation at the surface of the ground, to the greater retentiveness of cold over warm soil, and to the length of time in which the frost is in the ground.

In a long series of years, the average rainfall for each month is very nearly the same (see Table No. 8A), and in a given year, heavy rainfalls and droughts are quite as likely to occur in one month as another, but the proportion of the rainfall that enters the ground varies within wide limits; that is, in the summer a large part of the rainfall returns to the atmosphere by evaporation, and in the winter, when the ground is frozen hard, a large portion passes off as stream flow.

Effect of Frozen Ground—The frost seldom enters the ground on Long Island before December 1 and rarely leaves later than March 10, so that it would be reasonable to expect that the rains that fall shortly after the middle of March would furnish more water to the ground water resources than the winter rains.

Prof. King's observations on percolation through frozen ground, in Wisconsin, where the winters are much more severe than here, showed conclusively that considerable water percolated into the ground even when the surface was frozen. He states that, "During these times the water appears to find its way into the ground through shrinkage cracks, through perforations made by earth worms, and does so without apparently contributing much to the surface three feet of soil."

The heights of the ground water on Long Island, during the winters from 1897 to 1903, indicate that percolation occurred after every storm and it is probable that the ground is never frozen so hard on Long Island as to exclude more than a portion of the percolation that would otherwise take place. Still, it is clear from Plate IX. that the rainfall during the months from December to March did not furnish as much water to the surface of saturation as equal amounts of rain in late March and April.

Effect of Evaporation and Temperature of Soil—The increasing evaporation in May and June again reduces the percentage of the rainfall that reaches the water table and the rains that occur in the late fall, when the evaporation becomes small, furnish less water to the surface of saturation because through the cooling of the upper strata, the surface tension of the films of water on the soil grains is increased and the upper strata are able to retain a greater portion of the rainfall than during the summer.

Plate IX. brings out clearly the greater effect of the spring rains in raising the water table. It is seen that the storms occurring from the first of March to the last of April give the maximum annual elevations in the ground water surface; for example, in 1903, much more rain fell in each of the months of June and August than in April and but little less during July and September, yet the rainfall during these four months only slightly affected the height of the deeper ground water, because a large proportion of the precipitation from May to September was evaporated from the soil or taken up by the demands of vegetation and, later, retained in the surface-soil.

(4) *Amount of Annual Fluctuation in the Deep Ground Waters*—The observations on Long Island indicate that the annual rise and fall of the water table is not more than three feet.

(*c*) *Fluctuations of the Water Table Due Changes in Barometric Pressure.*

(1) *Observations of the Long Island Department*—The records from the recording depth gauges, placed by this Department on two moderately deep wells, showed a small daily tide in each well, coincident with the curve of temperature of the air as traced by our thermograph. The water in the wells at Floral Park and Brentwood, which were about 35 feet deep, rose from 0.01 to 0.02 foot each day to a maximum, at 2 P. M., the average hour of maximum temperature and fell to its original height during the afternoon. The cause of this rise in the middle of the day was apparently the decrease in the barometric pressure, due to the heating of the air above the earth. This change in barometric pressure was recorded on the barograph and amounted to 0.06 to 0.08 inch.

When a greater change in atmospheric pressure occurred, as during the passage of a storm or a large wave of low pressure, the surfaces of the two wells responded quickly; a depression of the curve of barometric pressure of 0.3 to 0.04 inch caused a rise in the well of 0.02 to 0.07 foot; an equal increase in atmospheric pressure, a corresponding depression of the water surface.

At a well near Valley Stream, in which the water was only 12 to 13 feet below the surface of the ground, the recording instrument showed no daily fluctuation and no rise and fall, even with rapid changes in barometric pressure.

The fluctuations in the deep wells due to changes in atmospheric pressure were probably confined to their immediate vicinity. The moist earth above the plane of saturation did not transmit the rapid increase of pressure to the water table and, consequently, a rapid rise in pressure merely crowded the water in the well into the pore spaces of the soil outside the well. In the same way, a rapid decrease in atmospheric pressure caused a rise in the well, due to the greater pressure on the water table about the well.

The shallow well was in coarse material which, for that reason probably, was less moist than the sands above the deep wells, and because of this and the comparatively short distance from the surface of the ground to the water, the changes in atmospheric pressure were quickly communicated to the surface of the water table and did not cause any fluctuation in the well.

A slowly increasing or decreasing atmospheric pressure did not apparently affect the elevation of the two deep wells; in view of this and the fact that no fluctuations occurred in the shallow well, it seems very improbable that the whole surface of the water table on Long Island rises and falls with a decrease or increase in the pressure of the atmosphere.

The recording instruments at the gauging stations recorded, at times, an increased flow, with a rapidly decreasing atmospheric pressure. This has been observed elsewhere, in many small streams that are " fed by springs " and, like the rise in the wells, the increased flow is probably due to a decrease in pressure at the outlet of the ground water and a more constant pressure on the water table at a short distance back from the " springs."

(2) *Observations of the United States Geological Survey*—Mr. A. C. Veatch, of the Geological Survey, made extensive observations on the fluctuations in a group of wells near Lynbrook. These were 5-inch wells, with solid casings, and varied in depth from about 40 feet to 500 feet. The fluctuations were greater in the shallower wells than those recorded in the dug wells that were observed by this Department, and increased with the depth; changes in elevation of 5 to 6 inches were observed in the deepest well.

The greater fluctuation in the shallow driven wells over those observed in the dug wells seems to have been due to the solid casings that did not permit the pressure above the water about the well to change as rapidly as about the dug wells which had fairly open brick curbs. The greater changes in the deep wells were undoubtedly due to the great sensitiveness to changes in pressure that has been observed in the surface of the water in the deep wells near the driven well stations; the curves from Mr. Veatch's deep wells showed that the pressure even at the bottom of the deep wells was affected by the tides in Jamaica Bay.

(D) *Uniformity of Delivery of the Underflow.*

(*a*) *From the Variation in Amount of Rainfall.*

The lowest elevation of the water table that occurs during a period of several years of low rainfall is such that the difference between such elevation and that of the sea or the head corresponding to the underflow is sufficient to cause the flow of that proportion of the rainfall which reached the surface of saturation. To maintain a higher stage of the water table, a greater rate of rainfall is required. The velocity of flow of the water in capillary spaces is proportional to the head. If the same percentage of the rainfall goes to the water table each year, the percentage difference between the mean minimum and the mean maximum rainfall is a measure of the maximum variation in the flow of the deep ground waters.

The mean minimum rainfall that is likely to occur during a period of, say, five years, is 35 inches; the maximum that is sufficient to maintain the water table at its highest stage is probably about 45 inches: from which it is evident that the underflow to the sea may vary within an amount equivalent to 28 per cent. of the mean, or 14 per cent. greater or less than the mean.

(*b*) *From the Fluctuations of the Ground Water.*

The velocity of underflow at a given point will vary from time to time as the head which causes this velocity is greater or less. This total head is the difference between the elevation of the summit of the water table and the elevation of the sea, as stated above. The studies on the fluctuation of the elevation of the Long Island water table have shown this to vary, within comparatively small limits, during a long period of years.

Twelve feet is probably the greatest range in rise or fall of the elevation of the water table that has occurred for perhaps sixty or seventy years; so that if the summit of the water table, at a given point, is at an average elevation of 60 feet, this change represents a change in head of 20 per cent.; or where the water table is 100 feet above the sea, a 12-foot change in head is only 12 per cent. of the total. Since the velocity of ground water flow is nearly proportional to the head or surface slope, it is thus seen to be probable that the velocity of flow of the ground water seaward is uniform within approximately 15 to 20 per cent.

The maximum annual fluctuation in head is probably not greater than 3 feet, which would cause a variation in flow of the ground water of probably not more than 5 per cent. The maximum flow occurs at the period when the deep ground waters near the summit attain their greatest elevation—in the months from June to August; at this time the surface of the ground water near the streams has fallen from the maximum spring elevations and the slopes of the water table, and, therefore, the velocities are increased, roughly speaking, probably about 10 per cent. over the corresponding slopes and velocities during the remainder of the year.

The seasonal variations in the velocity of the underflow toward the sea should not be confused with the ground water delivery into the streams, for the amount of ground water that enters the streams is dependent upon the height of the local water table in the immediate vicinity of the streams and is a maximum in April and May. The streams merely intercept the water from the upper portion of the saturated strata and, when the local water table falls, the flow naturally becomes smaller and if the water table sinks to the level of the stream the flow of ground water into the stream naturally ceases.

(*E*) *Amount of Ground Water.*

We have seen, on what appeared to be the most reasonable assumptions for evaporation and stream flow, that the most probable values for percolation, meaning by this the amount of rain that enters the ground, are 19.5 inches in equivalent depth over the whole face of this Long Island territory for a year of normal rainfall and 15 inches for the year of smallest rainfall near the end of a period of dry years. These have been computed from the existing data on rainfall evaporation and stream flow and are summarized in Table No. 30.

The difference between the total amount of percolation and the

TABLE NO. 30.

Summary of the Minimum Values Adopted for Rainfall, Evaporation, Run-off and Underflow on Long Island Watersheds.

	For Years of Average Rainfall.				For Long Period of Minimum Rainfall.			
	Total per Year in Inches, Depth.		Percentage of Annual Rainfall.		Total per Year in Inches, Depth.		Percentage of Annual Rainfall.	
Rainfall	42.56		100.		35.		100.	
Evaporation	17		40		17		49	
Stream flow: Flood flow	6		14		3		9	
Stream flow: Ground water flow / Percolation: Seepage into streams	8	14	19	33	5	8	14	23
Percolation: Underflow	11.5	19.5	25	44	10	15	28	42
Total	42.5		100		35		100	

ground water flow of the streams must give the total volume of the underflow toward the sea, and it is this which it is proposed to develop for a ground water supply, in addition to the stream flow filtered naturally or artificially. The minimum amount of this difference, during a period of dry years, is 10 inches, which corresponds to a uniform flow of 475,000 gallons per day from a square mile of ground water catchment area.

This value of 475,000 gallons is considered to be the lowest figure at which the underflow to the sea can be reasonably placed from a study of the existing data; considering, however, the uncertainties in these data, an underflow of 650,000 gallons per square mile in addition to the present stream flow is possible even in the very dryest periods.

(F) Depth of Underflow.

Before the amount of this underflow that is available can be determined and the best method of securing the run-off proposed, the depths at which the greater part of this underflow takes place must be known. The measurements of the velocity of underflow between Freeport and Massapequa, made for the Commission by the Slichter method during the past season, although incomplete, give the only means of estimating the relative velocity with which the underground waters flow at different depths.

(*a*) *Measurements of Velocity of Underflow.*

The results of the underflow measurements that were made at the wells driven by the Commission are shown in Fig. 46. The velocities given in brackets are approximate only. These measurements were made, by Prof. Slichter, of the United States Geological Survey, in July and August, 1903, and the final results of his computations have not been received.

The average velocity in the section from East Meadow Brook to Massapequa is seen to be about 4 feet per day, taking the average of various measurements, from the surface of the ground water to a depth of 60 feet or El.—50, the greatest depth at which a measurement was made. (See Fig. 46). The total area of this section is about 2,200,000 square feet. Allowing for the relative proportions of pore space and solid particles in the sand or gravel, the effective area will be about one-third of the total, or say 670,000 square feet. The flow corresponding to a velocity of 4 feet per day through this area is 2,680,000 cubic feet per day, or 978,000,000 cubic feet per year, which corresponds to a depth of 6.5 inches of water over the 64 square miles of ground water catchment area above the sections considered.

The difference between a total underflow of say 12 inches and the estimated flow of 6.5 inches from the surface to a depth of 60 feet, or 5.5 inches, represents the flow in the strata below this depth.

If the same velocity persists at depths below 60 feet, a further depth of 55 feet is required to pass the 5.5 inches that are not accounted for. As, however, the artesian conditions in deep wells indicate that the total resistance to the escape of the waters below 100 feet in depth is much greater than at depths from the surface to 60 feet, it is probable that the velocities de-

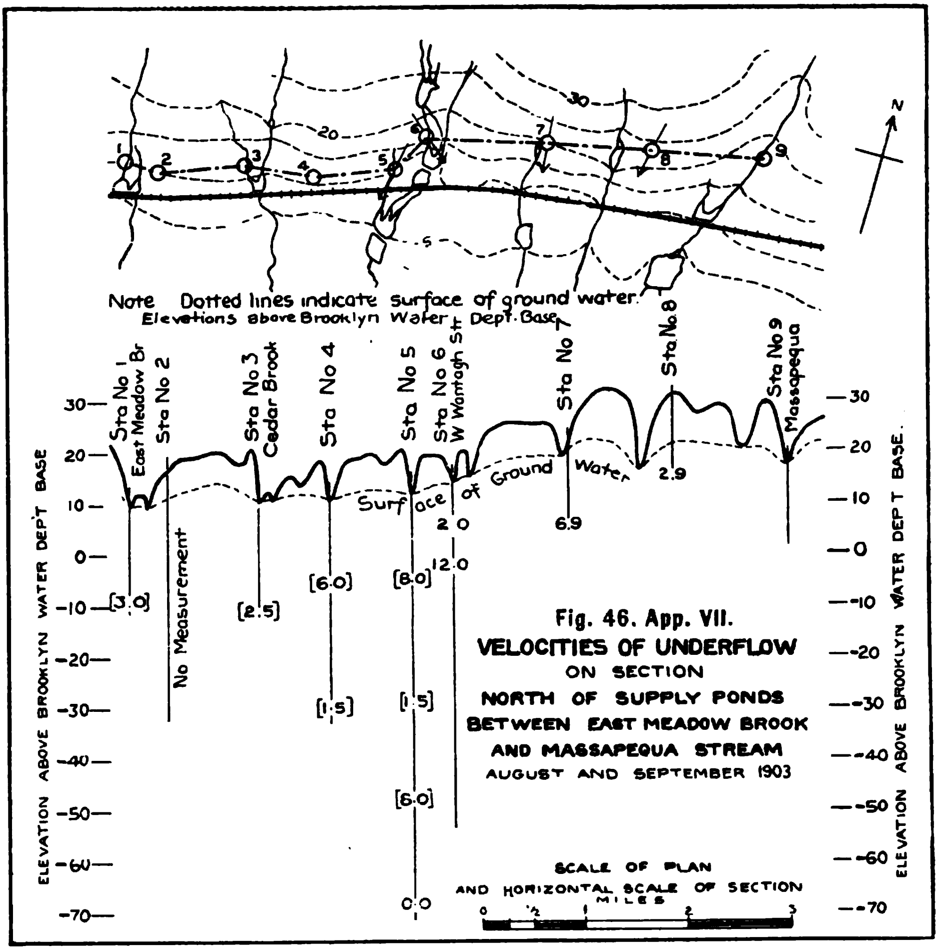


Fig. 46. App. VII.
VELOCITIES OF UNDERFLOW
ON SECTION
NORTH OF SUPPLY PONDS
BETWEEN EAST MEADOW BROOK
AND MASSAPEQUA STREAM
AUGUST AND SEPTEMBER 1903

crease somewhat with the depth, and that appreciable velocities are found, in general, at depths of 125 feet to 150 feet, save in those localities where the material is too fine. It is not unlikely, however, that where the material is fairly homogeneous the greater part of the underflow to the sea takes place within 100 feet of the surface of the ground.

When coarse strata exist at greater depths, as the "Jameco" gravels in the westerly end of the island which are found at depths exceeding 200 feet, large flows will be naturally found in these strata, as they extend back toward the centre of the island and furnish much less resistance to flow than the strata above. It is a mistake, however, to consider that such coarse strata of gravel are necessary to a supply of ground water, or that, if such strata do not exist, as appears to be the case along portions of the south shore in Suffolk County, a supply cannot be obtained. Although fine sands cannot deliver water at so great a velocity as the coarse sands and gravels, and cannot, therefore, be pumped as hard, if any water is flowing in them it can be obtained by a proper method of development.

(G) Comparison of the Material Along the Shore in Nassau and in Suffolk Counties.

Plate X. shows the material in our test wells and in those of the Brooklyn Water Department, between Ridgewood Reservoir and Patchogue. It is evident that the material of the cretaceous sands along this section in Suffolk County is fully as coarse as that from which a portion of the present Brooklyn ground water supply is drawn.

(H) Available Ground Water and Surface Supply.

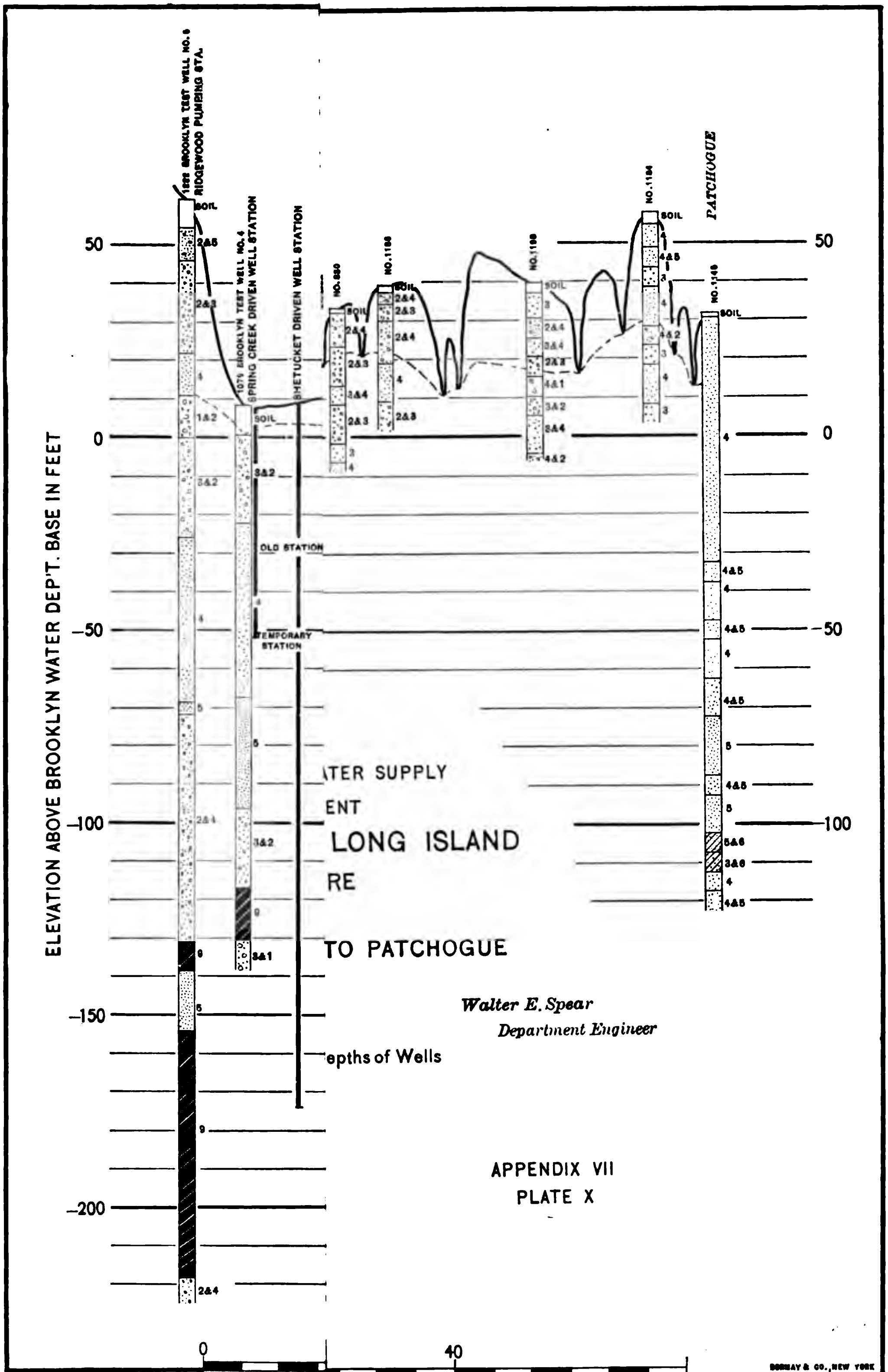
Considering that a small portion of the underflow probably passes at too great a depth and at too small a velocity to permit it to be economically developed, it is not safe to assume that the total estimated underflow can be made available for a ground water supply.

To obtain the total amount of available supply, the underflow per square mile of catchment area which was estimated to be between the limits of 475,000 gallons and 650,000 gallons should be reduced say five to ten per cent. to provide for the amount that cannot be secured.

The amounts thus reduced represent the amount of underflow that is naturally delivered and may be secured without materially depressing the water table at the wells. By lowering the water table large amounts of ground water become available, and during long periods of drought the normal yield from the underflow may be greatly increased by thus drawing upon the ground water storage. By increasing the amount of storage on the surface streams and constructing higher dams near the line of ground water development large amounts of surface water may be naturally or artificially filtered and added to the supply from the underflow. This filtered surface water may be largely used during the winter and spring, when the ground water reservoirs, that have been drawn upon during the previous summer and fall, are being replenished. A total supply from the underflow and the surface streams of fully 800,000 gallons per square mile may be considered a safe minimum in estimating the yield of the Long Island watersheds.

(a) Present Brooklyn Watershed.

The total area of the ground water catchment area south of the summit of the water table and north of the present conduit line, between Ridgewood



ATER SUPPLY

ENT

LONG ISLAND

RE

TO PATCHOGUE

Walter E. Spear

Department Engineer

epths of Wells

APPENDIX VII

PLATE X

Pumping Station and the Suffolk County line, is 140 square miles; the maximum supply from the underflow to the sea supplemented by amounts of ground water drawn from storage and by the flow of the surface streams on this area that it would be safe to estimate upon, in considering the future demand, is 112 million gallons. Considering the margin of error in the estimates of evaporation and stream flow and the probability that even larger quantities of surface water than have been estimated may be developed, a total supply of 112 to 140 million gallons may safely be estimated upon in considering the minimum yield of the watersheds in Nassau County. The Brooklyn Department has already developed a maximum of about 100 million gallons in their present watersheds, but the present available supply is less than this amount. It appears that yet 40 million gallons more of water may be developed in Nassau County.

Considering that many of the present driven well stations of the Brooklyn Water Works are not pumping more than two-thirds of the original amounts delivered, the most natural method of developing the proposed additional ground water supply would be to begin at the westerly end of the present watershed and replace the present station along the conduit line. In designing the new structures required, the ground water supply should not be estimated at less than 1,000,000 gallons per square mile, and in the first work provision should, perhaps, be made for 1,200,000 gallons per square mile, until it be proven that this amount cannot be obtained. The additional cost of construction required to provide for the larger quantity would be small and, if as large a quantity as that corresponding to 1,000,000 or 1,200,000 gallons should be found, provision would then have been made against a shortage in supply due to the not unusual delays that may occur in securing water from the north.

Although about 15 million gallons of underflow have been developed by municipalities and water companies, it is believed that there is a sufficient margin of safety in the above estimates to cover this, and this loss need not be considered.

A ground water supply, then, of 140 to 170 million gallons from Nassau County should be considered in the designs for new structures, but in estimating the date when a supply outside of Long Island must be sought, the possibility that a total ground water supply of not over 112 to 140 million gallons should be considered.

(*b*) *Suffolk County.*

Beyond Moriches, just east of the Connecticut or Carman's River, the ground water catchment area along the south shore becomes too small to provide any considerable underflow and this point has, therefore, been considered the easterly limit of development. Between Moriches and the Nassau County line, the total ground water catchment area above a probable line of development is 220 square miles, which, on the basis of 800,000 million gallons per day, should furnish a total minimum supply of 176 million gallons, providing that the present restrictions to such a development were removed.

A larger proportion of the watersheds in Suffolk County is covered by moraine and till surfaces than the watersheds in Nassau County and the depth of the gravel outwash plain is less. It is, therefore, possible that the underflow from the Suffolk County watersheds is less than from those that we have investigated in Nassau County: on the other hand, an additional amount of water could probably be obtained from surface ponds and streams that would offset the possible decrease in underflows.

Considering the lack of information, however, it would not be safe, at this time, to estimate upon a greater supply from Suffolk County than say 175 million gallons per day.

(*c*) *Total Supply on the South Side of Long Island.*

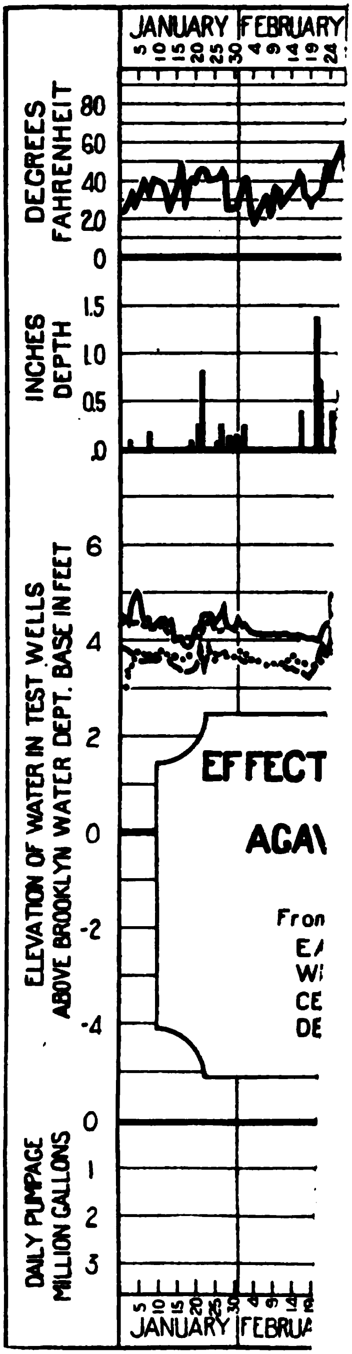
If the legal restrictions upon the development of a water supply in Suffolk County were removed, a total supply of 290 to 320 million gallons per day might perhaps be available on the south shore, between Ridgewood Pumping Station and Moriches, or at least 200 million gallons in excess of the total that has already been developed by Brooklyn and by private water companies and municipalities.

(*d*) *North Shore.*

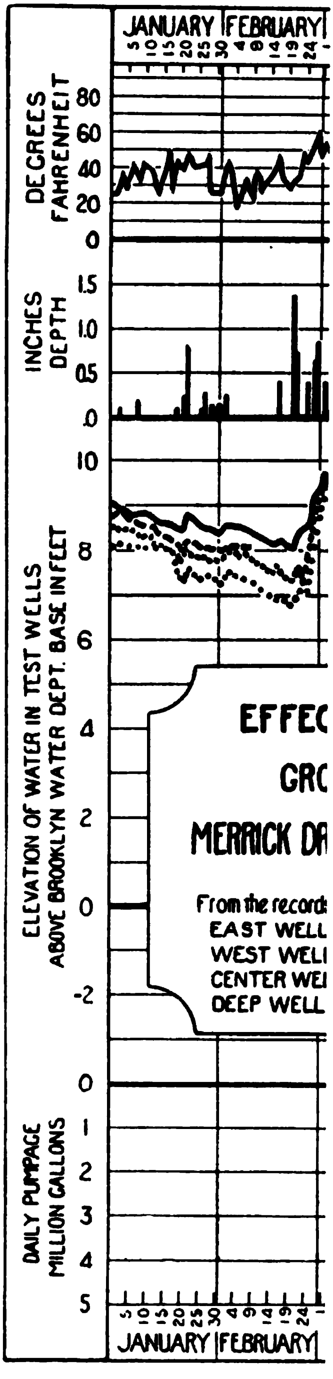
Unquestionably, large amounts of ground water may be obtained along the north shore of Long Island, but the yield of the watersheds are probably much less per unit of area than those on the south shore, because of the more impervious character of the glaciated surfaces. The irregular topography of the north shore would, furthermore, make a large ground water supply more expensive than on the south shore, and the development of a supply at such a distance from the south shore would be such a departure from the present system that a possible supply from the north shore has not been considered.

VI.—Suggested Method of Securing the Additional Ground Water Supply.

The investigations on Long Island made by this Commission during the past summer have been confined to those leading to a determination of the amount and quality of a ground water supply; the studies and experiments required to decide upon the best methods of utilizing the ground water resources and surveys to locate the new structures needed, have not been made because of lack of time and funds.



JANUARY
FEBRUARY
DEGREES FAHRENHEIT
80
60
40
20
0
INCHES DEPTH
1.5
1.0
0.5
.0
ELEVATION OF WATER IN TEST WELLS ABOVE BROOKLYN WATER DEPT. BASE IN FEET
6
4
2
0
-2
-4
EFFECT
AGA\
Fron
E/
W
CE
DE
DAILY PUMPAGE MILLION GALLONS
0
1
2
3
JANUARY



JANUARY
FEBRUARY
DEGREES FAHRENHEIT
80
60
40
20
0
INCHES DEPTH
1.5
1.0
0.5
.0
10
8
6
4
2
0
-2
ELEVATION OF WATER IN TEST WELLS ABOVE BROOKLYN WATER DEPT. BASE IN FEET
EFFEC
GRC
MERRICK DR
EAST WELL
WEST WELL
CENTER WEL
DEEP WELL
DAILY PUMPAGE MILLION GALLONS
0
1
2
3
4
5
JANUARY
FEBRUARY

During a period of dry years an amount of ground water corresponding to a depth of 10 to 12 inches upon the total ground water catchment area south of the summit line of the water table between Ridgewood and Moriches, is flowing southward at depths as yet not fully determined, but, in general, from the surface of saturation downward to 100 feet in depth; and of this amount at a low figure 450,000 gallons per day per square mile, and possibly much more, may be developed from the underflow that does not now reach the streams, in addition to the amount of surface flow that may be added to the ground water, which brings the total up to 800,000 gallons per day per square mile.

To obtain all the available underflow and surface flow from the southerly slopes of Long Island the development must be made along a line on the entire south shore, except where such development will interfere with existing private and municipal pumping stations, and along this line wells should be placed at points sufficiently near together to intercept the underflow without drawing down the water table to such an extent as to injure the farming lands.

(A) *Existing Methods of Obtaining the Ground Water on Long Island.*

The large ground water supplies on Long Island have been developed by three methods: (*a*) Large dug wells; (*b*) Driven wells, and (*c*) Combinations of dug and driven wells. There are also many hundred scattered dug wells for the supply of single dwellings, which need not be considered in the present discussion.

In addition to these methods, the Brooklyn Water Department has adopted a fourth method, the infiltration gallery, and a gallery from the designs of Mr. I. M. de Varona, Chief Engineer, is now being constructed at Wantagh.

(*a*) *Large Dug Wells.*

A limited amount of ground water has been obtained on Long Island from large wells 20 to 50 feet in diameter, but this method has been abandoned for the much cheaper driven well system. The large dug well in Prospect Park and the wells that furnish the supply for Rockville Centre are examples of this kind.

(*b*) *Driven Wells.*

All of the present Brooklyn driven well stations east of Ridgewood pump from batteries of wells of 2 inches to 8 inches in diameter; the water enters these wells through a screen section from 5 to 14 feet or more in length at the bottom of the well. In general, the wells of these stations are not sufficiently deep and the stations are not close enough together to obtain all of the underflow or properly located to secure the leakage from all of the supply ponds.

The cost of maintenance of these plants is greatly increased by the necessity of pulling and redriving the wells at frequent intervals, because of the clogging of the screens. This trouble is in some instances perhaps chiefly due to the high velocities that are maintained through the sand at the screens, and in some instances may result from the long periods of idleness.

Two-inch wells, when first driven, deliver from 30 to 40 gallons per minute, which would call for a velocity through the sand immediately around the well point of 3 to 4.5 feet per minute, or 4,000 to 6,000 feet per day. This is much greater than the natural velocity of flow, which was found in general not to exceed 15 feet per day. Where there is fine material mixed in with the coarse sand such high velocities must tend to clog the screens.

It has been observed that when a station is shut down the decrease in delivery after several months of idleness is greater than if the station had been run continuously. A possible reason for this decrease is that the high vacuum that is maintained at many stations, of 20 to 24 inches of mercury, perhaps withdraws the very fine sand from the mixture of coarse and fine about the wells and packs it against the screen; so that when the plant is shut down this finely packed material becomes consolidated by oxide of iron, of which some is present in the substrata at several stations. Some of this oxide cement is created at each well by the oxidization of the iron jacket of the well point.

A good example of this decrease in delivery was observed at the Agawam Driven Well Station, where observations were made by this Department in September. The delivery of the station in December, 1902, was approximately 30,000,000 gallons per day; after the plant was shut down in December three wells were pulled up and the remainder washed out. Each well was pumped after cleaning and furnished a reasonable supply. Yet in September, 1903, only 2.2 million gallons could be pumped with a vacuum of 24 inches of mercury.

Plate XIII. shows the configuration of the water table before pumping at the Agawam Driven Well Station and at the end of two weeks' operation in September. From the ground water contours it is seen that most of the small amounts of water that were obtained came from the easterly portion of the plant; this was confirmed by the measurements of the velocity of underflow, which indicated that the ground water was flowing toward the centre of the easterly suction line.

The positions of the screens at the bottom of the driven wells of the Brooklyn Stations require that a large part of the water be drawn vertically downward to the screen section at the bottom of the well across the lines of stratification of the sand, in which direction the resistance to flow is a maximum. The amount of this loss of head can be seen in the difference between the elevations in the shallow and in the deep test wells in Plates XI. and XII., which show the effect of pumpage on the ground water at Agawam and Merrick Stations. Were the whole casing of each well perforated, this loss of head would not be so large, because of the broader distribution of the flow and the smaller velocity in the sand near the orifices, and also because a part of the loss from the surface of the ground water to the water level inside the wells, outside the drop suction, is from this downward flow to the screen section.

(*c*) *Dug and Driven Wells.*

Several stations on Long Island draw from a large dug well 40 feet or more in diameter, into which some ground water enters directly, but the most of the ground water enters these wells through a number of driven wells in the bottom or outside of the large well. The No. 1 Station at Long Island City is an example of this type.

(*d*) *Infiltration Gallery.*

If the sands and gravels were homogeneous from top to bottom and unstratified, an infiltration gallery could be so planned as to abstract most of the underflow, but, unfortunately for this purpose, these beds of sand and gravel have impervious clay beds interstratified with them, and the gallery can intercept and abstract only that water which flows along on top of the uppermost "clay floor." Any difference in fineness, permeability or stratification within the upper sands and gravels will also influence the yield from a large deep well penetrating all these strata.

An infiltration gallery or a "blind drain," constructed at a depth of from 5 to 15 feet below the surface of saturation, under conditions above described, will intercept only a portion of the total underflow. The geological studies indicate that a very considerable portion of the underflow takes place in the deeper porous strata, and the yield of the deep wells of the Brooklyn Water Department confirms this.

The infiltration gallery is adapted to collecting the ground water flow when the greater part of the movement takes place over an impervious floor near the surface of the ground. The galleries of the Munich water works thus intercept the ground water flow in a thick stratum of gravel above a bed of sandstone; the collecting gallery is constructed in a shallow cut in the rock and very little water escapes.

(*B*) *Proposed Method of Intercepting Underflow on Long Island.*

The investigations of the Chemical and Biological Department of the Commission on additional water supply during the past summer have shown that with proper safeguards the ground water flowing at a depth of 10 to 15 feet is beyond any danger of surface pollution. As a safeguard, however, the casing of the wells should not be perforated within some distance below the water table.

(*a*) *Conduit Line.*

To thoroughly guard against the contamination of the ground water through pollution and to avoid damages claimed because of the lowering of the water table, a strip of land should be acquired, where the present right-of-way cannot be utilized, for the whole length of the south shore, of sufficient width not only to cover the construction work proposed, but also to protect the water against contamination. In some localities a strip 1,000 feet in width would not be extravagant, considering the small value per acre of much of this land.

(*b*) *Type of Well.*

The driven well required for the Long Island conditions must be sufficiently large to deliver all the water that is flowing within the distance at which the wells are spaced and must be designed to admit water at all depths from 5 to 10 feet below the surface of saturation down to whatever depth may be necessary to tap those deep pervious strata which may be shown by exploration wells to contain available underflow.

(1) *California Well*—A promising type of well, which seems well fitted to the above requirements, is one recently developed in California, of which a description has been given by Prof. Chas. S. Slichter in *Engineering News* of November 12, 1903, page 429, and which is called in California the "Stovepipe" well.

This well is commonly about 12 inches in diameter and consists of a double shell of short steel tubes, each tube about 2 feet long and made up with one longitudinal, lapped, riveted joint. The tubes are rolled up in two sizes, the larger fitting snugly over the smaller, and so placed that the ends of the outer shells come over the middle of the tube of the inner shell. These round-about joints are not riveted, but are held by friction, as in a stove-pipe, but the ends all butt together firmly. The bottom section is made of thick steel plate, with a strong heavy cutting edge, and the whole is forced down by powerful hydraulic jacks constantly under pressure, lifting against a heavily loaded platform and pressing down on a specially strong movable top section of well pipe, so designed that while the jacks are exerting their pressure the hole is free for the operation of the heavy sand bucket and boring tool. After being driven to the full depth the sides of the well are perforated with a special cutter at the depths where water-bearing sands exist. The wells are sunk rapidly. Their flexibility aids in passing boulders and the combined sand pump and boring tool is of such great weight and strength that it crushes or pushes aside small stones.

According to figures given, 12-inch wells of this type are sunk at less cost per foot than that for a 4-inch well of the type now used by Brooklyn, and not only is their capacity vastly greater but is is obvious that such a large well could be cleaned out at any time, if necessary, by the use of the sand bucket, and could be reperforated, and thus avoid much of the great expense now found in pulling up wells to clean them and replace their strainers. Several experimental wells of this type should certainly be driven to determine their adaptability to Long Island conditions.

(2) *Arrangement of Wells*—The wells should be driven along the conduit at sufficient intervals to intercept all the underflow without materially lowering the water table at the wells and to sufficient depths to tap all strata in which underflow measurements and analyses show any appreciable seaward flow of good water.

Obviously the mere fact that a deposit of coarse pervious sand or gravel exists and that its interstices are filled with water does not prove its availability for purposes of public water supply until it is known how rapidly the water in this subterranean reservoir is replenished and that it is free from iron chlorine and other objectionable chemical contents.

For a well of given diameter, depth and capacity and for a given uniform velocity through the sand around the well, the interval at which the wells may be spaced can readily be computed, particularly after tests on a few experimental wells.

(3) *Type of Conduit*—The type of conduit in which to collect the flow of the driven wells is one that depends entirely upon the method of pumping and has, for that reason, not been considered in the studies of this Department.

(4) *Pondage at South Shore*—In order to remove all salt or brackish water to the farthest practicable distance from the line of driven wells and thus lessen the chance for drawing in brackish water in seasons of drought and heavy pumping upon the ground water supply, and also in order to prevent any possible influx of salt water to the surface of the watersheds tributary to the proposed driven well system along the south shore, which influx through a probable slow subsidence of the land may be greater in the future

than at present, it would be advisable to build storage reservoirs between the driven well system and tide water similar to that at Massapequa Lake, by constructing small and inexpensive dams on substantially all these streams. Besides protecting the supply, these impounding reservoirs would increase the catchment areas and the amount of surface water that can be safely added to the supply obtained from the underflow. The expense will be moderate in comparison with the great benefit and safeguard that they would afford.

SUMMARY OF CONCLUSIONS.

The conclusions that have been drawn from the results of the investigations of this Department upon Long Island during the past season are, briefly stated, as follows:

I.—Rainfall.

The mean annual rainfall (and in this is always included the snowfall in equivalent inches of rain) on Long Island during the past seventy-eight years, from 1862 *to* 1903, *was* 42.56 *inches.* This rate, however, has not been uniform, as the mean annual rainfall during the past eighteen years was 44.92 inches, and during the years from 1832 to 1849, inclusive, only 37.39 inches.

The possibility that a period of rainfall as low as that from 1832 to 1849 may recur during the next twenty years requires that the periods of low rainfall that have occurred in the past be considered in the estimates for the future.

A minimum rainfall but little greater than 30 inches occurred in 1835, in 1849 and in 1860, but the mean for longer periods that included these years was much higher. The average rainfall during a period of not less than four or five years should be considered in studying the Long Island ground water problems, for it has been found that the maximum depletion of the ground water reservoirs does not take place until after several years of low rainfall.

The lowest period of five years, during the seventy-eight years in which rainfall observations have been made on Long Island, was that from 1835 to 1839, when the average precipitation was 35.20 inches.

A minimum rainfall, therefore, of not more than 35 *inches per year should be considered in estimating the minimum yield of the ground water resources on Long Island.*

II.—Evaporation.

The mean annual evaporation from the surface of the southerly watersheds of Long Island, including the amount of water dissipated by vegetation, is about 40 *per cent. of the mean annual rainfall, or* 17 *inches depth; during* *years of low precipitation, however, when the annual rainfall is only* 35 *inches, the evaporation may be as high as* 50 *per cent. of this rainfall, or* 17 *inches depth, as much as in a year of average rainfall.*

These values are considered to be the maximum amounts that can reasonably be assigned, after considering the demands of vegetation and the fine, compact nature of much of the highly cultivated soils that cover large areas in the westerly portion of Long Island. The acceptance of the value of 17 inches as the evaporation during a period of low rainfall is on the safe side in estimating the probable minimum ground water yield, but the data is not sufficient to determine the effect upon the evaporation of the porous substrata of the southerly outwash plains and the coarse, leachy soils of the uncultivated areas in the more easterly portions of the island. Considering the margin of error, it is possible that the mean evaporation from the southerly slopes of the island during a period of dry years may not be greater than 12 or 14 inches.

The evaporation from the surface of Long Island, as elsewhere in this climate, is a maximum in the summer during the months from May to September, and a minimum in the winter during the months from December to March.

III.—Stream Flow.

The average flow of the Long Island streams is 14 *inches per year, or* 33 *per cent. of the average annual rainfall;* of this amount 8 inches, or 19 per cent. of the mean rainfall, represents the ground water flow, and 6 inches, or 14 per cent. of the mean rainfall, the surface or flood flow. *In years of low rainfall the total annual flow of the streams is likely to be as small as* 8 *inches, or* 20 *per cent. of minimum rainfall of* 35 *inches; of this the ground-water-stream flow is* 5 *inches and the flood flow only* 3 *inches.* These comparatively low amounts of run-off are due to the porous soils and substrata of the southerly watersheds of the island. Even in the winter months, in consequence of this open soil, and the absence of long periods of cold weather, the total run-off of the streams from December to March is not greater than 40 per cent. of the total rainfall during those months.

IV.—Percolation.

The mean annual percolation of rainfall into the surface of the southerly watersheds of Long Island is probably about 19.5 inches depth, or 44 per cent. of the mean annual rainfall, but during years of low rainfall the percolation is probably not greater than 15 inches. The greater part of this percolation takes place in the early spring just after the frost leaves the ground and before the evaporation becomes large. In general, the percolation is a maximum in the winter and early spring and a minimum in the summer and early autumn.

The velocity of percolation or the downward capillary flow of the rainfall in the spring is about 0.5 foot per day. In consequence of this slow movement the spring rains which furnish the largest percentage of the percolation do not reach the surface of the deep ground waters until mid-summer.

V.—Ground Water.

The surface of the ground water conforms to the general topography of the surface of the ground, but the slopes are less steep and less irregular, A slow lateral movement of the water in the saturated strata is continually taking place from the summit toward the north and south shores; a portion of this flow enters the surface streams and the remainder, the underflow, flows directly to the sea.

The elevation of the shallow ground waters near the surface streams is, in general, highest in April and May and the ground water flow of the surface streams is, therefore, a maximum at that season.

Because of the seasonal distribution of the evaporation and the slow velocity of the percolation, the maximum elevation of the surface of the deep ground waters, however, occurs from June to August and, in consequence, the underflow to the sea is a maximum during those months.

The annual fluctuation of the surface of the deep ground waters is not over three or four feet and the delivery of the underflow does not, therefore, vary during the year more than 5 to 10 per cent. The greatest fluctuation that has occurred in the elevation of the surface of the ground water during the past 60 years has not exceeded 10 to 12 feet, from which fluctuations and a study of the variation in the rainfall, it is probable that the amount of underflow in one year as compared with another has not varied in the last sixty years more than 20 to 30 per cent.

During a series of dry years the seepage into the streams accounts for about one-third of the total annual percolation of 15 *inches, or* 5 *inches of water, and the underflow to the sea makes up the remaining two-thirds, or* 10 *inches, which is* 28 *per cent. of the minimum rainfall of* 35 *inches.*

From the maximum underflow of ten inches from each square mile of ground water catchment area, which is considered to be the lowest reasonable value during a period of dry years, probably 450,000 *gallons per day per square mile can be developed.* This amount is the natural flow of the underground waters, and may be obtained without materially lowering the water table. By drawing upon the ground water storage and supplementing the supply from the underflow and by properly filtering the flow of the surface streams, a total minimum supply of fully 800,000 gallons per day per square mile may be developed. This should be considered the minimum on which to base the estimates of the total yield that it is absolutely safe to depend upon from the Long Island watersheds.

Considering the probability of error in the data on which the estimates of the amount of underflow are based, a yield of 1,000,000 and perhaps 1,200,-000 gallons per day per square mile should be used in the estimates for the design of openings and waterways in new structures.

The minimum yield of the 140 square miles of ground water catchment area between Ridgewood and Suffolk County line, on the basis of a minimum yield from the underflow to the sea and the flow of surface streams of 800,000 gallons per day per square mile is 112 million gallons.

In the view of the possible error in the estimates of evaporation and percolation and the probability that even a larger quantity of surface water than estimated above may be added to the supply from the underflow by increasing the storage of surface waters, it seems probable that from 112 to 140 million gallons per day of ground water and surface water may be obtained in the present Brooklyn watersheds.

If legal restrictions were removed an additional supply of 100 million gallons of ground water and fully 75 million gallons of surface water may readily be obtained from the 220 square miles of ground water catchment area in Suffolk County from the Nassau County line to Moriches, and, therefore, with Nassau County a total supply of 290 to 320 million gallons per day, or fully 200 million gallons more than the present development of the Brooklyn Water Department. To obtain this requires a high order of scientific design and management, no greater, however, than is found to-day in certain of the water supply systems of this country and Europe.

A portion of the underflow has already been secured in Nassau County and in Suffolk County by private water companies and municipalities, but the amount that has been withdrawn in the watersheds that have been considered does not exceed 25 million gallons, which is well within the margin of safety that the above computations afford.

Table No. 31.

CITY OF NEW YORK—COMMISSION ON ADDITIONAL WATER SUPPLY.

LONG ISLAND DEPARTMENT.

Location and Description of Two-inch Test Wells.

Key to type of point on well: P—plain pipe; Q—perforated pipe in wells; C—closed end well points; O—open end well points.

For location of wells, see co-ordinated lines on Plates I. and VIII.

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet	Feet.	Feet.		
422..	Nassau..........	C + 21,800 7 + 10,200	82.9	36.64	17.1	P	9
423..	"	C + 23,300 7 + 16,100	70.3	33.55	1.9	P	8
424..	"	C + 25,000 8 + 00	72.4	123.67	1.0	P	30
425..	"	C + 19,600 7 + 19,500	79.6	59.56	19.0	Q	11
426..	Queens..........	C + 7,800 5 + 7,700	27.6	113.00	9.6	P	31
467..	"	C + 3,300 5 + 4,200	17.1	43.88	5.2	P	12
551..	"	C + 13,300 5 + 6,400	57.6	52.63	32.0	P	9
552..	Nassau..........	C + 14,800 6 + 16,800	69.5	38.48	19.8	P	11
553..	"	C + 20,600 6 + 21,500	67.2	32.29	6.0	P	9
567..	Queens..........	C + 10,600 4 + 19,200	45.9	47.44	26.5	P	13
587..	Nassau..........	D + 500 7 + 6,600	112.2	53.37	35.9	P	14
588..	Queens..........	C + 9,500 5 + 16,200	28.1	30.53	8.5	P	8
589..	Nassau..........	C + 22,800 7 + 4,400	84.3	37.58	15.9	P	10
590..	Queens..........	C + 12,000 6 + 2,400	42.8	25.86	6.0	P	7
591..	Nassau..........	C + 17,900 7 + 5,400	60.8	24.75	3.0	P	7
604..	"	C + 8,000 7 + 14,800	49.8	29.81	12.0	P	11
605..	"	B + 28,800 7 + 6,000	19.1	71.85	2.0	P	32
606..	Queens..........	C + 9,000 6 + 5,500	52.3	43.10	20.5	P	12
607..	Nassau..........	C + 17,000 6 + 11,500	68.4	41.11	19.4	P	10
615..	"	B + 27,000 7 + 10,000	19.2	25.56	1.0	P	9
616..	"	B + 27,900 7 + 10,700	22.0	24.93	2.3	P	8
617..	Nassau..........	B + 27,900 7 + 10,700	28.3	29.32	8.7	P	11

TABLE NO. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
618..	Nassau..........	B+27,900 7+11,500	28.3	32.53	10.0	P	12
619..	Queens..........	C+24,800 6+ 7,400	108.6	73.74	51.5	P	18
622..	Nassau..........	B+28,000 7+12,500	21.7	31.42	5.5	P	8
623..	"	B+28,400 7+10,700	22.1	24.39	2.0	P	8
627..	Queens..........	C+ 6,800 5+14,700	15.3	25.19	1.5	P	8
628..	"	C+ 3,300 5+15,300	18.4	29.25	7.8	P	9
629..	Nassau..........	B+27,400 7+10,100	20.1	24.73	1.9	P	8
630..	"	B+26,500 7+ 9,900	25.6	30.61	7.8	P	11
638..	Queens..........	C+ 4,400 5+11,500	18.2	30.72	6.5	P	10
639..	"	C+ 7,300 6+ 00	30.2	23.81	2.9	P	8
640..	Nassau..........	B+26,500 7+10,400	25.9	31.35	8.2	P	9
641..	"	B+26,400 7+11,200	28.4	30.74	12.0	P	8
658..	"	B+26,400 7+11,800	27.8	96.31	12.0	Q	28
659..	Queens..........	C+ 800 6+ 3,400	19.8	30.65	8.4	P	8
660..	"	C+ 3,400 6+ 6,300	35.5	35.22	17.0	P	10
661..	Nassau..........	C+ 3,400 6+13,500	20.9	27.55	2.5	P	8
662..	Queens..........	C+27,900 4+ 8,700	66.2	66.95	40.1	P	18
672..	Nassau..........	C+ 6,400 6+16,800	27.5	25.12	3.2	P	7
673..	Queens..........	C+ 6,700 5+ 1,300	40.8	50.33	24.0	P	12
687..	"	C+15,900 5+14,600	44.7	29.03	9.0	P	8
688..	"	C+20,200 6+ 00	78.6	62.80	35.0	P	11
695..	"	C+25,800 5+ 4,900	45.9	38.54	22.0	P	9
696..	Nassau..........	C+15,300 9+10,800	59.2	36.56	17.0	P	9
697..	"	B+26,500 7+12,200	27.8	37.24	13.4	P	12
717..	Queens..........	C+ 9,900 5+21,500	45.3	32.08	12.4	P	8
718	"	C+11,100 4+29,300	65.8	40.83	28.0	P	11
720..	Nassau..........	C+12,700 9+10,400	45.0	35.05	12.5	P	10
721..	"	B+26,600 7+12,100	50.9	46.04	36.2	P	14

TABLE No. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
722..	Nassau	B + 26,500 / 7 + 11,200	50.9	42.63	34.9	P	11
728..	Suffolk	C + 19,100 / 10 + 300	60.8	30.06	10.0	P	9
729..	"	C + 16,100 / 10 + 3,800	51.2	28.99	9.5	P	9
740..	Nassau	C + 23,800 / 6 + 19,400	94.3	56.27	31.0	P	13
741..	"	C + 27,200 / 6 + 18,300	117.5	74.00	51.7	P	17
743..	Suffolk	C + 10,000 / 10 + 3,400	32.5	24.55	2.5	P	8
753..	Nassau	B + 27,800 / 7 + 12,600	50.8	44.48	34.5	P	13
754..	"	B + 27,700 / 7 + 11,500	50.9	42.81	31.8	P	14
755..	"	B + 27,700 / 7 + 10,700	51.0	43.89	32.4	P	18
756..	"	B + 26,700 / 7 + 10,400	50.9	42.31	34.1	P	15
757..	Suffolk	C + 13,600 / 10 + 8,200	32.3	22.29	1.5	P	6
758..	"	C + 25,000 / 10 + 13,100	59.7	31.41	13.0	P	8
762..	Queens..........	D + 1,700 / 4 + 6,500	24.8	31.40	3.7	P	11
763..	Suffolk	C + 18,600 / 10 + 10,100	47.7	30.24	8.0	P	9
767..	Queens..........	D + 3,600 / 4 + 8,500	34.0	28.75	6.5	P	9
768..	"	D + 5,300 / 4 + 11,700	45.1	51.49	33.0	P	10
771..	Suffolk..........	C + 25,600 / 9 + 21,200	65.6	25.22	4.0	P	7
772..	"	D + 1,100 / 10 + 8,600	84.5	42.71	23.5	P	10
776..	Nassau	D + 1,700 / 6 + 17,200	113.7	43.05	Dry	P	12
825..	"	C + 3,000 / 7 + 3,500	33.2	34.97	15.5	P	11
826..	Suffolk..........	C + 21,900 / 7 + 5,100	62.6	88.07	12.8	Q	21
827..	Queens..........	D + 6,500 / 4 + 4,200	31.0	30.18	12.0	P	9
828..	"	D + 8,100 / 4 + 3,100	54.0	41.27	30.4	P	11
829..	Nassau	C + 20,800 / 6 + 13,400	....	129.71	33.5	Q	29
830..	Suffolk..........	D + 600 / 12 + 15,300	32.8	42.44	11.2	P	10
842..	"	D + 400 / 12 + 11,500	29.4	41.31	6.0	P	9
843..	"	C + 25,400 / 12 + 3,100	26.3	37.15	8.5	P	9
844..	Nassau	B + 23,500 / 7 + 7,900	11.8	25.10	2.1	P	8

TABLE No. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
845..	Nassau..........	C+ 3,200 7+ 11,500	31.5	31.51	8.3	P	9
846..	"	C+ 7,800 7+ 11,600	46.1	31.15	10.0	P	12
847..	"	C+ 10,800 7+ 11.000	51.0	35.45	14.0	P	11
848..	"	C+ 13,600 7+ 12,100	41.9	95.63	2.2	Q	24
849..	"	C+ 4,400 9+ 6,900	24.4	30.18	7.0	P	9
858..	"	C+ 13,200 9+ 4.700	44.7	24.41	3.7	P	7
859..	Queens..........	D—10,100 4+ 2,100	....	31.	Dry	P	11
860..	"	D+ 4,800 5+ 3,800	74.6	31.60	12.0	P	9
861..	Suffolk.....	D+ 1,300 12+ 1,600	....	103.15	11.0	P	22
862..	Nassau.........	C+ 19,400 7+ 9,300	71.8	36.27	11.1	P	10
863..	"	C+ 25,800 7+ 9,300	101.0	42.95	28.0	P	12
864..	"	D+ 5,200 6+ 12,300	225.2	38.34	28.0	Q	8
865..	"	C+ 20,400 9+ 3,300	75.8	89.13	19.0	Q	24
868..	"	C+ 20,800 6+ 13,400	89.7	41.06	33.5	Q	..
901..	"	C+ 27,100 7+ 8,800	106.8	57.50	32.0	Q	13
906..	"	D+ 3,400 7+ 8,500	107.7	55.27	29.0	P	14
907..	"	C+ 24,500 6+ 14,700	105.1	67.08	44.0	P	17
908..	"	C+ 25,600 9+ 1,100	91.7	42.23	22.0	P	12
909..	"	D+ 300 8+ 21,500	112.4	59.51	33.8	P	13
955..	"	D+ 4,700 8+ 17,500	141.6	137.50	58.0	Q	20
956..	"	D+ 9,100 6+ 12,800	77.2	47.12	23.6	P	11
957..	"	D+ 12,300 6+ 10,700	175.3	25.51	3.0	P	7
959..	"	D+ 7,500 7+ 8,100	110.9	38.10	28.2	P	10
960..	"	E+ 5,500 7+ 21,500	170.4	54.71	Dry	Q	5
963..	"	D+ 18,500 6+ 12,700	87.2	87.50	66.0	P	19
1007..	Suffolk..........	D+ 13,500 14+ 9,800	64.1	50.56	27.5	P	12
1008..	"	E+ 400 14+ 5,900	....	50.58	Dry	P	12
1013..	Nassau..........	C+ 15,300 6+ 10,300	....	30.18	13.5	Q	8

TABLE No. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1014..	Nassau........	C+15,300 6+10,300	....	20.05	13.5	P	0
1015..	"	C+15,300 6+10,300	....	15.53	13.5	Q	0
1016..	"	C+15,300 6+10,300	....	30.16	13.5	Q	0
1017..	"	C+15,300 6+10,300	....	20.13	13.5	P	0
1018..	"	C+15,300 6+10,300	....	15.38	13.5	Q	0
1019..	"	C+15,300 6+10,300	....	30.50	13.5	Q	0
1020..	"	C+15,300 6+10,300	....	20.23	13.5	P	0
1021..	"	C+15,300 6+10,300	...	15.53	13.5	Q	0
1022..	"	C+15,300 6+10,300	....	30.73	13.5	Q	8
1023..	"	C+15,300 6+10,300	....	20.57	13.5	P	0
1024..	"	C+15,300 6+10,300	....	15.50	13.5	Q	0
1025..	"	C+15,300 6+10,300	....	20.57	13.5	Q	0
1026..	"	C+15,300 6+10,300	63.0	20.45	13.5	Q	0
1027..	"	C+15,300 6+10,300	88.7	22.86	14.5	Q	0
1028..	"	C+15,300 6+10,300	....	24.25	7.0	Q	6
1029..	"	C+15,300 6+10,300	....	14.00	7.0	P	0
1030..	"	C+15,300 6+10,300	....	8.92	7.0	Q	0
1031..	"	C+15,300 6+10,300	....	14.03	7.0	Q	0
1032..	"	C+15,300 6+10,300	....	14.00	7.0	P	0
1033..	"	C+15,300 6+10,300	....	9.04	7.0	Q	0
1086..	Suffolk..........	C+24,500 12+22,600	21.3	29.83	15.0	P	8
1087..	"	D+ 3,000 12+ 1,300	50.9	30.12	10.4	P	8
1088..	"	D+ 6,600 12+ 1,100	73.0	31.40	23.4	P	8
1089..	Queens..........	D+ 3,000 5+10,000	56.4	44.63	25.3	P	9
1090..	"	D+ 4,900 5+11,300	65.2	37.15	38.3	P	11
1141..	Suffolk..........	D+11,800 12+ 2,400	85.4	102.35	34.6	Q	22
1142..	Nassau..........	D+14,300 8+10,800	147.8	78.83	58.2	P	18
1143..	"	D+27,000 6+14,400	103.0	86.34	48.6	P	20

TABLE No. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1144..	Queens...........	D+ 6,300 / 5+14,700	70.5	63.45	45.0	P	17
1145..	Suffolk..........	D+ 8,200 / 14+18,500	31.1	153.59	19.0	Q	33
1146..	Nassau..........	C+15,300 / 6+10,300	....	23.36	7.0	Q	0
1147..	"	C+15,300 / 6+10,300	....	13.87	7.0	Q	0
1148.	"	C+15,300 / 6+10,300	....	9.10	7.0	Q	0
1149..	"	C1+5,300 / 6+10,300	....	24.00	7.0	Q	6
1150..	"	C+15,300 / 6+10,300	....	14.00	7.0	P	0
1151..	"	C+15,300 / 6+10,300	....	9.01	7.0	Q	0
1152..	"	C+15,300 / 6+10,300	....	14.00	7.0	Q	0
1153..	"	C+15,300 / 6+10,300	....	14.00	7.0	Q	0
1154..	"	C+15,300 / 6+10,300	....	13.84	7.5	Q	6
1155..	"	B+28,800 / 8+ 7,500	....	21.20	4.3	Q	0
1156..	"	B+28,800 / 8+ 7,500	....	21.10	4.3	Q	0
1157.	"	B+28,800 / 8+ 7,500	....	23.09	4.3	Q	0
1158..	"	B+28,800 / 8+ 7,500	....	22.09	4.3	Q	0
1159..	"	B+27,700 / 8+ 3,900	....	21.29	1.5	C	0
1160..	"	B+27,700 / 8+ 3,900	....	23.29	1.5	C	0
1161..	"	B+27,700 / 8+ 3,900	....	23.26	1.5	C	0
1162..	"	B+27,700 / 8+ 3,900	....	23.26	1.5	C	0
1163..	"	B+27,700 / 8+ 3,900	....	34.39	1.5	C	0
1164..	"	B+27,700 / 8+ 3,900	....	34.39	1.5	C	0
1165..	"	B+27,700 / 8+ 3,900	....	34.01	1.5	C	0
1166..	"	B+27,700 / 8+ 3,900	....	34.39	1.5	C	0
1167..	"	B+29,800 / 8+ 4,000	11.0	18.18	1.5	C	0
1168..	"	B+29,800 / 8+ 4,000	11.0	20.03	1.5	C	0
1169..	Suffolk..........	D+16,109 / 14+18,000	54.0	50.88	27.0	P	12
1170..	Queens..........	D+ 6,200 / 5+19,500	79.2	71.86	64.1	P	18
1171..	Nassau..........	C+ 3,600 / 9+ 8,800	....	21.92	0.2	Q	0

TABLE NO. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1172..	Nassau..........	C+ 3,600 9+ 8,800	...	21.92	0.2	C	0
1173..	"	C+ 3,600 9+ 8,800	....	21.92	0.2	Q	9
1174..	"	C+ 3,600 9+ 8,800	....	21.92	0.2	Q	0
1175..	"	C+ 1,500 8+18,300	....	21.00	0.1	Q	0
1176..	"	C+ 1,500 8+18,300	....	21.06	0.1	Q	6
1177..	"	C+ 1,500 8+18,300	....	21.00	0.1	Q	0
1178..	"	C+ 1,500 8+18,300	....	21.00	0.1	Q	0
1179..	"	B+30,000 8+12,100	....	20.06	0.3	Q	8
1180..	"	B+30,000 8+12,100	....	22.20	0.3	Q	0
1181..	"	B+30,000 8+12,100	....	22.20	0.3	Q	0
1182..	"	B+30,000 8+12,100	....	22.20	0.3	Q	0
1183..	Suffolk..........	D+ 6,900 12+10,700	59.5	34.44	21.2	P	9
1184..	"	D+ 9,200 14+ 9,000	51.7	49.96	27.4	P	12
1185..	Nassau..........	D+16,200 7+ 5,100	54.9	24.52	Flows.	P	6
1186..	Suffolk..........	D+ 4,100 12+21,500	39.0	36.89	17.1	P	10
1187..	Queens	D+ 700 5+12,400	51.2	41.85	20.5	P	11
1188..	"	C+26,300 4+22,800	9.3	24.16	3.6	P	6
1189..	"	C+24,900 4+11,100	25.5	31.83	13.0	P	9
1190..	Nassau..........	D+16,000 6+16,900	....	33.68	Dry.	P	11
1191..	"	D+12,200 6+ 4,400	68.3	78.14	42.1	P	21
1192..	"	E+ 500 8+14,800	182.0	31.97	7.0	Q	7
1193..	"	D+20,600 8+ 6,200	32.8	59.50	Dry.	P	16
1194..	Suffolk..........	D+10,300 12+19,700	....	25.45	15.2	P	7
1195..	"	D+20,700 12+ 2,300	....	43.50	25.5	P	11
1196..	"	D+13,600 13+22,700	74.3	62.68	32.0	P	14
1197..	Nassau..........	C+13,400 6+10,900	....	120.11	22.1	Q	35
1198..	Suffolk..........	C+28,300 13+18,900	39.0	45.04	22.5	P	11
1199..	Nassau	D+14,900 7+ 6,500	124.4	68.20	Dry......	P	17

TABLE NO. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1200..	Suffolk.........	D+13,700 13+12,400	80.7	56.50	41.0	P	13
1201..	Nassau..........	B+29,800 8+ 4,000	11.0	20.03	1.5	C	0
1202..	Suffolk..........	D+22,600 13+11,400	....	34.64	Dry.	P	9
1203..	Nassau..........	D+14,400 8+12,100	....	18.04	Dry.	P	5
1204..	Queens..........	C+16,900 4+ 9,000	101.5	97.48	76.5	P	20
1205..	Suffolk..........	E+10,000 13+ 4,100	123.9	58.68	26.5	P	14
1206..	"	E+22,200 13+ 5,600	126.8	91.43	75.5	P	20
1210..	Queens..........	D+ 400 4+ 500	34.1	46.35	17.0	P	11
1214..	Suffolk..........	E+19,200 14+13,400	114.0	59.23	42.2	P	14
1215..	"	F+ 4,800 14+13,100	....	97.17	87.5	P	21
1226..	Queens..........	C+25,900 3+20,100	63.0	39.77	23.8	P	10
1227..	"	C+27,500 4+ 000	88.7	41.47	37.5	P	10
1233..	Suffolk..........	F+ 700 14+ 2,100	180.4	96.43	Dry.	P	20
1236..	"	E+21,000 13+13,600	136.8	71.17	71.0	P	16
1237..	"	E+21,500 14+ 2,300	122.4	70.24	43.5	P	16
1243..	Nassau..........	B+29,800 8+ 4,000	11.0	20.00	1.5	C	0
1244..	"	B+28,800 8+ 7,600	....	18.28	4.3	C	0
1245..	"	C+15,300 6+10,300	....	19.53	13.0	C	0
1246..	"	C+15,300 6+10,300	....	21.53	13.0	C	0
1247..	"	C+15,300 6+10,300	....	21.53	13.0	C	0
1248..	"	C+15,300 6+10,300	....	21.53	13.0	C	0
1249..	"	C+15,300 6+10,000	....	43.06	13.5	C	0
1250..	"	C+15,300 6+10,000	....	44.06	13.5	C	0
1251..	"	C+15,300 6+10,000	....	17.82	8.0	C	0
1252..	"	C+15,300 6+10,000	....	23.03	15.6	C	0
1253..	"	C+15,300 6+10,000	...	23.00	15.4	C	0
1254.	"	C+15,300 6+10,000	....	17.70	9.1	C	0
1255..	"	C+15,330 6+10,000	....	12.42	4.0	C	0

TABLE No. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1256..	Nassau.........	C+ 1,900 8+ 19,000	....	14.02	....	C	0
1257..	"	C+ 1,900 8+ 19,000	....	16.02	....	C	0
1258..	"	C+ 1,900 8+ 19,000	....	16.01	....	C	0
1259..	"	C+ 1,900 8+ 19,000	....	16.01	....	C	0
1260..	"	C+ 2,500 8+ 17,700	....	16.36	1.5	C	0
1261..	"	C+ 2,500 8+ 17,700	....	18.00	1.5	C	0
1262..	"	C+ 2,500 8+ 17,700	....	18.15	1.5	C	0
1263..	"	C+ 2,500 8+ 17,700	....	18.00	1.5	C	0
1264..	"	C+ 2,000 8+ 19,300	....	14.00	....	C	0
1265..	"	C+ 2,000 8+ 19,300	....	16.00	....	C	0
1266..	"	C+ 2,000 8+ 19,300	...	16.00	....	C	0
1267..	"	C+ 2,000 8+ 19,300	....	14.00	....	C	0
1268..	"	C+ 2,000 8+ 19,500	....	18.00	....	C	0
1269..	"	C+ 2,000 8+ 19,500	....	15.94	....	C	0
1270..	"	C+ 2,000 8+ 19,500	....	17.90	....	C	0
1271..	"	C+ 2,000 8+ 19,500	....	18.00	....	C	0
1272..	"	C+ 1,900 8+ 19,000	....	71.98	Flows.	O	18
1273..	"	C+ 2,000 8+ 19,300	....	16.20	....	C	0
1274..	"	C+ 1,900 8+ 19,000	....	74.30	Flows.	O	0
1275..	"	B+ 28,800 8+ 7,600	....	20.25	4.3	O	0
1276..	"	B+ 28,800 8+ 7,600	....	20.15	4.3	O	0
1277..	"	B+ 28,800 8+ 7,600	....	20.25	4.3	O	0
1278..	"	B+ 28,800 8+ 7,600	....	20.25	4.3	O	0
1279..	"	B+ 29,700 8+ 5,800	16.7	50.50	7.2	O	0
1280..	"	B+ 29,700 8+ 5,800	16.7	52.50	7.2	O	0
1281..	"	C+ 500 8+ 9,900	....	28.03	0.8	O	0
1282..	"	C+ 500 8+ 9,900	...	28.03	0.8	O	0
1283..	"	C+ 500 8+ 9,900	....	28.02	0.8	O	0

TABLE NO. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1284..	Nassau..........	C+ 500 8+ 9,900	....	28.02	0.8	O	0
1285..	"	B+28,000 8+ 3,400	....	20.01	In Reservoir.	P	0
1286..	"	C+ 900 8+13,900	10.5	29.93	0.5	O	0
1287..	"	C+ 900 8+13,900	10.5	33.23	0.5	O	0
1288..	"	C+ 900 8+13,900	10.5	31.86	0.5	O	0
1289..	"	C+ 900 8+13,900	10.5	32.42	0.5	O	0
1290..	"	C+ 500 8+ 9,900	...	27.72	0.8	O	..
1291..	"	C+ 2,500 8+17,700	12.7	81.41	Flows	O	..
1292..	"	C+ 2,500 8+17,700	16.3	63.32	"	O	..
1293..	"	C+ 2,500 8+17,700	12.7	78.22	"	O	..
1294..	"	C+ 2,500 8+17,700	12.7	64.12	"	O	..
1295..	"	C+ 4,300 8+18,800	....	65.76	"	O	..
1296..	"	C+ 4,300 8+18,800	....	67.83	"	O	..
1297..	"	C+ 4,300 8+18,800	....	67.85	"	O	18
1298..	"	C+ 4,300 8+18,800	....	67.81	"	O	..
1299..	"	C+ 4,300 8+18,800	15.2	14.07	0.5	C	..
1300..	"	C+ 4,300 8+18,800	15.2	16.04	0.5	C	..
1301..	"	C+ 4,300 8+18,800	15.2	16.05	0.5	C	..
1302..	"	C+ 4,300 8+18,800	15.2	16.05	0.5	C	..
1303..	"	C+ 1,900 8+13,900	10.5	14.04	0.5	C	..
1304..	"	C+ 1,900 8+13,900	10.5	16.04	0.5	C	..
1305..	"	C+ 1,900 8+13,900	10.5	16.03	0.5	C	..
1306..	"	C+ 1,900 8+13,900	10.5	16.05	0.5	C	..
1307..	"	B+28,800 8+ 7,600	....	17.03	4.3	O	..
1308..	"	B+29,700 8+ 5,800	16.7	52.55	7.2	O	..
1309..	"	B+29,700 8+ 5,800	16.7	52.54	7.2	O	..
1310..	"	C+ 500 8+ 9,900	16.7	25.04	0.8	O	..
1311..	Queens..........	C+ 2,400 5+12,400	3.4	8.40	2.1	C	..

TABLE No. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1312..	Queens..........	B + 28,800 5 + 12,300	6.4	8.00	5.5	C	..
1313..	"	C + 3,600 4 + 14,700	13.1	10.50	9.4	C	..
1315..	Nassau	B + 27.500 8 + 3,200	....	24.04	3.1	O	..
1316..	"	B + 27,600 8 + 3.000	....	27.26	6.5	C	..
1317..	"	B + 27,500 8 + 2,800	....	23.44	3.3	C	..
1318..	"	B + 27,200 8 + 2,800	....	9.31	2.2	C	..
1319..	"	B + 27,900 8 + 3,200	....	19.48	11.2	O	..
1320..	"	B + 28,000 8 + 3,400	....	11.61	5.6	C	..
1321..	"	B + 27,900 8 + 2,600	.. .	28.91	8.6	O	7
1322..	"	B + 27,400 8 + 3,000	....	23.34	2.3	C	..
1323..	"	B + 27,900 8 + 3,500	....	11.56	5.6	C	..
1324..	"	B + 27,700 8 + 3,900	....	42.39	1.2	O	..
1325..	"	B + 27,700 8 + 3,900	....	44.55	1.6	O	..
1326..	"	B + 27,000 8 + 3,200	....	9.16	4.1	C	..
1327..	"	B + 26,900 8 + 3,900	....	6.56	0.5	C	..
1328..	"	B + 27,100 8 + 4,400	....	14.58	7.0	O	4
1329..	"	B + 27,100 8 + 3,400	....	8.81	3.8	C	..
1330..	"	B + 27,400 8 + 3,500	....	24.24	3.2	C	..
1331..	"	B + 27,600 8 + 3,600	...	23.29	2.8	C	..
1332..	"	B + 27,700 8 + 3,500	....	7.21	2.2	C	..
1333..	"	B + 27,500 8 + 3,900	....	7.51	2.5	C	..
1334..	"	B + 27,500 8 + 4,000	....	7.66	1.5	C	..
1335..	"	B + 27,700 8 + 4,000	....	6.11	0.8	C	..
1336..	Queens..........	D + 6,100 3 + 21,900	40.2	31.81	11.1	P	8
1337..	Nassau	B + 27,700 8 + 3,900	....	45.00	1.1	O	..
1338..	"	B + 27,700 8 + 3,900	....	45.30	1.1	O	9
1339..	"	B + 27,800 8 + 4,100	....	16.33	11.3	C	..
1346..	"	B + 27,800 8 + 4,400	....	12.23	7.2	C	..

TABLE NO. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
		Feet.	Feet.	Feet.	Feet.		
1347..	Nassau........	B+27,800 8+ 3,800	....	8.31	3.2	C	..
1348..	"	B+27,500 8+ 3,800	....	9.16	4.1	C	..
1349..	"	B+26,900 8+ 3,700	....	5.02	0.0	C	..
1350..	"	B+26,700 8+ 3,200	...	8.36	1.4	C	..
1351..	"	B+27,500 8+ 2,500	....	15.73	8.1	C	..
1352..	"	C+ 1,900 8+19,000	....	8.90	....	C	..
1353..	"	C+ 2,000 8+19,000	....	9.55	....	C	..
1354..	"	C+ 8,000 9+ 9,100	29.7	18.01	8.2	P	6
1355..	"	C+ 3,800 8+14,900	....	12.74	4.9	P	4
1356..	"	C+ 7,000 8+15,400	....	13.09	6.6	P	4
1357..	"	C+ 3,500 8+ 7,100	....	19.16	10.3	P	5
1358..	"	C+ 8,200 9+12,600	....	4.00	1.5	C	..
1359..	"	C+ 8,200 9+12,600	2.08	14.00	2.3	C	..
1360..	"	C+ 8,200 9+12,600	20.8	16.00	2.3	C	..
1361..	"	C+ 8,200 9+12,600	20.8	16.00	2.3	C	..
1362..	"	C+ 8,200 9+12,600	20.8	16.00	2.3	C	..
1363..	"	C+ 6,700 9+ 6,700	31.7	14.00	10.2	C	..
1364..	"	C+ 6,700 9+ 6,700	31.7	16.00	10.2	C	..
1365..	"	C+ 6,700 9+ 6,700	31.7	16.00	10.2	C	..
1366..	"	C+ 6,700 9+ 6,700	31.7	16.00	10.2	C	..
1367..	"	C+ 6,000 9+ 1,400	22.8	14.00	1.7	C	..
1368..	"	C+ 6,000 9+ 1,400	22.8	16.00	1.7	C	..
1369..	"	C+ 6,000 9+ 1,400	22.8	16.00	1.7	C	..
1370..	"	C+ 6,000 9+ 1,400	22.8	16.00	1.7	C	..
1371..	Suffolk..........	D+15,600 12+ 800	107.0	44.54	Dry.	P	10
1372..	Queens.........	C+14,500 4+16,900	....	77.25	58.7	P	16
1373..	"	C+17,300 5+ 2,400	35.0	30.39	1.7	P	7
1374..	"	C+19,700 5+ 7,900	89.9	55.32	Dry.	P	11

TABLE NO. 31—*Continued.*

No. of Well.	County.	Location by Co-ordinates.	Elevation of Surface of Ground.	Depth of Well.	Depth to Ground Water.	Type of Point on Well.	Number of Samples Taken.
			Feet.	Feet.	Feet.		
1375.	Nassau	C+ 9,300 8+ 6,700	44.0	12.69	7.4	P	6
1376..	"	B+27,700 8+ 3,200	....	22.84	2.7	C	..
1377..	"	C+ 4,300 8+ 18,800	....	68.00	Flows.	O	..
333..				11,605.12			1,927
46..	Queens............					57 O	Number of wells from which samples were taken, 170.
249..	Nassau............					91 C	
38..	Suffolk............					38 O	

TABLE NO. 32.

SAMPLES OF SUBSTRATA ON LONG ISLAND.

Classification and Analysis of Samples from Well No. 422.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Co-efficient.
1..	0.0	2.0	Dry.........	Loam and coarse gravel	Colors changed by analysis...	*3.30	
2..	2.0	5.0	"	Coarse and fine gravel and coarse sand..............		0.510	12.16
3..	5.0	10.0	Wash	Fine gravel and medium sand..		0.230	6.52
4..	10.0	15.0	"	Fine gravel and coarse sand....		0.300	4.40
5..	15.0	22.0	"	" "		0.252	4.48
6..	22.0	28.0	"	Coarse sand..................		0.207	2.32
7..	28.0	35.0	"	....		0.100	6.80
8..	35.0	37.0	"	Coarse and medium sand.......		0.200	2.05
9..	37.0	37.5	"	Coarse and fine sand...........		0.231	2.10

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 607.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	0.5	Dry........	Loam	Dark	* 0.442.	
2..	0.5	1.0	"	Fine sand	Brownish yellow...	0.215	2.68
3..	1.0	10.0	Core........	Medium sand and fine gravel	Yellow............	0.229	5.07
4..	10.0	15.0	Washed and sand bucket	Medium sand and fine gravel.....	Gray..............	0.221	2.35
5..	15.0	20.0	Washed and sand bucket	Coarse sand and fine gravel	"	0.230	4.87
6..	20.0	25.0	Washed	Medium sand	Light yellow	0.206	3.16
7..	25.0	30.0	"	" "	"	0.220	2.05
8..	30.0	35.0	"	Fine gravel and medium sand....	Whitish...........	0.250	8.00
9..	35.0	40.0	"	Medium sand.......	Reddish yellow....	0.218	3.03
10..	40.0	41.0	"	Fine gravel and medium sand ...	Yellow	0.230	7.43

Classification and Analysis of Samples from Well No. 617.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.8	Dry	Loam	Dark brown.	* 0.305	
2..	1.8	2.3	"	Fine sand and subsoil...........	Reddish brown....	* 0.25	
3..	2.3	5.0	"	Coarse sand and fine gravel.....	Light yellow	0.350	3.57
4..	5.0	8.0	Wash	Fine gravel and coarse sand (little fine sand)...................	Grayish yellow....	0.346	4.05
5..	8.0	10.0	"	Coarse and medium sand........	Reddish yellow....	0.260	2.77
6..	10.0	15.0	"	Coarse gravel, medium sand	Deep yellow.......	0.220	2.41
7..	15.0	16.0	"	Coarse gravel, fine sand.........	Grayish yellow....	0.220	1.90
8..	16.0	20.0	"	Coarse and medium sand.........	Reddish yellow....	0.240	4.00
9..	20.0	25.0	"	Fine gravel, medium sand........	Grayish yellow....	0.236	3.18
10..	25.0	29.0	"	Medium sand..............	Yellow.	0.220	1.73
11..	29.0	29.8	"	Fine sand........................	Light yellowish gray	0.141	1.38

* Than which 60 per cent. is finer.

TABLE No. 32—*Continued.*

Classification and Analysis of Samples from Well No. 618.

Sample No.	Depth Below Surface.		Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby.	
	From	To				Effective Size.	Uniformity Coefficient.
1..	0.0	1.5	Dry.........	Loam............................	Dark brown.......	*0.42	
2..	1.5	2.5	Dry.........	Superfine sand	Reddish brown....	*0.35	
3..	2.5	5.0	Dry.........	Fine gravel and coarse sand......	Brownish yellow...	0.345	6.67
4..	5.0	3.0	Wash........	Fine gravel and coarse sand (little superfine sand)...............	Greenish yellow...	0.240	10.83
5..	8.0	10.5	"	Fine gravel and medium sand....	" ...	0.240	2.35
6..	10.5	14.0	"	Medium and fine sand	Reddish yellow...	0 247	2.00
7..	14.0	16.0	"	Coarse and medium sand	" ...	0.251	2.11
8..	16.0	18.5	"	Fine sand.......................	Light yellow	0.211	1.36
9..	18.5	23.0	"	Fine gravel and coarse sand......	Deep yellow.	0.310	3.32
0..	23.0	26.5	Sand bucket.	" "	Light grayish yellow..........	0.390	7.12
11..	26.5	31.0	Wash........	Fine sand.......................	Light gray..	0.159	2.52
12..	31.0	32.5	"	Superfine sand	Yellow	0.170	1.40

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 619.

Sample No.	Depth Below Surface.		Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby.	
	From	To				Effective Size.	Uniformity Coefficient.
1..	0.0	1.0	Dry.........	Loam	Brown.............	*0.168	
2..	1.0	5.0	"	Subsoil..........................	Reddish brown....	*0.22	
3..	5.0	9.5	" Core	Coarse gravel and medium sand..	Light yellow.......	0.262	17.18
4..	9.5	15.0	Wash........	Medium sand....................	"	0.260	2.27
5..	15.0	20.0	"	Fine gravel and medium sand (little superfine sand).........	Grayish yellow....	0.240	6.75
6..	20.0	24.0	"	Fine gravel, medium sand........	Yellowish gray....	1.500	2.67
7..	24.0	30.0	"	Medium sand (little superfine flour)	Brownish gray.....	0.182	3.00
8..	30.0	35.0	"	Fine sand (little superfine flour)...	"	0.160	1.56
9..	35.0	40.0	"	Medium sand (little superfine sand)	Bluish gray........	0.220	10 10
10..	40.0	43.0	"	Coarse sand (little superfine flour)	Brownish gray.....	0.230	7.61
11..	43.0	45.0	"	Coarse and medium sand.........	Bluish gray........	0.150	5.27
12..	45.0	50.0	"	Fine gravel, medium and coarse sand (little fine sand)..........	Gray...............	0.350	3.71
13..	50.0	55.0	"	Coarse sand (little superfine flour)	Brownish gray.....	0.190	4.00
14..	55.0	60.0	"	Fine gravel, coarse sand (little superfine sand)...............	Bluish gray.......	0.225	6.49
15..	60.0	65.0	"	Fine sand.......................	Brownish gray.....	0.207	2.00
16..	65.0	70.0	"	Coarse and medium sand........	Yellowish gray....	0.220	2.91
17..	70.0	72.0	"	Coarse sand......................	"	0.242	3.05
18..	72.0	73.0	"	Fine sand.	Bluish gray........	0.211	2.60

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 627.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.0	Dry.........	Loam..........................	Dark brown........	*0.96	
2..	1.0	5.0	"	Loam and superfine sand.........	Brown.........	0.107	5.79
3..	5.0	10.0	Core........	Fine gravel, medium and superfine sand........	Brownish yellow...	0.245	8.16
4..	10.0	15.0	Wash........	Medium and fine sand...........	Gray............	0.229	2.25
5..	15.0	20.0	"	Coarse and medium sand.........	"	0.265	3.32
6..	20.0	23.0	"	Fine gravel and coarse sand......	Light gray	0.290	4.24
7..	23.0	25.0	"	Fine gravel and medium sand....	Gray.............	0.400	7.13
8..	25.0	25.5	"	Medium sand....................	"	0.270	2.78

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 628.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.0	Dry.........	Loam..........................	....	*0.32	
2..	1.0	5.0	"	Medium sand and loam...........	Reddish brown....	0.117	5.70
3..	5.0	10.0	Wash	Coarse and medium sand (little superfine flour)..............	Brownish gray.....	0.200	4.00
4..	10.0	15.0	"	Fine gravel and coarse sand (little superfine flour).	"	0.225	4.00
5..	15.0	17.0	"	Fine gravel, coarse and fine sand	Grayish yellow....	0.220	9.71
6..	17.0	20.0	"	Coarse sand....................	Yellow...........	0.260	2.56
7..	20.0	25.0	"	Fine gravel and coarse sand......	"	0.265	2.11
8..	25.0	29.0	"	Fine gravel and medium sand	Gray........	0.228	2.76
9..	29.0	29.5	"	Fine gravel and coarse sand......	Grayish yellow....	0.280	3.00

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 638.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Co-efficient.
1..	0.0	0.5	Dry.........	Loam..........................	Brown............	0.160	3.25
2..	0.5	1.0	"	Fine sand and subsoil............	Reddish yellow....	0.182	3.13
3..	1.0	10.0	Core........	Medium sand..................	Yellowish..........	0.213	2.72
4..	10.0	11.0	Wash........	" "	"	0.210	2.33
5..	11.0	12.0	"	" "	Light yellow.......	0.211	1.34
6..	12.0	15.0	"	" "	"	0.190	2.27
7..	15.0	20.0	"	Medium and coarse sand.........	"	0.240	2.13
8..	20.0	25.0	"	Medium sand..................	"	0.218	3.56
9..	25.0	30.0	"	Medium and coarse sand.........	Yellow............	0.243	1.83
10..	30.0	31.1	"	Medium sand and fine gravel.....	"	0.335	8.06

Classification and Analysis of Samples from Well No. 639.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity. Co-efficient.
1..	0.0	0.5	Dry.........	Loam..........................	Dark..............	0.132	2.71
2..	0.5	1.0	"	Medium sand and coarse gravel..	Yellowish..........	0.212	4.13
8..	1.0	5.0	"	Medium sand..................	"	0.230	2.39
4..	5.0	10.0	Wash.	Medium and fine sand...........	Brownish yellow...	0.245	5.22
5..	10.0	15.0	"	Medium sand...................	Light yellow.......	0.229	2.16
6..	15.0	20.0	"	Medium sand and fine gravel	Yellowish..........	0.247	3.54
7..	20.0	24.0	"	Medium sand..................	"	0.260	1.81
8..	24.0	24.5	"	" "	"	0.240	2.07

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 658.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	0.5	Dry	Fine gravel and medium sand	Reddish yellow	....	....
2..	0.5	5.0	Core	Coarse gravel, coarse and fine sand	Yellow	....	....
3..	5.0	10.5	Wash	Fine sand and rock flour	Brownish yellow	0.212	3.30
4..	10.5	15.0	"	Fine gravel, medium sand (little rock flour)	Reddish yellow	0.237	3.54
5..	15.0	20.0	"	Medium sand	"	0.228	2.06
6..	20.0	25.0	"	"	"	0.216	2.69
7..	25.0	29.0	"	Coarse sand	"	0.280	2.18
8..	29.0	31.5	"	Medium and fine sand	Yellow	0.238	1.97
9..	31.5	34.5	"	Superfine sand	Nearly white	0.168	1.40
10..	34.5	35.5	"	Fine gravel	White and yellow stones	0.189	1.42
11..	35.5	40.0	"	Superfine sand	Nearly white	0.124	2.00
12..	40.0	41.0	"	Medium and fine sand	Yellow	0.196	2.32
13..	41.0	46.0	"	Superfine sand	White (slightly yellow)	0.138	1.42
14..	46.0	50.0	"	Coarse sand (little superfine sand).	Light yellow	0.198	2.65
15..	50.0	54.0	"	Sand	Grayish yellow	0.282	1.88
16..	54.0	56.0	"	Fine sand	White	0.245	1.51
17..	56.0	58.0	"	Fine and superfine sand	Dark gray	0.187	1.26
18..	58.0	63.0	"	Fine sand	White	0.213	1.46
19..	63.0	68.0	"	Medium and superfine sand	"	0.213	1.62
20..	68.0	73.0	"	" "	"	0.170	2.03
21..	73.0	78.0	"	Fine sand	"	0.378	2.07
22..	78.0	81.0	"	Medium and fine sand	Light yellow	0.280	1.48
23..	81.0	86.0	"	Medium sand	Nearly white	0.239	1.76
24..	86.0	91.0	"	Superfine sand and rock flour	Light gray	0.209	1.45
25..	91.0	93.0	"	Fine sand superfine sand	"	0.177	2.06

Classification and Analysis of Samples from Well No. 659.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.0	Dry	Loam and fine sand	Light brown	*0.380	
2..	1.0	5.0	"	Fine sand	Yellow reddish	0.215	1.47
3..	5.0	10.0	Core	"	Light yellow	0.192	2.24
4..	10.0	15.0	Wash	Medium sand	Yellow	0.224	1.83
5..	15.0	20.0	"	"	"	0.233	2.11
6..	20.0	23.0	"	Medium and fine sand	Reddish yellow	0.212	1.25
7..	23.0	25.0	"	Medium sand	Yellow	0.245	1.00
8..	25.0	30.0	"	Coarse and medium sand	Greenish yellow	0.243	1.87
9..	30.0	30.5	"	Medium sand	"	0.250	1.79

*Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 660.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity. Coefficient.
1..	0.0	1.0	Dry	Loam and fine sand.............	Brown	0.128	2.91
2..	1.0	5.0	"	" "	Reddish brown....	0.200	2.20
3..	5.0	10.0	Core	Fine gravel and medium sand....	Light grayish yellow....	0.220	2.77
4..	10.0	15.0	Wash........	Medium sand (little rock flour) ...	Brownish yellow...	0.220	2.09
5..	15.0	20.0	"	" "	" ..	0.258	2.33
6..	20.0	23.0	"	Medium sand....................	" ..	0.207	1.75
7..	23.0	25.0	"	"	Grayish yellow....	0.212	1.30
8..	25.0	29.0	"	"	"	0.226	2.57
9..	29.0	35.0	"	"	"	0.215	2.64
10..	35.0	35.5	"	Medium sand (clay)..............	Light yellow.......	(No sample.)	

Classification and Analysis of Samples from Well No. 662.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Coefficient.
1..	0.0	0.5	Dry.........	Loam...........................	Light	*0.700	
2..	0.5	1.0	"	Loam and superfine sand.........	Yellow	*0.138	
3..	1.0	6 0	Wash	Coarse and superfine sand........	"	*1.300	
4..	6.0	10.0	Dry.........	Fine gravel and superfine sand...	"	0.181	23.20
5..	10.0	15.0	Wash	Medium and coarse sand.........	"	0.220	5.co
6..	15.0	19.0	"	Coarse sand and fine gravel	Yellowish gray....	0.235	6.21
7..	19.0	24.5	Sand bucket.	Fine gravel and coarse sand......	Pinkish gray......	0.160	3.05
8..	24.5	30.0	"	" "	"	0.350	4.57
9..	30.0	35.0	"	" "	Greenish gray.....	0.241	7.97
10..	35.0	36.5	Wash	" "	Pinkish gray......	0.455	5.05
11..	36.5	40.5	"	Medium sand....................	Gray.............	0.245	2.82
12	40.5	45.0	"	Fine sand......................	Yellow............	0.165	3.58
13..	45.0	48.5	"	"	"	....	....
14..	48.5	49.0	"	Superfine sand......	Brown	....	....
15..	49.0	54.5	"	Fine and medium sand...........	Brownish yellow..	....	....
16..	54.5	59.5	"	Coarse and fine sand............	" ..	0.178	4.78
17..	59.5	64.5	"	Coarse sand.....................	Pinkish gray......	0.310	3.61
18..	64.5	65.5	"	Medium sand....................	Yellowish gray....	0.204	2.84

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 687.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity. Co-efficient.
1..	0.0	0.4	Dry.........	Loam	Dark	*0.220	
2..	0.4	1.5	"	Loam and superfine sand.........	Light (reddish)....	*0.260	
3..	1.5	10.0	Core.........	Fine sand	Reddish...........	*0.435	
4..	10.0	15.0	Wash.......	Medium sand and rock flour......	Brown.............	0.172	4.65
5..	15.0	20.0	"	Fine gravel and coarse sand	Reddish yellow....	0.310	2.99
6..	20.0	25.0	"	" "	Pinkish gray.......	0.518	5.79
7..	25.0	28.0	"	Fine gravel and medium sand	Gray..............	0.282	3.72
8..	28.0	29.0	"	Medium sand.....................	"	0.295	1.88

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 688.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Co-efficient.
1..	0.0	0.5	Dry.........	Loam	Light	*0.37	
2..	0.5	1.5	"	Superfine sand..................	Reddish...........	*0.34	
3..	1.5	10.0	Core	Coarse and fine sand............	Light yellow	0.120	4.58
4..	10.0	15.0	Wash	Medium sand....................	"	0.233	3.86
5..	15.0	26.0	"	Medium sand and fine gravel.....	"	0.238	3.82
6..	20.0	26.0	"	Medium sand....................	Gray..............	0.190	3.36
7..	26.0	39.0	"	Coarse sand.....................	"	0.212	3.82
8..	39.0	45.0	"	"	"	0.262	3.36
9..	45.0	55.0	"	Medium sand....................	"	0.247	2.15
10..	55.0	59.0	"	Coarse sand.....................	"	0.250	2.48
11..	59.0	60.0	"	"	"	0.283	2.86

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 695.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.5	Dry.........	Loam	Dark brown.......	*0.255	
2..	1.5	5.0	Wash........	Subsoil..........................	Reddish brown....	*0.280	
3..	5.0	10.0	"	Coarse and medium sand.........	Yellowish gray....	0.221	4.12
4..	10.0	15.0	"	Fine gravel and fine sand	"	0.208	3.66
5..	15.0	20.0	"	Coarse and fine sand	"	0.205	2.24
6..	20.0	25.0	"	Coarse and medium sand........	Dark gray	0.240	2.63
7..	25.0	30.0	"	Medium sand....................	Yellowish gray....	0.220	2.14
8..	30.0	34.0	"	"	"	0.229	1.49
9..	34.0	35.0	"	Superfine rock flour..............	Yellowish brown...	*0.112	

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 697.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	6.0	Dry.........	Fine gravel and coarse sand......	Yellow............	....	....
2..	6.0	8.0	Core	Coarse gravel, medium sand and rock flour	Yellowish brown...	....	....
3..	8.0	16.5	Wash........	Medium sand and rock flour......	Yellow............	0.180	2.02
4..	16.5	19.0	"	Coarse and fine sand.............	Yellow	0.224	1.72
5..	19.0	24.0	"	Coarse and medium sand........	Reddish yellow....	0.290	3.17
6..	24.0	25.5	"	Coarse sand......................	Yellow	0.233	3.15
7..	25.5	28.5	"	Coarse and fine gravel and medium sand.................	Deep yellow.......	0.270	11.40
8..	28.5	29.0	"	Medium sand.....................	Yellow	0.240	2.125
9..	29.0	34.0	"	Fine sand and fine gravel.........	Bluish white.......	0.187	4.81
10..	34.0	35.0	"	Superfine sand...................	White, black streaks	0.148	1.34
11..	35.0	37.0	"	Fine sand.........................	Red, brick color...	0.169	1.65
12..	37.0	38.0	"	Superfine sand............	Very light yellow..	0.169	1.95

TABLE No. 32—*Continued.*

Classification and Analysis of Samples from Well No. 717.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Coefficient.
1..	0.0	0.4	Dry........	Loam	Dark..............	0.119	3.53
2..	0.4	1.0	"	Loam and fine sand.............	Reddish	....	....
3..	1.0	10.0	"	Fine sand	Brown.............	0.238	2 15
4..	10.0	15.0	Wash	Medium sand....................	Yellowish gray	0.220	2.50
5..	15.0	19.0	"	Fine gravel and fine sand	"	0.231	7.27
5½	19.0	21.0	"	....	....	0.220	2.66
6..	21.0	25.0	"	Coarse sand.....................	Yellowish gray	0.244	3.80
7..	25.0	31.0	"	Medium sand....................	Yellow	0.225	2 71
8..	31.0	32.0	"	Coarse and fine sand..	Reddish yellow....	0.245	6.53

Classification and Analysis of Samples from Well No. 729.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Coefficient.
1..	0.0	0.5	Dry.........	Loam.	Very dark.........	*1.13	
2..	0.5	1.0	"	Fine gravel and subsoil..........	Light brown.......	*0.80	
3..	1.0	5.0	"	Fine gravel and medium sand...	Light yellow......	0.308	8.08
4..	5.0	10.0	Wash	" "	"	0.358	8.10
5..	10.0	15.0	"	Fine gravel and coarse sand......	"	0.435	7.13
6..	15.0	20.0	"	Coarse sand and fine gravel	"	0.250	4.80
7..	20.0	24.0	"	Medium sand.....................	Yellowish gray....	0.230	2.70
8..	24.0	29.0	"	Fine gravel and medium sand....	Light yellow......	0.345	2.43
9..	29.0	29.5	"	Coarse sand and fine gravel......	Grayish yellow....	0.338	5.47

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 743.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	0.5	Dry.........	Loam..........................	Very dark.........	*0.605	
2..	0.5	1.0	"	Fine gravel and subsoil	Reddish brown....	*2.0	
3..	1.0	5.0	"	Coarse and fine gravel and superfine sand	Yellowish brown...	0.530	6.51
4..	5.0	10.0	Wash.......	Fine gravel and fine sand........	Light grayish yellow..............	0.380	7.37
5..	10.0	15.0	"	Fine gravel and medium sand....	Light yellow.......	0.341	7.68
6..	15.0	19.0	"	Fine gravel and coarse sand......	"	0.398	4.22
7..	19.0	24.0	"	" "	"	0.280	4.57
8..	24.0	25.0	"	" "	"	0.380	2.60

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 762.

Sample No.	Depth of Surface. From	Depth of Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.0	Dry	Loam..........................	Dark..............	*0.458	
2..	1.0	5.0	"	Superfine sand.	Light..............	*0.205	
3..	5.0	10.0	"	Lignite.........................	Black..............	*0.700	
4..	10.0	12.5	Wash	Fine sand..............	Dark..............	*0.329	
5..	12.5	15.0	"	"	Brown.............	*0.379	
6..	15.0	17.0	"	"	"	0.131	5.88
7..	17.0	19.0	"	Coarse sand and fine gravel......	Pinkish gray.......	0.840	3.18
8..	19.0	22.0	"	Coarse and fine sand............	Brown.............	0.167	3.89
9..	22.0	25.0	"	Coarse sand and fine gravel......	Pinkish gray.........	0.825	2.16
10..	25.0	30.0	"	Medium sand....................	"	0.235	4.51
11..	30.0	31.0	"	Fine sand.......................	Pinkish brown.....	0.102	4.16

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 826.

Sample No.	Depth Below Surface.		Kind of Sampling.	Classification of Material.	Color of Material.	Mechnical Analysis by Prof. W. O. Crosby.	
	From	To				Effective Size.	Uniformity Coefficient.
1..	0.0	0.5	Dry..........	Loam and fine sand.............	Reddish brown ...	*0.74	
2..	0.5	5.0	"	Medium sand and fine gravel.....	Yellow............	0.156	6.73
3..	5.0	10.0	Wash........	Fine gravel and coarse sand	Brownish yellow...	0.259	4.02
4..	10.0	15.0	"	Fine gravel and coarse sand......	Light yellow......	0.434	4.61
5..	15.0	20.0	"	Coarse and medium sand (little rock flour)...................	Yellow............	0.219	4.93
6..	20.0	25.0	"	Fine gravel and coarse sand......	"	0.365	2.8
7..	25.0	29.0	"	" " "	"	0.420	6.21
8..	29.0	35.0	"	Medium sand....................	"	0.220	1.59
9..	35.0	40.0	"	Fine sand......................	Gray.............	0.209	1.55
10..	40.0	45.0	"	Fine gravel and coarse sand......	Light yellowish gray	0.314	3.12
11..	45.0	50.0	"	Medium sand....................	Bluish gray	0.265	3.21
12..	50.0	55.0	"	Coarse sand....................	Light yellow......	0.340	1.76
13..	55.0	60.0	"	Medium sand....................	"	0.266	2.03
14..	60.0	65.0	"	Medium and fine sand..	Gray.....	0.220	1.93
15..	65.0	70.0	"	Fine gravel and coarse sand......	Light yellowish gray	0.370	2.51
16..	70.0	75.0	"	Coarse and medium sand.........	" "	0.382	2.49
17..	75.0	80.0	"	Coarse sand..........	" "	0.281	3.47
18..	80.0	85.0	"	" "	" "	0.231	2.86
19..	85.0	87.0	"	Fine gravel and coarse sand......	Light yellow.......	0.460	2.72
20..	87.0	91.0	"	Superfine sand..................	Dark bluish gray..	0.125	1.72
21..	91.0	92.0	"	" "	" " ..	....	....

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 827.

Sample No.	Depth Below Surface.		Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby.	
	From	To				Effective Size.	Uniformity Coefficient.
1...	0.0	3.0	Dry.........	Loam and fine sand.............	Dark brown.......	*0.203	
2...	3.0	4.0	"	Fine and superfine sand.........	Reddish brown....	*0.153	
3...	4.0	10.0	"	" "	"	*0.165	
4...	10.0	15.0	Wash........	" "	Brown............	*0.145	
5...	15.0	17.0	"	" "	Reddish brown....	*0.200	
6...	17.0	20.0	"	Medium and coarse sand.........	Brownish yellow...	0.131	7.25
7...	20.0	25.0	"	Coarse sand....	Grayish yellow....	0.195	3.25
8...	25.0	29.5	"	Coarse and medium sand.........	Grayish brown.....	0.170	5.15
9...	29.5	30.5	"	" "	"	0.202	2.27

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 828.

Sample Nos.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	2.0	Dry.........	Loam..........................	Dark brown.......	*0.125	
2..	2.0	5.0	".........	Fine and superfine sand.........	Reddish brown ..	*0.112	
3..	5.0	8.5	".........	Fine gravel and medium sand....	Yellowish brown...	*0.595	
4..	8.5	15.0	Wash.......	Coarse sand.........................	Yellowish..........	0.182	3.85
5..	15.0	20.0	".......	".........................	Grayish yellow....	0.108	3.28
6..	20.0	23.8	".......	Fine gravel and coarse sand......	Pinkish gray......	1.280	2.27
7..	23.8	26.0	".......	Fine gravel..........................	".......	2.500	1.32
8..	26.0	29.5	".......	Medium and coarse sand.........	".......	0.185	2.49
9..	29.5	35.0	".......	Coarse sand and fine gravel......	".......	0.238	6.72
10..	35.0	37.0	".......	".....	".......	0.475	4.00
11..	37.0	37.5	".......	Coarse and medium sand.........	".......	0.166	2.29

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 829.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	0.5	Dry.........	Loam..........................	Dark..............	*0.23	
1..	0.5	1.5	".........	"............................	Reddish............	*0.38	
3..	1.5	8.0	".........	Fine gravel and medium sand....	Yellow............	0.230	3.83
4..	8.0	15.0	Wash........	Fine gravel and coarse sand......	Gray.............	0.358	4.47
5..	15.0	19.0	"........	" " " ".....	"...............	0.225	3.78
6..	19.0	25.0	"........	Coarse and medium sand.........	"...............	0.230	3.00
7..	25.0	30.0	"........	Coarse sand..........................	Yellowish gray....	0.260	3.85
8..	30.0	33.0	"........	Coarse sand and fine gravel......	" "...	0.239	6.86
9..	33.0	40.0	"........	Medium sand........................	Light yellow.......	0.220	2.48
10..	40.0	45.0	"........	" "......................	" "......	0.220	2.45
11..	45.0	50.0	"........	Coarse and medium sand.........	Yellow............	0.245	4.00
12..	50.0	55.0	"........	Medium sand........................	Light yellow.......	0.220	1.82
13..	55.0	60.0	"........	Course sand.........................	Reddish yellow...	0.300	2.83
14..	60.0	64.5	"........	Fine gravel..........................	Yellow............	0.500	4.00
15..	64.5	70.0	"........	Course sand.........................	Light yellow......	0.41	3.53
16..	70.0	75.0	"........	Coarse sand and fine gravel......	Yellow............	0.600	4.00
17..	75.0	80.0	"........	Fine gravel..........................	"............	0.570	5.26
18..	80.0	83.0	"........	Fine sand............................	Light yellow......	*0.37	
19..	83.0	90.0	"........	" "........................	" "......	0.247	2.27
20..	90.0	95.0	"........	" "........................	" "......	0.241	2.57
21..	95.0	99.0	"........	" "........................	" "......	0.227	1.78
22..	99.0	105.0	"........	" "........................	" "......	0.230	1.65
23..	105.0	109.0	"........	" "........................	" "......	0.213	1.70
24..	109.0	113.0	"........	" "........................	" "......	*0.26	
25..	113.0	115.0	"........	Fine gravel..........................	" "......	1.480	1.96

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 843.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.5	Dry.........	Loam...........................	Light brown......	*0.46	
2..	1.5	5.0	"	Subsoil, coarse and fine gravel ...	Reddish brown ...	*0.65	
3..	5.0	10.0	Core........	Coarse gravel and medium sand ..	Light yellow......	0.22	4.64
4..	10.0	15.0	Wash.......	Coarse and fine gravel...........	Yellowish gray....	1.27	1.73
5..	15.0	20.0	"	Fine gravel and medium sand....	Light yellowish gray............	0.22	4.50
6..	20.0	25.0	"	Medium sand...................	Yellowish gray....	0.22	2.75
7..	25.0	30.0	"	Fine gravel and medium sand....	Yellowish gray....	0.42	7 33
8..	30.0	35.0	"	Coarse and medium sand........	Yellowish gray....	0.23	2.52
9..	35.0	36.0	"	Fine gravel aud coarse sand......	Grayish yellow....	0.235	3.83

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 845.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.3	Dry.........	Loam...........................	Light yellow.......	*0.225	
2..	1.3	2 0	"	Coarse gravel and fine sand......	Brown............	0.410	15.24
3..	2.0	6.0	"	Fine gravel and medium sand.....	Yellow............	0.415	6.14
4..	6.0	11.0	Wash.......	Medium sand....	Deep yellow.......	0.289	2.01
5..	11.0	16.0	"	Fine gravel and coarse sand......	"	0.225	3.02
6..	16.0	21.0	"	Coarse sand............	Reddish yellow....	0.313	3.04
7..	21.0	26.0	"	Coarse and medium sand.........	Deep yellow.......	0.240	2.06
8..	26.0	31.0	"	Fine gravel and coarse sand......	Yellow............	0.290	2.76
9..	31.0	32.0	.. ..	Fine sand........................	Very light yellow..	0.211	1.96

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 846.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.2	Dry.........	Coarse gravel and loam..........	Light brown.......	*0.63	
2..	1.2	2.5	"	Superfine sand and clay.........	Yellowish brown..	*0.30	
3..	2.5	5.4	"	Fine gravel and coarse sand......	" ..	0.380	3.74
4..	5.4	9.5	Wash	Coarse gravel, medium sand, little rock flour.......	Brownish yellow...	0.220	4.09
5..	9.5	14.5	"	Coarse sand.....................	Reddish yellow....	0.256	3.28
6..	14.5	19.0	"	Fine gravel and coarse sand......	Yellow............	0.205	2.63
7..	19.0	20.0	"	Fine gravel, coarse sand, little superfine sand...............	Brownish yellow...	0.300	7.83
8..	20.0	21.5	"	Fine gravel, coarse sand.........	Dark gray.........	....	....
9..	21.5	23.0	"	Fine gravel and fine sand........	Yellow............	0.120	3.50
10..	23.0	28.0	"	" "	Light grayish yellow	0.180	3.00
11..	28.0	31.0	"	Coarse sand.....................	Light yellow......	0.230	2.39
12..	31.0	32.0	"	Fine gravel and coarse sand......	Whitish yellow....	0.300	6.83

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 847.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.5	Dry.........	Loam and coarse gravel	Brown	*1.38	
2..	1.5	3.0	"	Coarse gravel and fine sand......	Reddish brown....	0.290	12.76
3..	3.0	8.0	"	Fine gravel and medium sand....	Reddish yellow....	0.450	11.10
4..	8.0	10.0	Wash	Coarse sand.....................	Light yellow	0.223	2.24
5..	10.0	12.0	"	"	Yellowish gray....	0.228	2.63
6..	12.0	15.0	"	Fine gravel and medium sand....	"	0.410	12.70
7..	15.0	18.0	"	Coarse sand.....................	Reddish yellow....	0.315	3.10
8..	18.0	23.0	"	Coarse gravel and medium sand..	"	0.540	8.15
9..	23.0	28.0	"	Medium sand....................	Light yellow......	0.216	2.50
10..	28.0	33.0	"	Fine gravel, fine sand and coarse sand..........................	Deep yellow.......	0.230	2.70
11..	33.0	33.5	"	Medium sand....................	Dark gray.........	0.240	2.04

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 849.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	0.3	Dry........	Loam.........................	Brown............	*0.41	
2..	0.3	2.4	"	Coarse and superfine sand......	Yellowish brown...	*0.605	
3..	2.4	10 0	"	Coarse gravel and medium sand..	Yellowish.........	0 239	7.66
4..	10.0	12.0	Wash	Fine gravel and medium sand....	Reddish yellow....	0.270	3.89
5..	12.0	15.0	"	" "	Yellowish.........	0.270	3.89
6..	15.0	20.5	"	Coarse sand.....................	Light yellowish....	0.340	2.91
7..	20.5	25.0	"	Fine gravel and medium sand ...	Yellowish.........	0.260	4.12
8..	25.0	30.0	"	Coarse and medium sand.........	Reddish yellow....	0.238	2.48
9..	30.0	31.0	"	Fine gravel and coarse sand	Yellowish.........	0 490	3.67

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 858.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	0.7	Dry.........	Loam..........................	Light brown.......	*0.875	
2..	0.7	1.2	"	Medinm sand and coarse gravel..	Yellowish brown...	0.360	13.90
3..	1.2	9.5	Wash........	Coarse sand and fine gravel......	Grayish yellow....	0.231	4.16
4..	9.5	15.0	"	Coarse and medium sand.........	"	0.229	2.53
5..	15.0	20.0	"	Fine gravel and medium sand....	Light gray........	0.620	4.66
6..	20.0	24.0	"	Fine gravel and coarse sand......	Yellowish gray.....	0.233	6.86
7..	24.0	25.0	"	Coarse and medium sand.........	"	0.233	2.49

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 859.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	2.0	Dry	Loam	Brown	*0.128	
2..	2.0	5.0	"	Superfine sand	Reddish yellow	*0.170	
3..	5.0	9.5	Wash	Medium sand	Brownish yellow	0.180	3.44
4..	9.5	12.5	"	Coarse sand	Yellowish gray	0.225	6.22
5..	12.5	14.5	"	Clay	Light brown	All material in this sample is more than 60 per cent. finer than 0.10 millimeter.	
6..	14.5	15.0	"	Pebbles	Dark gray		
7..	15.0	18.0	"	Coarse and fine sand, rock flour	Brownish gray		
8..	18.0	18.5	"	Fine gravel, caorse sand, superfine sand	Dark brown		
9..	18.5	25.5	"	Coarse and medium sand	Dark gray		
10..	25.5	30.0	"	Pebbles and coarse sand	Pinkish gray		
11..	30.0	31.0	"	Pebbles, coarse sand and superfine flour	Brownish gray		

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 861.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. O. W. Crosby. Effective Size.	Mechanical Analysis by Prof. O. W. Crosby. Uniformity Coefficient.
1..	0.0	1.0	Dry	Loam	Brown	*0.50	
2..	1.0	5.0	"	Coarse gravel and subsoil	Reddish brown	*0.37	
3..	5.0	10.0	Dry core	Medium sand and fine gravel	Light yellow	0.224	2.63
4..	10.0	15.0	Wash	Fine gravel and medium sand	Light grayish yellow	0.220	15.23
5..	15.0	20.0	"	" "	Light grayish yellow	0.195	3.33
6..	20.0	30.0	"	" "	Light grayish yellow	1.100	3.19
7..	30.0	35.0	"	Fine gravel and coarse sand	Grayish yellow	0.300	3.67
8..	35.0	40.0	"	Coarse sand	"	0.330	2.73
9..	40.0	45.0	"	Coarse and medium sand	Gray	0.230	3.00
10..	45.0	50.0	"	Medium sand	Grayish yellow	0.214	1.54
11..	50.0	55.0	"	Fine gravel and coarse sand	"	0.238	5.25
12..	55.0	60.0	"	Coarse sand	"	0.222	3.47
13..	60.0	65.0	"	Medium sand	"	0.190	1.37
14..	65.0	69.0	"	Fine gravel and fine sand	"	0.224	2.28
15..	69.0	75.0	"	Coarse and medium sand	"	0.229	2.10
16..	75.0	80.0	"	Medium and fine sand	Yellowish gray	0.242	1.90
17..	80.0	85.0	"	Fine sand	"	0.208	1.25
18..	85.0	90.0	"	Medium sand	"	0.209	1.82
19..	90.0	95.0	"	"	"	0.200	1.17
20..	95.0	100.0	"	"	Brownish yellow	0.220	1.59
21..	100.0	101.5	"	Fine sand	Brownish gray	0.180	1.23
22..	101.5	102.5	"	Superfine sand (little clay)	Bluish gray	*0.22	

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 862.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.2	Dry.........	Loam..........................	Light brown. ...	0.161	1.32
2..	1.2	2.3	"	Fine sand and pebbles..........	"	0.753	8.13
3..	2.3	7.0	"	Medium sand...................	Yellow...........	0.318	1.80
4..	7.0	12.0	Wash.......	Medium sand and pebbles.......	"	0.230	2.39
5..	12.0	17.0	"	Medium sand and coarse grrvel..	Deep yellow.....	0.270	4.26
6..	17.0	22.0	"	Coarse gravel and medium sand..	Yellow..........	0.410	11.00
7..	22.0	27.0	"	" " ..	"	0.459	7.01
8..	27.0	32.0	"	Fine sand......................	Reddish yellow....	0.215	2.80
9..	32.0	36.0	"	Fine gravel and coarse sand......	Light yellow......	0.241	5.18
10..	36.0	36.8	"	Medium sand...................	"	0.232	3.44

Classification and Analysis of Samples from Well No. 863.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	1.2	Dry.........	Loam..........................	Dark brown.......	*0.236	
2..	1.2	3.2	"	Coarse gravel and subsoil........	Light brown.......	*2.08	
3..	3.2	6.0	"	Fine gravel, medium sand and subsoil......................	"	0.280	16.07
4..	6.0	11.0	Wash	Fine gravel and medium sand....	Brownish yellow...	0.280	4.43
5..	11.0	16.0	"	" " ...	" ...	0.380	6.58
6..	16.0	21.0	"	Fine gravel and coarse sand.	" ...	0.445	6.14
7..	21.0	26.0	"	" "	" ...	0.410	8.78
8..	26.0	30.9	"	" "	"	0 380	6.32
9..	30.9	31.0	"	Fine sand (little rock flour)..	Reddish yellow....	*0.229	
10..	31.0	36.0	"	Fine gravel and coarse sand......	Brownish yellow...	0.363	9.32
11..	36.0	41.5	"	Fine gravel and medium sand....	Yellowish gray....	0.330	9.09
12..	41.5	42.5	"	" "	"	0.365	8.22

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 864.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1...	0.0	0.5	Dry.........	Loam	Reddish brown	*0.22	
2...	0.5	8.0	"	Fine gravel and fine sand	Brown.............	*0.359	
3..	8.0	14.0	Wash	Medium sand....................	Yellow (dark)......	0.137	3.00
4...	14.0	19.0	"	Medium sand and cobbles........	"	0.130	2.70
5...	19.0	24.0	"	" "	"	0.136	2.71
6...	24.0	29.0	"	" "	Yellow	0.141	2.73
7..	29.0	34.0	"	Medium sand and coarse gravel ..	"	0.110	2.82
8...	34.0	35.0	"	" " ..	"	0.150	2.53

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 865.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.7	Dry	Loam and coarse gravel.........	Black..............	*0.216	
2..	1.7	2.7	"	Superfine sand....................	Brownish yellow...	*0.205	
3..	2.7	5.0	"	Fine gravel and superfine sand...	" ..	*0.230	
4..	5.0	9.0	Wash..	Fine gravel and medium sand....	Yellow............	0.310	2.97
5..	9.0	15.0	"	Coarse gravel and coarse sand....	Light yellow	0.300	10.67
6..	15.0	20.0	"	Fine gravel and coarse sand......	"	0.540	6.30
7..	20.0	25.0	"	" "	Gray.............	0.375	2.97
8..	25.0	30.0	"	" "	"	0.260	3.90
9..	30.0	35.0	"	Fine gravel........................	"	0.650	4.06
10..	35.0	37.5	"	Coarse gravel and coarse and medium sand................	Grayish yellow....	0.213	2.07
11..	37.5	40.0	"	Fine sand	" ...	0.144	2.19
12..	40.0	45.0	"	Medium sand....................	Yellow............	0.242	2.40
13..	45.0	50.5	"	Coarse and fine sand...	"	0.228	4.17
14..	50.5	52.4	"	Fine gravel and coarse sand......	Light gray	0.520	4.33
15..	52.4	55.0	"	Coarse and fine sand............	Reddish yellow....	0.110	7.82
16..	55.0	58.5	"	Fine gravel and fine sand.........	"	0.105	8.39
17..	58.5	60.5	"	Coarse and fine sand............	Grayish yellow....	0.118	3.31
18..	60.5	63.0	"	Medium sand....................	Reddish yellow....	0.222	1.85
19..	63.0	65.5	"	"	Gray............	0.190	2.80
20..	65.5	70.0	"	Fine gravel and coarse sand......	Pinkish white.	0.650	1.77
21..	70.0	74.5	"	Medium sand....................	Reddish yellow....	0.200	2.90

*Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 901.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	2.0	Dry	Loam	Dark brown.......	*0.44	
2..	2.0	6.5	"	Coarse and fine gravel and medium sand......................	Brownish yellow..	0.480	13.33
3..	6.5	11.0	Wash	Coarse and fine gravel and medium sand....................	Yellow	0.368	6.71
4..	11.0	16.0	"	Fine gravel and medium sand	Deep yellow	0.350	11.14
5..	16.0	21.0	"	" "	Grayish yellow.. .	0.362	9.67
6..	21.0	26.0	"	Fine gravel and coarse sand......	Reddish yellow....	0.362	8.01
7..	26.0	31.0	"	" "	Yellow.............	0.325	7.88
8..	31.0	36.4	"	" "	Grayish yellow....	0.330	9.09
9..	36.4	41.0	"	Fine sand and little fine gravel...	Brownish yellow ..	0.198	3.80
10..	41.0	45.0	"	Fine gravel and medium sand....	Yellowish gray ...	0.350	6.91
11..	45.0	51.0	"	Fine and superfine sand...	Light yellow	*0.242	
12..	51.0	53.8	"	Medium sand....................	"	0.221	1.81
13..	53.8	57.5	"	Coarse sand......................	"	0.350	2.29

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 906.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Coefficient.
1..	0.0	2.7	Dry.........	Loam	Brown.............	*0.34	
2..	2.7	7.5	"	Fine sand and fine gravel.........	Reddish yellow....	0.206	5.34
3..	7.5	12.2	Wash	Coarse and fine gravel, coarse medium and fine sand.........	Yellow	0.269	14.50
4..	12.2	17.5	"	Fine gravel and medium sand....	Brownish yellow...	0.220	6.27
5..	17.5	22.5	"	Coarse and medium sand.........	Grayish yellow....	0.243	5.10
6..	22.5	25.0	"	Coarse and fine sand.............	Yellow.............	0.230	3.91
7..	25.0	30.0	"	Fine gravel and medium sand.....	Very dark gray....	0.220	7.73
8..	30.0	35.0	"	Fine and coarse sand............	Grayish yellow....	0.215	3.02
9..	35.0	40.0	"	Medium sand	"	0.228	2.76
10..	40.0	41.0	"	Coarse sand.....................	Light yellow......	0.290	3.62
11..	41.0	45.0	"	Fine gravel.......................	"	1.300	2.38
12..	45.0	50.0	"	Fine sand.........................	Light gray........	0.229	2.75
13..	50.0	54.0	"	"	"	0.220	2.70
14..	54.0	55.0	"	Fine gravel and coarse sand......	"	1.100	2.41

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 907.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Co-efficient.
1..	0.0	0.8	Dry.........	Loam...........................	Dark brown.......	*0.28	
2..	0.8	2.5	"	Subsoil.........................	Yellow	*0.282	
3..	2.5	6.0	"	Fine gravel and medium sand....	Brownish yellow...	0.275	8.73
4..	6.0	10.0	Wash........	Coarse and medium sand........	" ..	0.231	2.56
5..	10.0	15.0	"	Fine gravel and coarse sand......	Yellowish gray....	0.347	5.48
6..	15.0	20.0	"	Coarse and medium sand.	"	0.274	4.05
7..	20.0	25.0	"	" " "	"	0.264	3.51
8..	25.0	30.5	"	" " "	Gray..............	0.268	6.34
9..	30.5	32.0	"	" " "	"	0.360	9.78
10..	32.0	35.0	"	Coarse and fine sand.............	Whitish...........	0.228	11.40
11..	35.0	40.0	"	Fine gravel and coarse sand.....	Very light yellow..	0.257	11.28
12..	40.0	44.0	"	" " "	" " ..	0.260	8.12
13..	44.0	50.0	"	Medium sand.................. .	Yellowish gray....	0.220	2.50
14..	50.0	55.0	"	Fine gravel and coarse sand......	Brownish gray	0.216	4.31
15..	55.0	60.0	"	Coarse and medium sand.........	Yellowish gray	0.226	5.66
16..	60.0	65.0	"	Medium sand......	"	No	Sample.
17..	65.0	66.0	"	Fine gravel and medium sand.....	"	"	"

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 908.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Co-efficient.
1..	0.0	1.5	Dry.........	Coarse gravel and loam..........	Dark brown.	0.145	7.93
2..	1.5	3.0	"	Coarse gravel and coarse sand....	Brownish yellow...	0.620	6.05
3..	3.0	6.0	"	Fine gravel and medium sand....	Yellow	0.330	6.06
4..	6.0	10.0	Wash........	Fine gravel and coarse sand......	Light yellow.......	0.370	7.03
5..	10.0	15.0	"	" "	Yellowish gray	0.363	7.71
6..	15.0	20.0	"	Coarse and fine gravel and medium sand....................	"	0.529	7.37
7..	20.0	24.0	"	Coarse and medium sand.........	Grayish yellow...	0.213	2.63
8..	24.0	27.0	"	Fine sand........................	Light (pinkish) yellow,............	0.193	1.13
9..	27.0	31.0	"	"	Light yellow	0.215	1.08
10..	31.0	35.0	"	"	"	0.218	1.09
11..	35.0	40.5	"	"	Nearly white......	0.218	1.3
12..	40.5	41.5	"	"	"	0.2 8	1.5

TABLE No. 32—*Continued.*

Classification and Analysis of Samples from Well No. 909.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W.O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	2.5	Dry.........	Loam	Dark brown	*0.55	
2..	2.5	5.0	"	Fine gravel and fine sand	Reddish brown....	0.243	3.00
3..	5.0	10.0	Wash.......	Fine gravel and medium sand....	Yellow	0.235	4.04
4..	10.0	15.0	"	Fine gravel and medium sand, little superfine sand	Brownish yellow...	0.205	2.88
5..	15.0	20.0	"	Fine gravel and coarse sand......	Yellowish gray	0.780	5.00
6..	20.0	25.0	"	Medium sand	Gray...	0.193	2.33
7..	25.0	30.0	"	Fine gravel and medium sand....	Light yellow	0.229	2.90
8..	30.0	35.0	"	Coarse and fine gravel, medium sand	Light gray	0.260	5.19
9..	35.0	40.0	"	Coarse and medium sand.........	Yellowish gray.....	0.310	2.90
10..	40.0	45.0	"	Coarse sand.....................	Light gray	0.235	2.68
11..	45.0	50.0	"	Coarse and medium sand.........	Light yellow	0.208	1.61
12..	50.0	55.0	"	Rock flour	"	0.210	3.33
13..	55.0	56.0	"	"	Yellowish gray....	0.178	1.40

* Than which 60 per cent. is finer.

Table No. 32—*Continued.*

Classification and Analysis of Samples from Well No. 955.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Mechanical Analysis by Prof. W. O. Crosby. Uniformity Co-efficient.
1..	0.0	1.0	Dry........	Loam	Dark brown.......	*0.25	
2..	1.0	2.5	"	Subsoil............................	Brownish yellow...	*0.725	
3..	2.5	4.5	"	Coarse gravel, coarse sand and subsoil	Dark brown.......	0.235	13.62
4..	4.5	6.0	Wash........	Coarse gravel, coarse sand (little rock flour).....................	Reddish yellow....	0.640	6.64
5..	6.0	10.0	"	Coarse gravel and medium sand..	Yellow	0.450	11.56
6..	10.0	15.0	"	Coarse sand, fine gravel and medium sand................	Grayish	0.215	10.00
7..	15.0	20.0	"	Fine gravel, medium sand and superfine sand................	Very dark brown..	0.219	5.02
8..	20.0	25.0	"	Fine gravel, medium and superfine sand	Dark brown.......	0.230	10.00
9	25.0	30.0	"	Gravel, fine, and coarse sand.	Light grayish yellow	0.270	7.89
10..	30.0	35.0	"	Fine gravel, coarse sand and fine sand	" "	0.234	11.54
11..	35.0	41.0	"	Fine gravel and medium sand	Light gray	0.365	8.36
12..	41.0	45.0	"	" " ..	"	0.218	5.83
13..	45.0	50.0	"	Fine gravel and coarse sand (little medium sand)	"	0.540	4.91
14..	50.0	55.0	"	Fine gravel...	"	.....	....
15..	55.0	59.0	"	"	White gray........	2.000	1.26
16..	59.0	64.5	"	Fine sand	Light grayish yellow	*0.535	
17..	64.5	70.0	"	Coarse sand.....................	" "	0.470	2.26
18..	70.0	75.0	"	Coarse and medium sand	" "	0.365	2.66
19..	75.0	80.0	"	Fine gravel and coarse sand	Light yellow	0.420	3.52
20..	80.0	81.0	"	Coarse and medium sand, superfine sand............	"	0.225	4.00
21..	81.0	83.0	"	Fine gravel....	"	2.210	1.35
22.	83.0	88.0	"	Fine gravel (little fine sand)......	"	0.630	4.41
23..	88.0	92.5	"	Fine gravel coarse sand (fine sand)	Brownish gray.....	0.380	9.37
24..	92.5	98.0	"	Fine gravel, medium sand (fine sand)........................	Yellowish gray	0.220	5.45
25..	98.0	101.0	"	Fine gravel, medium sand........	Light yellow.	0.370	5.14
26..	101.0	104.0	"	Medium sand....................	"	0.230	2.26
27..	104.0	107.0	"	"	"	0.219	1.89
28..	107.0	113.0	"	Fine sand	"	0.200	1.65
29..	113.0	118.0	"	"	"	0.185	1.52
30..	118.0	125.0	"	"	"	0.218	1.66
31..	125.0	130.0	"	"	"	0.218	1.66
32..	130.0	133.0	"	"	"	0.226	1.61
33..	133.0	137.5	"	Coarse and fine sand.....	Yellow	0.233	4.68

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 956.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	1.0	Dry	Loam...........................	Light brown.......	*0.110	
2..	1.0	4.0	"	"	Dark brown.......	*0.345	
3..	4.0	9.0	Wash........	Medium sand, rock flour (little clay)	Brown	0.130	3.35
4..	9.0	14.0	"	Coarse and medium sand.........	Brownish yellow...	0.150	3.00
5..	14.0	19.0	"	Fine gravel and coarse sand......	Light yellow	0.225	3.82
6..	19.0	24.0	"	Coarse sand........	"	0.220	4.05
7..	24.0	29.0	"	Coarse and medium sand	Grayish yellow....	0.209	2.11
8..	29.0	34.0	"	" "	Yellow............	0.181	3.15
9..	34.0	39.0	"	Coarse sand.....................	"	0.290	2.24
10..	39.0	45.0	"	Medium sand....................	Gray..............	0.198	1.77
11..	45.0	47.0	"	Fine sand (little superfine flour)..	Brownish yellow...	0.172	3.25

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 959.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size.	Uniformity Co-efficient.
1..	0.0	3.0	Dry	Loam...........................	Nearly black	*0.136	
2..	3.0	8.0	Core.........	Subsoil	Reddish brown....	§0.10	
3..	8.0	10.5	Wash	Coarse sand and superfine flour ..	Brownish gray	0.180	7.50
4..	10.5	15.0	"	Fine gravel and coarse sand	Gray.	0.200	4.25
5..	15.0	20.0	"	Fine gravel, medium sand, superfine flour	Yellowish brown ..	0.214	7.01
6..	20.0	23.0	"	Fine gravel and coarse sand	Grayish yellow	0.239	2.76
7..	23.0	27.0	"	Fine gravel, coarse and medium sand...........	"	0.440	10.11
8..	27.0	31.0	"	Coarse sand and fine gravel	"	0.280	3.24
9..	31.0	36.0	"	Fine gravel and coarse sand......	"	0.230	4.43
10..	36.0	37.0	"	" "	"	0.259	3.47

* Than which 60 per cent. is finer.
§ Than which 61 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 1087.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.
1..	0.0	1.0	Dry........	Loam	Light brown.
2..	1.0	5.0	"	Subsoil and coarse gravel..........................	Reddish brown.
3..	5.0	10.0	Core........	Medium sand and fine gravel..........................	Light yellow.
4..	10.0	15.0	Wash........	Fine gravel and medium sand..........................	Yellowish gray.
5..	15.0	20.0	"	Coarse gravel, coarse and medium sand..................	"
6..	20.0	25.0	"	Fine gravel and medium sand..........................	Gray.
7..	25.0	29.0	"	" "	Yellowish gray.
8..	29.0	30.0	"	Fine gravel and fine sand..........................	"

Classification and Analysis of Samples from Well No. 1088.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.
1..	0.0	0.3	Dry........	Loam and medium sand..........................	Brown.
2..	0.3	1.5	"	Subsoil, fine and coarse gravel..........................	Yellow.
3..	1.5	5.5	Core........	Coarse gravel and clay..........................	Reddish yellow.
4..	5.5	8.0	Wash........	Coarse gravel and coarse sand..........................	Light gray.
5..	8.0	15.5	"	Fine gravel and medium sand..........................	Yellowish gray.
6..	15.5	20.5	"	Coarse gravel and coarse sand..........................	"
7..	20.5	25.5	"	Fine gravel and coarse sand..........................	"
8..	25.5	30.5	"	Fine gravel and medium sand..........................	"

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 1090.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size	Uniformity Co-efficient.
1..	0.0	2.0	Dry.........	Loam..........................	Light brown.......	*0.11	
2..	2.0	5.0	"	"	"	*0.10	
3..	5.0	10.0	"	Fine gravel and fine sand........	Brownish yellow...	0.134	4.04
4..	10.0	15.0	Wash.......	Coarse and fine sand............	Yellow............	0.195	2.80
5..	15.0	20.0	"	Coarse and medium sand........	"	0.209	3.21
6..	20.0	22.0	"	Coarse gravel, coarse and medium sand......................	"	0.245	7.00
7..	22.0	26.0	"	Coarse gravel, coarse sand and rock flour....................	Brownish yellow...	0.220	7.05
8..	26.0	28.0	"	Coarse gravel, coarse and medium sand and rock flour.........	" ...	0.206	3.40
9..	28.0	33.0	"	Fine and superfine sand (little clay)........................	Bluish gray........	*0.233	
10..	33.0	37.0	"	Fine gravel and coarse sand (little rock flour)..................	Brownish yellow...	......	
11..	37.0	38.0	"	Fine gravel, coarse sand and rock flour........................	Brownish gray.....	......	

* Than which 60 per cent. is finer.

Classification and Analysis of Samples from Well No. 1142.

Sample No.	Depth Below Surface. From	Depth Below Surface. To	Kind of Sampling.	Classification of Material.	Color of Material.	Mechanical Analysis by Prof. W. O. Crosby. Effective Size	Uniformity. Co-efficient.
1..	0.0	1.5	Dry.........	Loam..........................	Brown.............	* 0.23	
2..	1.5	4.0	"	Fine sand and coarse gravel......	Dark brown.......	0.275	7.27
3..	4.0	6.0	Wash........	Coarse and medium sand and coarse gravel	Yellow	0.226	4.56
4..	6.0	11.0	"	Coarse and fine sand, coarse gravel	Light yellow.......	0.510	7.25
5..	11.0	16.0	"	Fine gravel and medium sand....	Grayish yellow....	0.290	3.72
6..	16.0	21.0	"	Fine gravel and coarse sand (little medium sand)................	Yellow............	0.480	6.04
7..	21.0	26.0	"	Fine gravel and coarse sand (little medium sand)................	Light yellow	0.500	4.6
8..	26.0	32.0	"	Coarse and medium sand.........	Brownish yellow...	0.230	3.91
9..	32.0	37.0	"	Fine gravel and fine sand.........	Very light yellow..	0.400	7.75
10..	37.0	41.0	"	Fine gravel and medium sand....	Light yellow.......	0.350	5.71
11..	41.0	46.0	"	Fine gravel, coarse and medium sand.........................	"	0.335	5.08
12..	46.0	51.0	"	Fine gravel and medium sand....	"	0.275	3.42
13..	51.0	59.0	"	Fine gravel and medium sand....	"	0.230	9.13
14..	59.0	61.0	"	Fine sand (little rock flour).......	Cream yellow......	0.220	2.09
15..	61.0	66.0	"	Fine sand........................	Light gray........	0.218	1.51
16..	66.0	71.0	"	Fine sand (little rock flour).......	"	0.218	1.80
17a.	71.0	75.0	Core.......	Clay..............................	Brownish gray.....	.....	....
17b.	75.0	76.0	Wash.......	Medium sand....................	Light yellow.......	0.200	2.25
18..	76.0	80.5	"	Fine sand........................	Light gray........	0.190	1.21

* Than which 60 per cent. is finer.

TABLE NO. 32—*Continued.*

Classification of Samples from Well No. 1169.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.
1..	0.0	1.0	Dry.........	Loam and medium sand..............................	Reddish brown.
2..	1.0	3.0	"	Subsoil, coarse gravel and medium sand..............	Reddish yellow.
3..	3.0	9.0	"	Medium sand..	Yellow.
4..	9.0	14.0	Wash	Fine gravel and medium sand	Very light yellow.
5..	14 0	19.0	"	Medium sand..	"
6..	19.0	24.0	"	Fine gravel and medium sand..	"
7..	24.0	29.0	"	Coarse and medium sand.......	"
8..	29.0	34.0	"	" "	"
9..	34.0	39.0	"	Medium sand	"
10..	39.0	44.0	"	Fine sand	"
11..	44.0	49.0	"	Medium sand................	"
12..	49.0	51.0	"	"	"

Classification of Samples from Well No. 1187.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.
1..	0.0	1.0	Dry.........	Loam..............................	Dark brown
2..	1.0	3.0	"	"	"
3..	3.0	10.8	"	Coarse gravel and subsoil............................	Yellowish brown.
4..	10.0	15.0	Wash	Fine gravel and medium sand..........................	"
5..	15.0	17.0	"	Medium sand.....................	"
6..	17.0	23.0	"	Fine and superfine sand........	Dark yellowish brown.
7..	23.0	30.0	"	Coarse sand	Yellow.
8..	30.0	32 0	"	"	Grayish yellow.
9..	32.0	36.0	"	Coarse and medium sand...............	Brownish yellow.
10..	36.0	40.0	"	" "	Light yellow.
11..	40.0	42.0	"	" "	"

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 1198.

Sample No.	Depth Below Surface.		Kind of Sampling.	Classification of Material.	Color of Material.
	From	To			
1..	0.0	0.4	Dry.........	Fine sand and loam.....	Dark brown.
2..	0.4	2.0	"	Fine sand and subsoil.	Brownish yellow.
3..	2.0	9.0	"	Coarse gravel, fine and medium sand................	Yellow.
4..	9.0	14.0	Wash........	Fine gravel and medium sand........................	Yellowish gray.
5..	14.0	19.0	"	Coarse and medium sand..............................	"
6..	19.0	24.0	"	Coarse and fine gravel and coarse sand................	"
7..	24.0	29.0	"	Coarse gravel and medium sand.......................	Yellow.
8..	29.0	34.0	"	Coarse and fine gravel and coarse sand................	Yellowish gray.
9..	34.0	39.0	"	Coarse and medium sand..............................	"
10..	39.0	44.0	"	" "	"
11..	44.0	45.0	"	Fine gravel and coarse sand..................	"

Classification and Analysis of Samples from Well No. 1199.

Sample No.	Depth Below Surface.		Kind of Sampling.	Classification of Material.	Color of Material.
	From	To			
1..	0.0	0.5	Dry.........	Loam..	Dark brown.
2..	0.5	3.0	"	Coarse gravel, coarse sand and subsoil................	Reddish brown.
3..	3.0	6.0	Core	Superfine sand and superfine flour....................	"
4..	6.0	10.0	Wash.......	Fine gravel and coarse sand.	Yellow.
5..	10.0	12.5	"	" "	"
6..	12.5	16.0	"	Fine gravel, coarse sand and rock flour................	Brownish yellow.
7..	16.0	23.0	"	Fine gravel and coarse sand...........................	Yellowish gray.
8..	23.0	26.0	"	" "	"
9..	26.0	34.0	"	" "	"
10..	34.0	39.0	"	Fine sand and rock flour..............................	Light brownish yellow.
11..	39.0	42.5	"	" "	Light brownish yellow.
12..	42.5	49.0	"	Coarse sand..	Light yellow.
13..	49.0	51.0	"	Fine gravel and coarse sand...........................	"
14..	51.0	54.0	"	" "	Yellow.
15..	54.0	59.0	"	Coarse and fine sand..............	Grayish yellow.
16..	59.0	62.5	"	" "	Yellow.
17..	62.5	65.0	"	Medium sand, little rock flour.........................	Brownish yellow.

TABLE NO. 32—*Continued.*

Classification and Analysis of Samples from Well No. 1200.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.
1..	0 0	0.6	Dry.........	Loam..	Dark brown.
2..	0.6	4.0	"	Subsoil, coarse and fine gravel.........................	Reddish brown.
3..	4.0	9.0	Wash.......	Coarse gravel and medium sand......................	Yellow.
4..	9.0	14.0	"	Coarse gravel and medium sand......................	Grayish yellow.
5..	14.0	19.0	"	Coarse gravel and coarse sand........................	Yellow.
6..	19.0	24.0	"	Fine sand and superfine flour.........................	Brick red.
7..	24.0	29.0	"	Fine gravel and medium sand.........................	Very light yellow.
8..	29.0	34.0	"	Coarse and medium sand............................	"
9..	34.0	39.0	"	" "	Very light grayish yellow.
10..	39.0	44.0	"	" "	Very light gravish yellow.
11..	44.0	49.0	"	Pine gravel and coarse sand..........................	Very light grayish yellow.
12..	49.0	54.0	"	Coarse gravel and coarse sand........................	Very light grayish yellow.
13..	54.0	55.0	"	Fine gravel and medium sand.........................	Very light grayish yellow.

Classification and Analysis of Samples from Well No. 1204.

Sample No.	Depth Below Surface. From	To	Kind of Sampling.	Classification of Material.	Color of Material.
1..	0.0	1.0	Dry.........	Fine gravel, superfine sand and loam..................	Brownish.
2..	1.0	2.0	"	Fine sand and clay subsoil............................	Brownish yellow.
3..	2.0	5.0	Wash..	Fine gravel, coarse sand and clay.....................	"
4..	5.0	10.0	"	Fine gravel, medium sand, little superfine flour........	Grayish yellow.
5..	10.0	18.0	"	Fine gravel, fine sand, little superfine flour............	"
6..	18.0	21.0	"	Medium sand..	Yellow.
7..	21.0	22.0	"	Coarse gravel, medium and fine sand...................	"
8..	22.0	25.0	"	Coarse and fine gravel and medium sand..............	Brownish yellow.
9..	25.0	32.0	"	Coarse and fine gravel, medium sand, little superfine flour	Yellowish gray.
10..	32.0	36.0	"	Fine gravel and medium sand........................	"
11..	36.0	41.0	"	Fine and medium sand................................	Yellow.
12..	41.0	46.0	"	Fine gravel and coarse sand..........................	Yellowish gray.
13..	46.0	53.0	"	Coarse and fine sand.................................	"
14..	53.0	60.0	"	" "	"
15..	60.0	67.0	"	Coarse, medium and fine sand........................	Gray.
16..	67.0	74.0	"	" "	Pinkish gray.
17..	74.0	81.0	"	Medium and fine sand................................	Yellowish gray.
18..	81.0	88.0	"	" "	"
19..	88.0	97.0	"	" "	"
20..	97.0	97.5	"	" "	Brownish yellow.

APPENDIX VIII.

Department of Pumping.

Appendix VIII.

DEPARTMENT OF PUMPING.

WILL J. SANDO, *Department Engineer.*

The work of this Department was begun with a view of preparing estimates, plans and specifications for a pumping plant, taking the supply wholly from the Hudson River and lifting the water to an elevation of about 400 feet to the filters. This station would have contained engines having ultimately a total combined daily capacity of 500,000,000 gallons, requiring 35,000 pump horse-power, and exceeding in capacity and power any plant now in existence supplying water for municipal use.

The magnitude of this project made it of the utmost importance that most careful studies be made of its design relative to cost of installation, pumping and maintenance as compared with the cost of building and maintaining a gravity system. Studies were made in regard to other plants of various sizes for pumping from reservoir sites that lay at an elevation below the aqueduct.

TYPE OF ENGINES AND ARCHITECTURE OF STATIONS FORMING BASIS FOR ESTIMATES OF COST OF CONSTRUCTION.

There have been great advances in this branch of steam engineering in recent years, and a number of the later stations built and equipped with the most improved machinery show remarkably low cost of pumping. Engines in actual service pumping at lowest rates found by investigation, results of examination of official public reports giving the cost of operating pumping stations and information received from engineers in charge of the Water Works in the several cities mentioned, are shown in plates 1, 2 and 3. The type of vertical triple expansion pumping engine shown is recommended, and in plate 4 is shown the architecture of building suggested as suitable and forming the basis of estimates of costs for the plants considered.

The estimated total cost of labor, repairs and supplies shown in Diagram 5, for pumping with large plants under conditions found in the proposed watersheds, is based on similar costs which obtain in regular operation at several works. The amount of coal required per horse-power has been modified in consequence of the increased economy which engines of the latest design are capable of maintaining when operated under the same degree of efficiency in management found to-day in certain municipal water works.

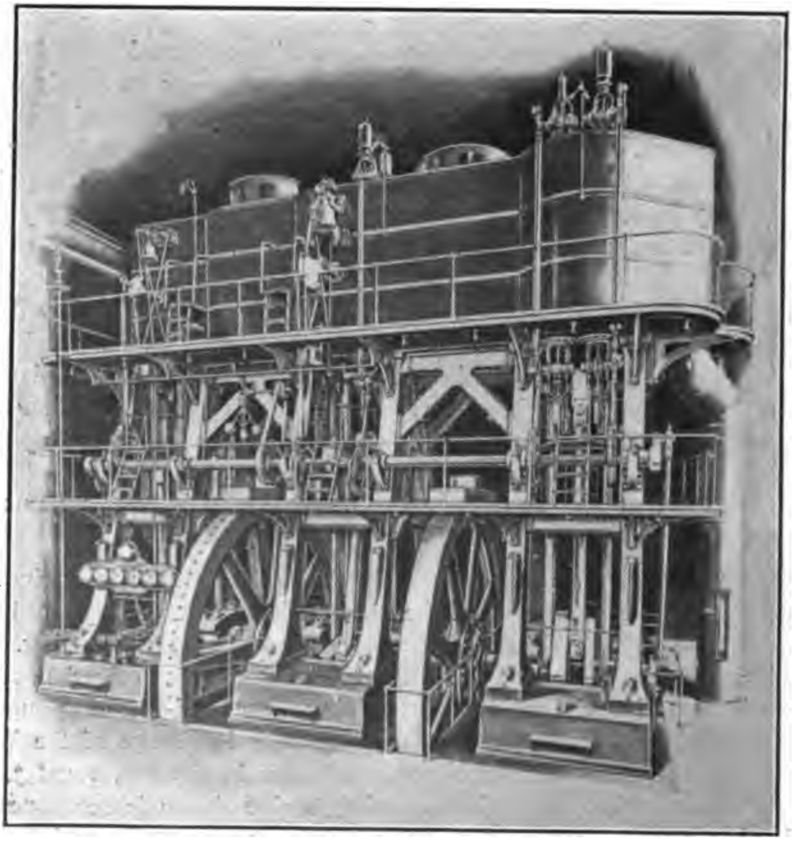


PLATE NO. 1. APP. VIII.

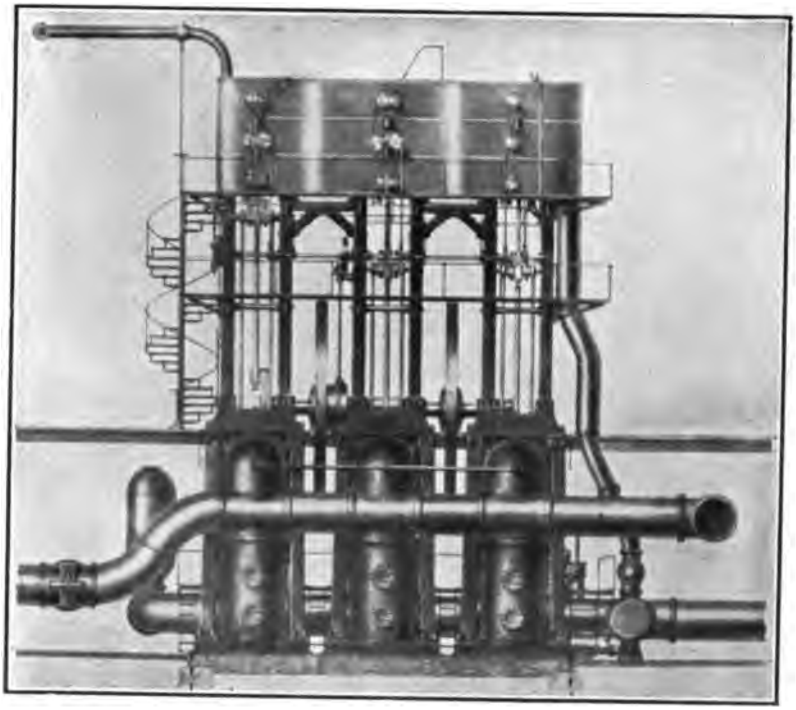


PLATE NO. 2. APP. VIII.

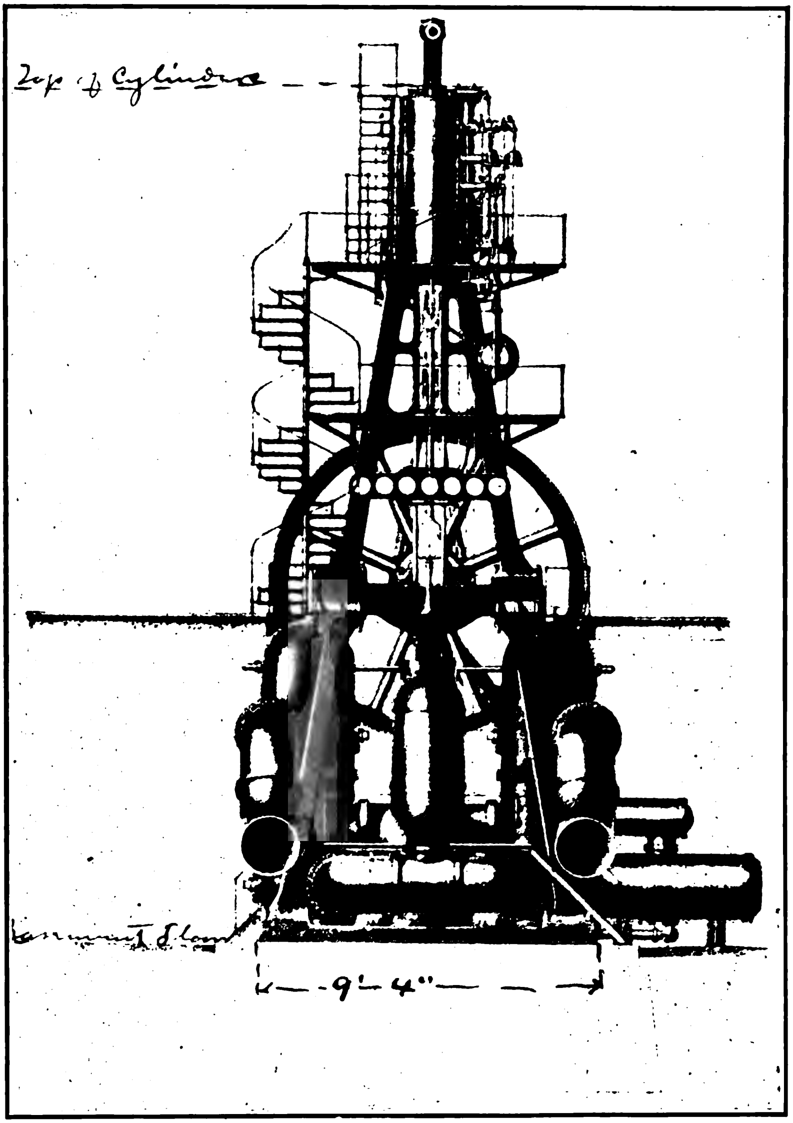


PLATE NO. 3. APP. VIII.

PLATE NO. 4. APP. VIII.

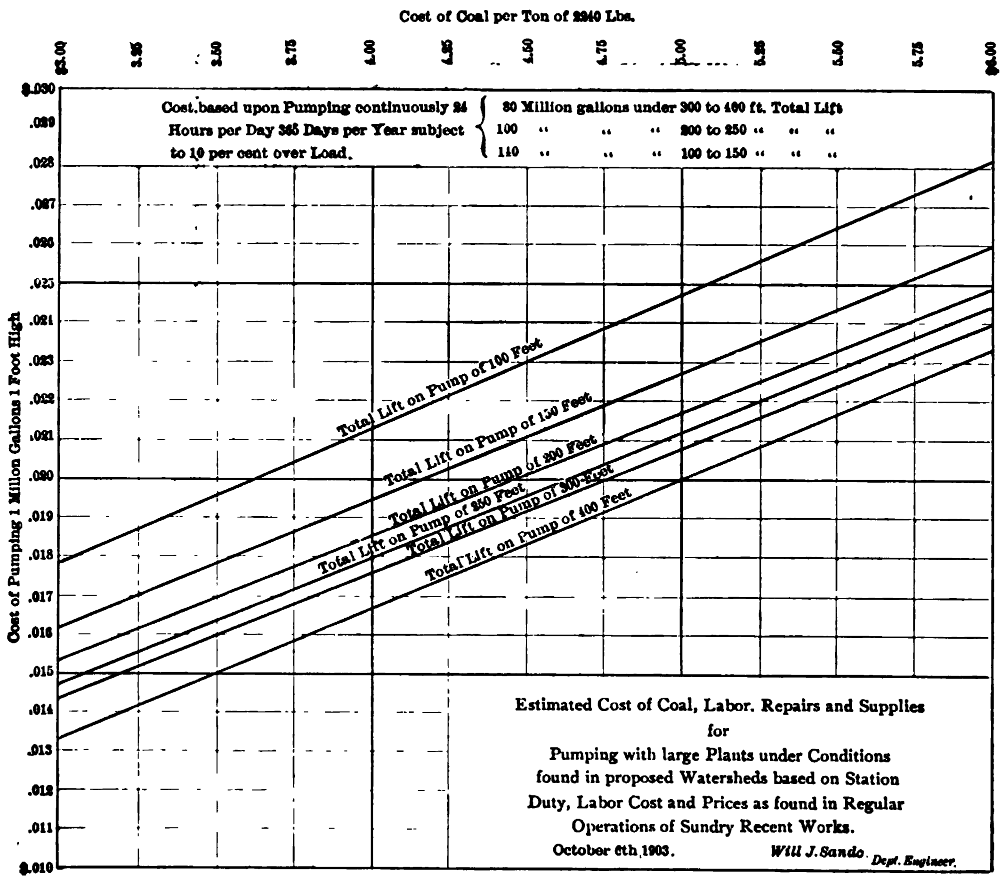


DIAGRAM 5. APP. VIII.

The total pump capacity required to provide for the probable consumption by the time the new works could be put in use, which at the earliest is 1908 according to the assumed rate of growth, will be 168 million gallons daily.

The capacity of the pumps designed for the different lifts is limited by the size of the steam cylinders and other large castings, in order that they may not be too large for handling in the shops and for transportation. The following table gives the largest capacity probably expedient for the lifts and conditions considered in these studies:

Total Lift. Feet.	Nominal Capacity, Million Gallons, 24 hours.	Emergency Capacity, Million Gallons, 24 hours.	Total Lift. Feet.	Nominal Capacity, Million Gallons, 24 hours.	Emergency Capacity, Million Gallons, 24 hours.
100	35	43.75	250	25	31.25
150	35	43.75	300	20	25.
200	25	31.25	400	20	25.

The working steam pressure decided upon was 200 lbs. per square inch gauge pressure. Regular duty on 100 lbs. of coal consumed, 145,000,000 foot lbs.; plunger speed for nominal capacity, 330 feet, or 30 revolutions per minute. The cost of labor for operating the engines, boilers, and caring for the station is based upon 2.58 men on a watch for each engine. This is above the average found by investigation, as shown in Table 12. The rate of wages per man per day estimated is $2.77; which is also above the present average in several of the larger American stations. In these estimates the cost of labor, supplies and repairs are based upon the operation of two pumping units and consequently are the same regardless of capacity or head pumped against. The effect of the price of coal upon the cost of pumping is taken as shown by Diagram 5, with coal ranging in price from $3 to $6 per ton.

For the first installation of a Hudson River pumping plant, it is estimated that a supply of 168 million gallons would be taken from the Hudson River and pumped against a lift of 400 feet. This would require eight engines, each having a nominal daily capacity of 20 million gallons. The additional eight million gallons called for by the assumed conditions could be made up by increasing the speed of these engines slightly. The estimated time for constructing this plant is four years, provided the contract for station and machinery equipment are let together. Anticipating the increasing consumption, it would be less expensive to plan and contract for a plant containing twelve engines with a stipulation that eight engines are to be running in four years and twelve engines in six years from date of contract. The time required for delivery would, however, depend upon the condition of the market for labor and materials. It is estimated that this first plant completed in 1908 could continue to supply the demand until 1910, but meanwhile, say in 1908, the erection of a second or a duplicate plant should be begun to provide for the growing consumption. The second plant should be entirely independent of the first plant and built at a safe distance for protection against fire, boiler explosions and accidents.

The plants for which the ultimate capacity is estimated at 500 million gallons daily of Hudson River water are thus supposed divided into two works, to be separated and independent of each other, except in management.

In addition to the project for supplying water from the Hudson River above Poughkeepsie various other designs for large pumping plants were required; among them, one was for a supply of 250 million gallons daily from the so-called lower Fishkill reservoir. This required lifting a minimum of 87 feet and a maximum of 136 feet. These conditions are so different from those of the Hudson River plant that the machinery would be different in its proportions. For the Hudson River supply it was proposed to provide for each of the two plants pumping 250 million gallons per day, twelve engines, while for the Lower Fishkill reservoir, eight engines could pump the same amount because of the smaller lift. The relative capacities and lifts provided for in these estimates are given in the following table:

	Hudson River Plants.	Lower Fishkill Plants.
Total lift—feet	400	87 to 136
Nominal capacity of each engine, million gallons, 24 hours	20	35
Emergency capacity of each engine, million gallons, 24 hours	25	43.75
Nominal aggregate capacity, million gallons, 24 hours	240 (12 engines).	280 (8 engines).
Emergency aggregate capacity, million gallons, 24 hours	300 (12 engines). 250 (10 engines).	350 (8 engines). 262.5 (6 engines).
Desired capacity each station, million gallons, 24 hours	250	250

Engines and boilers are designed for maximum economy when running at nominal speed, but this economy does not decrease much for overloads up to 25 per cent. when pumps are properly designed to avoid excessive friction and condensers are amply large to take care of the additional steam economically. The pumps should have sufficient clear waterway through the valves to permit of a 25 per cent. overload.

In stations containing so many engines it is not considered necessary to provide for reserve capacity by an extra engine for use when any engine is undergoing repairs, for having provided this waterway and steam supply for 25 per cent. overload allowable in case of necessity, the putting of one or two engines out of commission in any plant would still permit pumping the regular amount by increasing the speed of the other engines. This contemplates only the best class of machinery constructed and installed under inspection and managed intelligently. The records of large pumping engines running in every-day service demonstrates this to be a safe proposition. Sundry public records show that remarkably long runs of pumping engines are practicable under competent supervision.

The No. 3 engine of the Louisville Water Company, Louisville, Ky., is reported to have been in operation over twenty-three hours every day continuously for the seven years since 1896.

The No. 3 engine at Chestnut Hill High Service Pumping Station, Boston, Mass., was in constant operation 23.4 hours per day during the year 1898.

The No. 4 engine in the same station during the years 1900, 1901 and 1902 ran 89, 88 and 94 per cent., respectively, of the entire time, and has been operated continuously for 81 days and also on one occasion ran 116 days with only one stop of half an hour.

The No. 7 engine at the Chestnut Hill Low Service Pumping Station ran slightly over 22 hours every day during the year 1902, and was operated continuously with not a moment's stop for 72 days, and again 180 days with only three stops, one being of six hours and five minutes, one of five hours and one of ten hours and fifty minutes. There are three engines in this station all operated more or less every day, and sometimes it is necessary to have all three running at their rated capacity simultaneously.

In view of these records it has been deemed advisable to estimate the cost of the proposed plants by providing only for maintaining the capacity by increasing the speed of the engines in case of emergency. This is, obviously, only safe in large plants and could not be recommended where less than five engines of the same size are available for daily use.

Approximate Cost of the Hudson River Plants.

Two stations similar in architecture to that of the building illustrated in Plate 4, of sufficient size to accommodate twelve engines, each, and built of the best fire-proof materials by first-class workmen under thorough inspection, including foundation walls, machinery foundations, walls, boiler and basement floors of concrete; steel beams for the engine room floor and tiled flooring; exterior walls of the superstructure of Roman brick, with sandstone and gran-

ite trimmings; interior walls of pressed red brick; steel roof trusses and tiled roof, it is estimated would cost, each.	$536,000
Twelve vertical triple expansion crank and fly wheel engines, including suction piping from the pumps to the wells, delivery piping from the pumps to the inside of the walls of the building provided with hydraulic lift gate valves; boilers; economizers; superheaters; steam piping; traveling crane; coal-conveying machinery; sluice gates for wells and all miscellaneous details to complete a first-class plant having all machinery built under thorough inspection, it is estimated would cost........................	1,616,000
Engineering inspection and contingencies.................	310,000
Estimated total cost of one plant, capacity 250 million gallons, exclusive of land, conduits to pump wells and intake crib........	$2,462,000
Estimated total cost of two plants, capacity 500 million gallons, exclusive of land, conduits to pumps wells and intake crib......	4,924,000

APPROXIMATE COST OF THE LOWER FISHKILL RESERVOIR PLANTS.

Two stations, each having a total daily capacity of 250 million gallons, the same as those specified for the Hudson River plants, with size to accommodate eight engines, would cost	$342,000
Eight vertical triple expansion crank and fly wheel engines, including the same appurtenances specified for engines for the Hudson River plant, would cost...................	998,000
Engineering inspection and contingencies..................	194,000
Estimated total cost of one plant, having capacity of 250 million gallons, exclusive of land, conduits to pump wells and intake crib........	$1,534,000
Estimated total cost of two plants, having capacity of 500 million gallons, exclusive of land, conduits to pump wells and intake crib........	3,068,000

These estimates, like others, are based on prices prevailing during the summer of 1903, and are subject to the fluctuations in the cost of labor and materials.

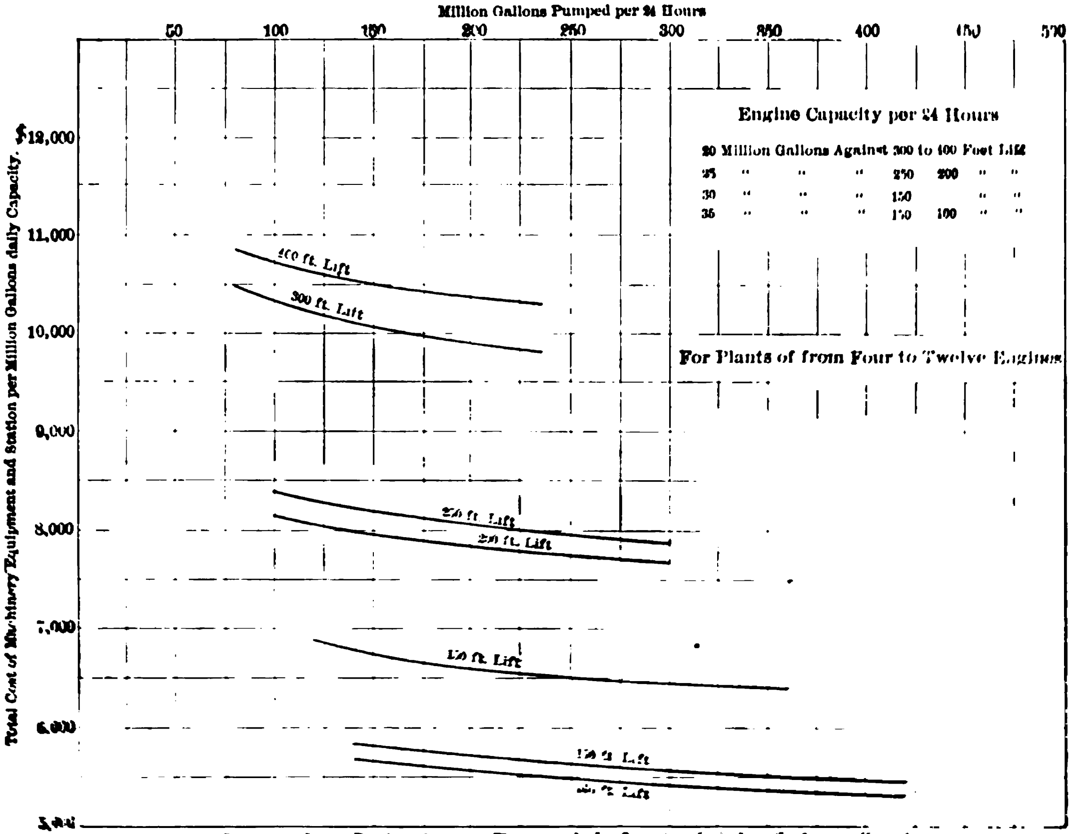
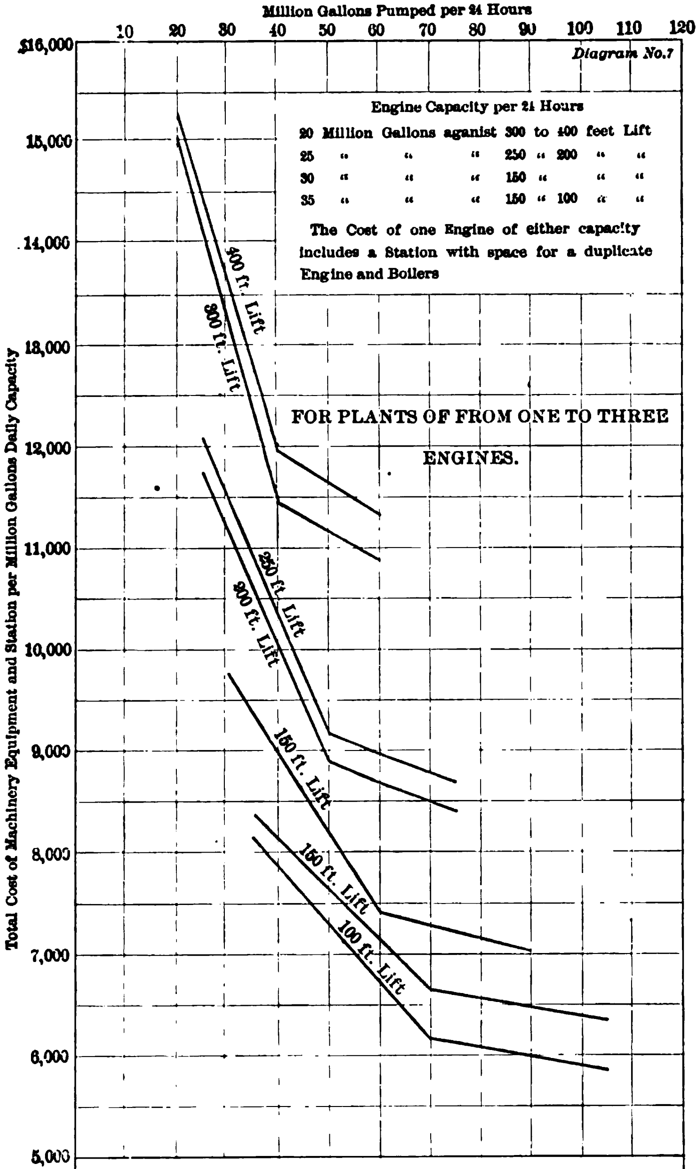


DIAGRAM 6. APP. VIII.



Estimated cost of building pumping plants, ready for operation including the suction wells to the delivery nozzles on pumps, having from ONE TO THREE ENGINES ranging in capacity from 20 to 35 million gallons daily under lifts from 100 to 400 feet. Based upon prices prevailing in 1903.

Will J. Sando
Oct. 29th 1903 *Dept. Engineer*

DIAGRAM 7. APP. VIII.

Progress in Pumping Engine Practice.

In a paper containing much valuable information, entitled "Present Pumping Engine Practice Compared with 25 Years Ago," by Mr. Irving H. Reynolds, Engineer Water Works Department, E. P. Allis Co., read before the New England Water Works Association, December 14, 1898, he predicted a probable duty of 160 million foot pounds per 1,000 pounds of steam under favorable conditions with the vertical type of triple expansion crank and fly-wheel engine, using steam from 175 to 200 pounds per square inch guage pressure. There were at that time three engines credited with a duty of 152 to 154.9 million foot pounds per 1,000 pounds of dry steam, and a duty of 167 million foot pounds per 1,000 pounds of dry steam had been previously obtained on an engine built by the Snow Steam Pump Works for the Indianapolis Water Company on a test of July 8, 1898, by Prof. W. F. M. Goss of Purdue University. Since then several engines of this type have shown on official tests a duty above 172 million foot pounds per 1,000 pounds of dry steam at pressures from 150 to 185 pounds per square inch, and other engines of the direct acting, high duty type have developed a duty of 165 million foot pounds per 1,000 pounds of steam at a pressure of 150 pounds per square inch, superheated to about one hundred and twenty-five degrees.

There have been important modifications in the design of reciprocating pumping engines in the past six years, and possibly there may be more in the future, which may reduce materially the cost of installation and increase the economy. There is a tendency toward increasing the rotative speed and providing more liberal area of waterway through the valves in order to reduce the velocity of the water and friction and to use larger and more direct passages from the suction well to the delivery mains. In 1894 an engine of the vertical triple expansion three crank type, provided with Riedler mechanically operated pump valves designed by Mr. E. D. Leavitt, M. E., was started at the Chestnut Hill Pumping Station of Boston. This engine was intended to run at a nominal speed of fifty revolutions per minute with a daily capacity of 20 million gallons, and intended to be capable in case of emergency of running seventy revolutions per minute and delivering 28 million gallons daily, an overload of 40 per cent. The corresponding plunger speeds are 400 and 560 feet per minute, respectively. During the past five years this engine has been operated when necessary successfully and economically at the greater speed.

This speed and the pump valves which were operated mechanically were at the time regarded with little favor, and even with prejudice by some of the manufacturers of pumping machinery.

Mr. Leavitt, in 1893, designed a vertical compound beam engine having ordinary voluntary pump valves to run fifty-one revolutions per minute, representing a plunger speed of 408 feet per minute, and the regular running of this engine demonstrated that mechanically operated pump valves were not essential to such high speed. The former engine is still in service, and the cost of repairs during its nine years of use has not been any greater than that of slower running engines. The latter engine is still in existence but very seldom used on account of being superseded by a larger and more economical engine.

The next engines for municipal water works having higher rotative speed than the customary sixteen to twenty revolutions per minute were built for the City of New York and installed in the One Hundred and Seventy-ninth Street Pumping Station. These engines are operated for the rated capacity at thirty revolutions per minute, and the revolutions may be safely increased to thirty-five, or about 17 per cent. These were followed by the Boston Low Service and Spot Pond engines, started in 1900, running thirty and twenty-five revolutions per minute, corresponding with 300 and 250 feet plunger speed, respectively.

The rotative speed and piston speed have thus been increased, chiefly through the demands of engineers representing the purchasers, until now the manufacturers in many cases are advocating higher speed and consequently less expensive engines, and from favorable experience it seems probable that the speed of large pumping engines will be increased materially in the next few years. The situation as a whole is interesting and encouraging, and any improvement in reciprocating pumping machinery that will reduce the cost of the fuel per horse power and will increase the volume of water that a pump of given size can deliver into the reservoir will lessen the estimates of cost of pumping and pumping plants presented above.

There is reason to expect that cost of plants may be lessened by the improvement of pumps of the centrifugal type and their adoption for heavier work.

At the present time there are in the course of construction centrifugal pumps of the one stage type for which the builders claim an efficiency as high as 80 per cent. and have guaranteed to deliver water against a pressure of 110 pounds per square inch, pumping directly into the delivery main, at the end of which is to be provided a standpipe. It seems probable that this type of pump operated by an economical motor might be considered favorably if the experiments with these pumps should prove successful. Numerous experiments and tests in shops have been made in the last two years, and manufacturers feel confident that the centrifugal pump will be adapted for municipal pumping. The data so far published regarding actual tests have not been sufficiently extensive or conclusive to command the attention of more than a small number of water works engineers, but efficiency and availability may soon be proven and this type become an important factor on account of the reduced cost of installation, which for the complete plant will probably be not more than half to two-thirds the cost of reciprocating engines of the types now common.

Highest Duty Records.

The highest records of duty obtained on official tests of recent pumping engines under different conditions regarding lift and pressure of steam have not been changed for several years and are held by the triple-expansion crank and fly-wheel engine No. 4 at the Boston Chestnut Hill High Service Station, built by the E. P. Allis Company, and the triple-expansion crank fly-wheel engine No. 7 at the Chestnut Hill Low Service Station, built by the Holly Manufacturing Company. Both stations are included in the Metropolitan Water Works, Boston, Mass., operated under the control of the Massachusetts Metropolitan Water and Sewerage Board.

> The No. 4 engine record is 178 million foot pounds per 1,000 pounds of dry steam, including steam used by all auxiliaries, working under a total lift of 140 feet, with steam at a pressure of 185 pounds per square inch. The record made by the No. 7 engine under an extremely low lift is 158.7 million foot pounds per 1,000 pounds of dry steam, including steam used by all auxiliaries working under a total lift of 44 feet, with steam at a pressure of 150 pounds per square inch.

Higher Duty by Use of Superheated Steam.

The above are the records at present to be improved upon. They both show very high economy. The prospects, however, in the immense modern plants under construction for the Cincinnati, Philadelphia and Cleveland Water Works under high lifts, and the sewerage engines for the Metropolitan Sewerage Works, Boston, Mass., under low lift, seem favorable for higher records chiefly by the use of superheated steam. It is possible and even probable that a record as high as 185 million foot pounds per 1,000 pounds of steam superheated to about 250 degrees is attainable under high lifts, and 162 million foot pounds per 1,000 pounds of steam superheated to the same degree, under lifts as low as 45 feet. The use of superheaters has been adopted by engineers in water works practice quite generally in large stations under construction in the last two years, and superheaters have proved more or less successful and economical under careful management. Higher superheat is in successful use in several European power plants, and an American power engine using steam superheated to about 500 degrees has been recently tested and shows remarkable economy; so that duty even higher than that mentioned above is not impossible of achievement prior to the earliest date at which these pumping stations can be completed.

Comparison of Test and Regular Station Duty.

The discrepancy between the annual duty in regular running and that shown by the official tests of different engines, in most cases, seem to indicate that the designing engineers and builders of pumping engines are far in advance of the pumping station managers. The incentive for builders to improve and perfect designs with a view to increased economy depends largely on the care the machinery will receive and upon the chances for making a record on reduced cost of annual pumping. There are no sufficient reasons, judging from records of operations and cost of pumping at several large plants, why the efficiency of machinery should be reduced much below that guaranteed in the builder's contract. This guaranteed duty is in most cases materially below that shown in the tests for acceptance, and thus allows leeway for the mismanagement and deterioration of the plant. This is especially so in cases where careful design is stimulated by a bonus offered for additional duty above that required by the contract and in cases where the machinery is built under careful inspection.

Among the larger plants running in every day service within close range of contract duty may be mentioned the Chestnut Hill High Service and Low Service and the Spot Pond Stations of the Metropolitan Water Works, Boston, Mass. All three show by yearly performance that the " duty trial " efficiency of machinery can be kept up in yearly performance. The Low Service Station is taken for comparison because all its engines are alike and were installed and started at the same time. These engines were built under specifications requiring the contractor to guarantee 145 million foot pounds duty for each 1,000 pounds of commercially dry steam used by the engine and its auxiliaries, and each engine was to deliver 35 million gallons of water in 24 hours, against a dynamic head of only 45 feet, with a steam pressure of not more than 150 pounds per square inch at the throttle. This duty was the highest ever specified under similar conditions and remains so to-day; so far as the writer knows. For the year ending December 31st, 1902, the annual duty for this plant given in the report of the Metropolitan Water and Sewerage Board, per 100 pounds of coal consumed, including heating and steam used by electric lighting engine, is 119.5 million foot pounds. The water evaporated per pound of coal by the boilers is not given, but assuming 9 pounds of water per 1 pound of coal, under actual conditions of temperatures and pressures, which is .968 of a pound or 10 per cent. less than that obtained on the official trial of these boilers, the duty on a steam basis would be 132.8 million foot pounds, or only 8.4 per cent. below the guaranteed contract duty, a part of which difference is accounted for by the use of steam from the same boilers for heating and lighting the building.

Another interesting station in regard to annual duty is at Louisville, Ky., where a compound engine, working against a total head of 193 feet with a steam pressure of 140 pounds per square inch, has been running since 1893, showing an average duty per year of 122 million foot pounds per 100 pounds of coal consumed. On the official trial of this engine of 144 hours' duration, the average duty was 125.44 million foot pounds per 100 pounds of Pittsburg coal. In this case the efficiency has been kept up to within 2.74 per cent. of that shown on the official trial.

No instructive comparison of station duty with test duty can be made fairly between a station having a number of engines of different makes, capacities and efficiencies and a station containing engines all of about the same efficiency. The records of annual cost at most of the large municipal pumping stations give little data of value for showing what it would cost to pump water in a new and thoroughly modern plant.

Some work of this Department has been devoted to the collection of data upon costs of pumping in different cities and stations, and on inspecting Tables 8, 9, 10, 11 and 12. it will be seen that there is a wide range.

Table 8.

Statistics of Pumping the Entire Water Supply of Different Cities for a Period of One Year, 1902, Unless Otherwise Noted.

	Amount Pumped Once. (Million Gallons per Year.)	Amount Pumped Twice. (Million Gallons per Year.)	Total Pumpage (Million Gallons per Year.)	Average Amount Pumped Mil. Gallons in 24 Hours.	Range of Cost of Pumping Based Upon Total Pumping Expenses, 1 Mil. Gals. 1 Ft. High, Including Only the Larger Stations.	Average Head Pumped Against In Feet.	Average Cost of 1 Mil. Gals. 1 Ft. High Including All Stations.	Average Cost of Coal Delivered Into Bins per Ton of 2240 Lbs.	Cost of Pumping Based Upon Total Pumping Expenses, 1 Mil. Gals. 1 Ft. High With Coal $1.00 per 2,240 Lbs. Including All Stations.	Division of Total Pumping Expenses. Labor Per Cent.	Division of Total Pumping Expenses. Fuel Repairs and Supplies. Per Cent.	Total Pump Horse Power (P.H.P.)	Cost of a 24 Hour (P. H. P.) Based on Cost of Fuel Only.	Cost of a 24 Hour (P. H. P.) Based on Total Pumping Expenses.	Cost of Coal Required for a 24 P. H. P. Hour Based on Coal at $1.00 per Ton of 2,240 Lbs.
Philadelphia, Pa.	114,460	2,338	116,798	320.00	$0.0364 to $0.01671	205.00	$0.0480	$3.38	$0.01421	34	66	11,480	$53.27	$100.36	$15.77
Baltimore, Md.	8,856	None.	8,856	24.26	.02969 " .0489	177.30	.03114	3.46	.00908			753	46.75	64.97	13.51
Boston, Mass.	38,838	3,162	42,000	115.07	.030 " .305	71.23	.03513	5.07	.00692	44	56	1,435	32.26	73.34	6.36
c Pittsburg, Pa.	19,442	2,605	22,046	60.40	.0130 " .500	256.00	.02355	.9856	.02389	44	56	2,706	17.29	49.00	17.53
Cincinnatti, O.	14,603	5,684	20,287	55.58	.0462 " .1011	248.60	.06420	1.39	.04675	43	57	2,400	36.10	139.74	25.97
Buffalo, N. Y.	41,610	None.	41,610	114.00	1 Service " .0368	147.73	.0368	1.86	.01984	39	61	2,947	25.64	76.76	13.82
St. Louis, Mo.	25,046	24,526	49,572	135.80	.01927 " .0465	154.20	.0315	1.50	.02100	40	60	3,665	25.99	65.71	17.32
Milwaukee, Wis.	8,786	2,077	10,863	29.76	.0316 " .0753	145.47	.0372	3.30	.01126	59	41	758	25.17	77.73	7.62
Cleveland, O.	25,537	1,374	26,911	73.72	.... .026	205.10	.026	1.48	.01645	48	52	2,645	19.19	51.40	12.59
Providence, R. I.	4,321	519	4,840	13.26	.0377 " .1224	171.60	.0414	5.18	.00799	35	65	398	36.84	86.51	7.11
New York, N. Y.															
b Bor. of Brooklyn.			*d* 63,300	173.40	.0468 " .1617	107.40	*e* .07745	3.15	.02459	42	58	3,259	52.44	161.60	16.65
Bor. of Manhattan	*a* 19,255	None.	19,265	52.77	.050 " .1620	111.55	.06276	5.25	.01195	48	52	1,030	66.63	128.46	12.69
Chicago, Ill.	130,707	"	130,707	358.10	.0335 " .0522	102.40	.04190	2.85	.01459	35	65	6,417	40.17	101.43	14.24

a Based on average pumpage per day for four months, May, June, July and August, 1903.
b Data taken from last published reports of the Department of City Works, 1896.
c Data taken from last published reports of the Department of Public Works, 1899.
d Pumped from one to four times.
e Includes interest and sinking fund.

WILL J. SANDO,
Dep't Engineer.

TABLE 9.

Statistics of Pumping at the Principal Stations in Different Cities Covering a Period of One Year, 1902, Unless Otherwise Noted.

Stations.	Average Amount Pumped Mil. Gals. 24 Hours.	Total Head Pumped Against In Feet.	Cost per 1 Mil. Gals, 1 Ft. High, Based on Total Pumping Expenses.	Cost of Coal Per Ton of 2,240 Lbs In Bins.	Cost, Based Upon Total Pumping Expenses, per 1 Mil. Gals 1 Ft. High With Coal at $1.00 per Ton of 2,240 Lbs.	Kind of Coal Used.
Philadelphia, Pa.--						
Queen Lane	71.20	274.9	$0.0364	$3.6833	$0.00988	Bituminous and Anthracite in small sizes.
Spring Garden	140.37	156.1	.0446	3.1233	.01427	
Baltimore, Md.—						
Mt. Royal	14.40	170.75	.02969	3.39	.00875	Bituminous.
Boston, Mass.—						
Chestnut Hill, High Service	29.85	128.	.032	4.72	.0067	Bituminous mixed with Anthracite screenings.
Chestnut Hill, Low Service	76.55	42.48	.032	5.20	.00615	
*a*Spot Pond	7.97	133.	.036	5.19	.00693	
*c*Pittsburg, Pa.—						
Brilliant	53.30	268.	.0164	.9856	.01663	Bituminous and Pittsburg nut and slack.
Buffalo, N. Y	114.00	147.73	.0368	1.854	.01984	Bituminous and Anthracite screenings.
St. Louis, Mo—						
Chain of Rocks, Low Service	68.62	57.75	.040	1.50	.02666	Bituminous, Illinois Mines.
Baden—						
High Service	35.42	300.	.01927	1.50	.01284	
Bissell's Point—						
High Service	31.78	200.	.0466	1.50	.03105	
Milwaukee, Wis.—						
North Point	24.26	156.77	.0316	3.302	.00956	Bituminous Screenings Fairmount.
High Service	5.69	97.69	.0753	3.302	.02280	
Cleveland, O.—						
Division St	69.96	205.1	.026	1.48	.01645	Youghiogheny and Salineville Slack.
Providence, R. I.—						
Perraconset	11.84	171.6	.0378	5.18	.00729	Bituminous and Anthracite, egg size.
New York, N. Y.—						
*b*Borough of Brooklyn,						
Ridgewood (old)	40.56	173.2	*d*.0636	3.02	.02105	Anthracite, egg size.
Ridgewood (new)	40.33	169.1	.0485	2.54	.01909	
Millburn	39.16	53.6	.0670	3.72	.01801	
Borough of Manhattan—						
179th St	30.40	129.43	.0506	5.09	.00994	Anthracite, egg size.
High Bridge	1.93	114.35	.1630	5.35	.03046	
98th St	20.46	89.7	.0831	5.30	.01567	
Chicago, Ill.—						
Springfield Ave	38.73	93.2	.0370	2.89	.01241	Bituminous.
14th St	70.09	110.8	.0335	3.17	.01056	

Compiled and computed from published reports and information received from engineers in charge of Water Works.

a Engine 20 000,000 gallons daily capacity operated at rated speed sufficient time each day to supply the demand.

b Data taken from last published report of the Department of City Works, 1896.

c Data taken from last published report of the Department of Public Works, 1899.

d Cost of pumping with beam engines Nos. 1, 2, 3 and 4, compound condensing direct-acting engine; triple expansion high duty engines in present use in the old Ridgewood Station, Nos. 1, 2 and 3 were started first in September, 1897.

Costs of pumping in the Borough of Brooklyn include interest and Sinking Fund amounting to $0.0129 for the old Ridgewood plant, $0.0122 for the new Ridgewood plant, and $0.0204 for the Millburn plant.

WILL J. SANDO,
Dep't Engineer.

Comparative Economy of Pumping Plants.

TABLE NO. 10.

Comparative Percentage of Cost, Based Upon Total Pumping Expenses, Exclusive of Interest and Sinking Fund, of Pumping 1 *Million Gallons* 1 *Foot High, with Coal at* $1.00 *Per Ton of* 2,240 *lbs., Based Upon the Entire Pumpage for Each City During the Year* 1902.

	Per cent.
Boston, Mass	100
Providence, R. I	115
Baltimore, Md.	131
Milwaukee, Wis	163
Borough Manhattan, New York, N. Y	173
Philadelphia, Pa.	205
Cleveland, O	238
Buffalo, N. Y	287
St. Louis, Mo	303
* Pittsburg, Pa.	345
† Borough Brooklyn, New York, N. Y	355
Cincinnati, O	668

* Based upon statistics of pumping for the year 1899.
† Based upon statistics of pumping for the year 1895.

Comparative Economy of Pumping Plants.

TABLE NO. II.

Comparative Percentage of Cost, Based Upon Total Pumping Expenses, Exclusive of Interest and Sinking Fund, of Pumping 1 *Million Gallons* 1 *Foot High, with Coal at* $1.00 *Per Ton of* 2,240 *lbs., Based Upon the Total Pumpage for Each Station, During the Year* 1902.

Cities.	Stations.	Per Cent.
Boston, Mass	Chestnut Hill, Low Service	100
	Chestnut Hill, High Service	109
	Spot Pond	112
Providence, R. I	Pettaconset	118
Baltimore, Md	Mt. Royal	142
Milwaukee, Wis	North Point	155
Philadelphia, Pa	Queen Lane	160
Borough Manhattan, New York, N. Y	One Hundred and Seventy-ninth Street	162
St. Louis, Mo	Baden, High Service	209
Philadelphia, Pa	Spring Garden	232
Borough Manhattan, New York, N. Y	Ninety-eighth Street	255
Cleveland, O	Division Street	267
Pittsburg, Pa*	Brilliant	270
Borough Brooklyn, New York, N. Y	Millburn	293
	Ridgewood (New)	310
Buffalo, N. Y	Niagara River	322
Borough Brooklyn, New York, N. Y. †	Ridgewood (Old)	342
Milwaukee, Wis	High Service	371
St. Louis, Mo	Chain of Rocks, Low Service	433
	Bissells Point, High Service	505

* Based upon statistics of pumping for the year 1899.
† Based upon statistics of pumping for the year 1896.

TABLE No. 12.

Comparison of Number of Engines and Boilers with Numbers of Men Employed and Rate of Wages at Sundry Pumping Stations.

Station.	Total No. of engines.	Nominal capacity of engines 24 hours (million gallons).	No. of engines in daily use.	Total No. of boilers.	Total No. of men employed.	Total cost of labor, 1902.	No. of men per engine on each watch based on total No. of engines.	No. of men per engine on each watch based on No. of engines in daily use.	Average rate of wages per man for each watch.
Boston, Mass.—c.									
Chestnut Hill, High Service.	4	58	2	5 }	38	$31,239	1.81	2.53	$2.25
Chestnut Hill, Low Service..	3	105	3	3 }					
Spot Pond..................	2	30	1	3	7	6,999	1.22	2.44	2.61
Cleveland, O.—									
Division Street..............	8	115	8	34	70	44,810	2.91	2.91	1.75
New York, N.Y., Borough of Manhattan.—									
179th Street................	5e	28	4	11	28	8,614a	1.87	2.33	2.50
98th Street.................	3	25	2	8	19	6,270a	2.11	3.16	2.25
High Bridge.................	2	11	1	3	7	1,326b	1.17	2.33	3.05
Borough of Brooklyn.—c									
Ridgewood (Old)...........	5d	90	3	24 }	160	148,042	4.85	7.61	2.53
" (New)...........	6d	57 5	4	8 }					
Buffalo, N. Y.—c									
Niagara River	9	187	7	20	126	88,427	4.66	6.00	1,92
Providence, R. I.—f									
Pettaconset.................	4	35	2		12	10,192	1.00	2.00	2.32
Proposed stations for additional supply, N. Y.—c............	12	250	12	25	94	96,900	2.61	2.61	2.82

CONDITIONS NECESSARY FOR PUMPING WATER CHEAPLY.

The elements conducive to pumping water cheaply are: Efficient engines and boilers, the latter carefully fired, operated continuously under contract conditions or overload not beyond that for which the machinery is designed; simplicity and directness in steam and water piping within stations; the prevention of radiation from boilers, steam pipes and cylinders; the heating of feed water by waste heat; the supplying dry or superheated steam, and the minimum amount of auxiliary machinery operated otherwise than by the main engine. Independent auxiliary machinery (air compressor and feed pumps) is necessary and should always be installed to be used in case of an emergency.

The station duty is liable to be reduced from 5 per cent. to 10 per cent., according to the size of the plant, when the independent air compressor and feed pumps are used in regular running.

a Average for four months.
b " " two "
c Have electric lighting plants.
d Includes one reserve engine, seldom used.
e Including the new Worthington engine No. 5 not yet accepted by the City. This engine was started March 16, 1903, and has been running in regular service more or less every day since.
Engine No. 6, a duplicate of engine No. 5, is in course of erection and it is expected will be ready for regular service by December 1.
f Including two engines not run in several years.

There are sundry safeguards and attention to details of firing and engine driving which add almost nothing to the expense and are insisted on during a duty trial that are often abandoned as soon as the test is over. It is customary for contractors to adjust the machinery and see that everything is in the best condition for the highest efficiency before the official duty test or final payment on contract is made. Gages, thermometer and indicators are used to adjust pressures in the steam cylinders and jackets, to record temperatures of steam, flue gases and feed water, and to show the steam distribution in the cylinders. The use of these instruments is absolutely essential to good economy, and in order to keep the machinery in good condition they should be made permanent adjuncts to every plant, instead of being taken away or neglected when the trial is over.

Records should be kept hourly of the revolutions made by the engines, amount of water pumped, total lift on pumps, fuel consumed, supplies used, all pressures and temperatures and notes made daily of anything out of the ordinary about the machinery and station, and indicator cards taken and computed as often as it is found necessary to keep engines in good order.

Supplies in sufficient quantities and duplicates of small parts, known from experience to require renewal frequently, should be kept on hand. Lubricants should not be curtailed. Efficient means should be provided for preventing any waste.

The organization must be composed of a sufficient number of men to accomplish all the work easily in a systematic and thorough manner. Each man should be assigned to certain duties and instructed in every detail. Provision of regular "days-off" should be made for men who are compelled to attend machinery which must run seven days in the week, and such provision should be enforced without discrimination.

Repairs should be attended to promptly *by employees of the station*, unless they are too large and require parts which cannot be made in the station.

The Present Pumping Stations in the Borough of Manhattan

The Croton Aqueduct delivers its water at elevations only up to 122 feet above tide, and therefore pumping is required for buildings on the higher portions. About 20 per cent. of the entire Croton supply now has to be pumped to the higher levels by engines in three stations. The largest is located between Amsterdam avenue and the Harlem River at One Hundred and Seventy-ninth street and is known as the One Hundred and Seventy-ninth Street Station, containing pumps of 58 million gallons daily nominal capacity. The next in size is the Ninety-eighth Street

Station, located on the southerly side of Ninety-eighth street, near Columbus avenue containing pumps of 25 million gallons daily nominal capacity. The smallest is known as the High Bridge Station, and is located between Amsterdam avenue and the Harlem River at One Hundred and Seventy-fourth street, and contains pumps of 11 million gallons daily capacity.

PUMPING STATIONS UNDER CONSTRUCTION.

Situated on Jerome avenue, between Van Cortlandt avenue and Mosholu Parkway, and taking water from Jerome Park Reservoir at an elevation of 131.5 feet above tide, there is under construction a pumping station containing pumps of 20 million gallons daily nominal capacity, of a guaranteed duty of 105 million foot pounds per 100 pounds of coal, delivering into the High Service at an elevation of 300 feet above tide. The engines and boilers for this station are now in the contractor's shops in a more or less completed condition.

In connection with this plant this Department has recommended that the original plans be changed to include an economizer to heat the feed water by utilizing the waste gases from the boilers, a superheater to furnish dry or superheated steam to the engines, also to include boiler feed pumps and air compressors for charging the pumps when necessary, all to be attached and operated by the main engines. These changes can be made now with minimum expense and will add materially to the station duty of the plant.

Table No. 13 shows the principal dimensions of these engines and type of the boilers and individual capacities and pressures under which they work.

TABLE NO. 13.

Principal Dimensions of Pumping Engines, Capacities and Pressures, New York City Croton Supply.

ONE HUNDRED AND SEVENTY-NINTH STREET STATION.

Engine No.	Type of Engine.	Diameter of Steam Cylinders. Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger in Inches. All Double Acting.	Stroke of Steam Piston and of Pump Plunger. Inches.	Year Installed.	Manufacturer.	Steam Pressure, lbs. per sq. in. Gauge.	Revolutions per Minute for Nominal Capacity.	Nominal Capacity 24 hours. Million Gallons.	Total Lift. Feet.	Service Supplied.
1	Verticle Triple Expansion Fly Wheel	15	27	42	11¾	40	1897	Geo. F. Blake Mfg. Co.	160	28	4	224	Tower or Upper High Service, Territory North of One Hundred and Sixty-ninth Street, known as Washington Heights District.
3	Vertical Triple Expansion Fly Wheel	15	27	42	11¾	40	1897	Geo. F. Blake Mfg. Co.	160	28	4	224	Tower or Upper High Service, Territory North of One Hundred and Sixty-ninth Street, known as Washington Heights District.
2	Vertical Triple Expansion Fly Wheel	15	27	42	17½	40	1897	Geo. F. Blake Mfg. Co.	160	30	10	100	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
4	Vertical Triple Expansion Fly Wheel	15	27	42	17½	40	1897	Geo. F. Blake Mfg. Co.	160	30	10	100	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
5	Vertical Triple Expansion High Duty Direct Acting	16	25	46	31	36	1903	Henry R. Worthington.	160	23	15	100	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
6	Vertical Triple Expansion High Duty Direct Acting	16	25	46	31	36	1903	Henry R. Worthington.	160	23	15	100	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
	Total Capacity, nominal										58		

Boiler equipment, eight return tubular externally fired boilers, in brick settings, three marine corrugated furnace, return flue, internally fired boilers. One direct fired superheater.

Table No. 13—*Continued.*

NINETY-EIGHTH STREET STATION.

Engine No.	Type of Engine.	Diameter of Steam Cylinders. Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger in Inches. All Double Acting.	Stroke of Steam Piston and of Pump Plunger. Inches.	Year Installed.	Manufacturer.	Steam Pressure, lbs. per sq. in. Gage.	Revolutions per Minute for Nominal Capacity.	Nominal Capacity 24 hours Million Gallons.	Total Lift. Feet.	Service Supplied.
1	Horizontal Compound Direct Acting............	21	36⅜	26	48	....	1880	Henry R. Worthington	60	13	7.5	100	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
2	Horizontal Compound Direct Acting............	21	36⅜	26	48	....	1880	Henry R. Worthington..............	6c	13	7.5	1co	
3	Horizontal Compound High Duty Direct Acting....................	18	36	26	35	....	1891	Henry R. Worthington..............	120	22	10	100	High Service, Territory between Thirty fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
	Total capacity, nominal....										25		

Boiler equipment, six return tubular externally fired boilers, in brick settings, two marine return tubular internally fired boilers. One direct fired superheater.

HIGH BRIDGE STATION.

Engine No.	Type of Engine.	High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger	Stroke	Year Installed.	Manufacturer.	Steam Pressure	Revolutions per Minute	Nominal Capacity	Total Lift.	Service Supplied.
1	Vertical Simple Crank and Flywheel.	32	..	..	32	72	1875	Delameter Iron Works.	60	15	5	97	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
2	Horizontal Compound High Duty Direct Acting	19¼	..	36⅜	24	36	1883	Henry R. Worthington.	60	16	6	97	High Service, Territory between Thirty-fourth Street and One Hundred and Sixty-ninth Street, Levels Higher than Croton Gravity Supply.
	Total Capacity, nominal....										11		

Boiler equipment, three return tubular externally fired boilers in brick settings.

JERROME PARK STATION.

(Under Construction.)

1	Vertical Triple Expansion high duty direct acting.	16	25	46	25	36	..	Henry R. Worthington.	150	22	10	176	High Service, levels higher than Williams Bridge Reservoir, elevation 191 feet above tide.
2		16	25	46	25	36	..		160	22	10	175	
	Total Capacity, nominal										20		

Boiler Equipment, three marine corrugated furnace return tubular boilers.

THE PRESENT MANHATTAN SYSTEM OF PUMPING AND CHANGES SUGGESTED.

The ordinary High Service is at present supplied by the following pumps:

In the One Hundred and Seventy-ninth Street Station pumps No. 2 and No. 4, each of 10 million gallons capacity per 24 hours, and No. 5 and No. 6, each of 15 million gallons daily capacity, and in the Ninety-eighth Street Station, three pumps having an aggregate daily capacity of 25 million gallons, all pumping directly into the High Service distribution pipe system, delivering their water at about 221 feet above tide level. Any small hourly surplus from these pumps is stored in the High Bridge Reservoir and the Ninety-eighth street standpipe.

The extra high service known as "The Tower Service" is supplied by pumps No. 1 and No. 3 in the One Hundred and Seventy-ninth Street Station, having a daily capacity each of 4 million gallons. These pump into the standpipe at High Bridge about 321 feet above tide. Pumps Nos. 1 and 2 in the High Bridge Station deliver directly into High Bridge Reservoir and thence into the high service system. A moderate increase in supply to the ordinary high service may be given by overflowing into its reservoir at High Bridge from the standpipe from the extra high service known as the "Tower Service."

Prior to the recent repairs of May, 1903, upon engines Nos. 1, 2, 3 and 4 in the One Hundred and Seventy-ninth Street Station, it was found necessary very often to keep both engines in the Tower Service in operation to aid in supplying the "High Service," by overflowing probably 4 million gallons daily into the High Service Reservoir. The wasteful extra lift on the pumps under those conditions was about 126 feet.

The cost of pumping has been and still is increased by using the compound engines Nos. 1 and 2 in the Ninety-eighth Street Station; also by the use of either engine in the High Bridge Station.

The arrangement of engines and the system of delivery mains and gate valves in connection with the High Bridge Reservoir and Ninety-eighth Street standpipe admit of every combination desirable to run the plants together in order to obtain the highest economy. Obviously, the best economy is attainable when engines are run continuously at the rated capacity for which they are built or at the increased capacity of which they are capable, as previously noted. Within this range of high efficiency the engines in the One Hundred and Seventy-ninth Street Station alone will be capable of pumping the entire consumption as soon as the new engine No. 5, now nearly completed, is ready for daily use, and the Ninety-eighth Street and High Bridge pumps can stand idle, or ready for emergencies.

The average daily pumpage (as measured by plunger displacement, including an allowance for slippage) for the months of May, June, July and August, 1903, was as follows:

Furnished by the One Hundred and Seventy-ninth Street Station	30,400,000	gallons
Furnished by the Ninety-eighth Street Station	20,460,000	"
Furnished by the High Bridge Station	1,494,000	"
Total	52,354,000	"

The aggregate nominal capacity of all engines in the One Hundred and Seventy-ninth Street Station per 24 hours is 58,000,000 gallons, which may be increased safely with economical results to 63,800,000 gallons, which presents an ample margin or surplus of from 6,216,000 to 11,016,000 gallons over the actual average consumption for the four months mentioned.

By centralizing the pumping at the One Hundred and Seventy-ninth Street Station, which now seems feasible, the economy of pumping all the high service water for Manhattan could be greatly increased without impairing the efficiency of the service in case of fire or other emergency. The excess capacity of 11,016,000 gallons in the One Hundred and Seventy-ninth Street Station would be available instantly.

At the Ninety-eighth Street Station a force of men could be maintained who would keep the No. 3 high duty engine and the necessary boilers constantly under pressure and in readiness to start on short notice in case of emergency. This engine if kept partially warmed could be started for additional capacity in the same time it now requires to start an engine at any of the stations. This simple type of engine is well adapted for a quick start and for emergency use.

Engines Nos. 1 and 2 in the Ninety-eighth Street Station have been in service 23 years. They are hardly worth the expense of repairing, the cost of which, together with the high cost of pumping, make them expensive to maintain in constant operation. Two new high duty engines, each having a daily capacity of 15 million gallons, have previously been recommended by this Department to be installed as soon as possible to provide for future consumption until such times as the plant may be superseded either by enlarging to provide for future consumption at the One Hundred and Seventy-ninth Street Station, and centralizing pumping at that point, or by a high level gravity supply.

The High Bridge Station has been operated only occasionally during the past few months, and might well be put out of commission and the men withdrawn.

POSSIBLE ECONOMIES BY CENTRALIZING PUMPING.

The saving by pumping the entire present high service consumption with the engines in the One Hundred and Seventy-ninth Street Station, instead of doing a part of this work with engines in the Ninety-eighth Street Station, would come mainly from the smaller amount of fuel required by the more economical engines in the One Hundred and Seventy-ninth Street Station as compared with the present engines at Ninety-eighth street and High Bridge and their smaller demand for oil and petty supplies per million gallons pumped. The difference is shown in table No. 14.

The cost of pumping one million gallons 1 foot high in Manhattan, based upon the operating expenses for four months, after recent repairs had been commenced, but not entirely finished, range from 5.06 cents at the One Hundred and Seventy-ninth Street Station to 16.3 cents at the High Bridge Station, and the average cost per million gallons 1 foot high for the total pumpage in Manhattan during the same period was 6.276 cents. By pumping the total consumption with engines in the One Hundred and Seventy-ninth Street Station in the same condition during the four months referred to, the cost would be reduced from 6.276 cents to 5.06 cents, a saving of about 20 per cent., or $2,200 per month. When the repair work now in progress is completed, it is expected that a further saving will be made, so that it will be possible to pump water with these engines at a cost not exceeding 4 cents per million gallons 1 foot high, which represents a saving of 34 per cent., or about $4,000 per month, as compared with the recent conditions.

The probable saving by pumping the entire consumption with the engines in the One Hundred and Seventy-ninth Street Station when the repairs on the engines now in progress are completed, changes in method of firing and feeding the boilers are made, and closer vigilance in management maintained, is shown in table No. 14.

TABLE No. 14.

Possible Saving in Expenses, Based Upon Pumping with Engines at One Hundred and Seventy-ninth Street Station, Compared with Cost of Pumping by Present Method.

	Amount Pumped (Million Gallons).	Average Head Pumped Against (Feet).	Amount Lifted 1 Foot High (Million Gallons).	Total Cost of Pumping (4 Months).	Cost per Million Gallons 1 Foot High.
Statistics of pumping with three stations, namely, One Hundred and Seventy-ninth street, Ninety-eighth street and High Bridge, during the months of May, June, July and August, 1903	6,192.79	110.34	703,360	$44,106	$0.06277
Comparative cost of pumping same amount based upon cost per million gallons 1 foot high during same period of time with engines at One Hundred and Seventy-ninth street	6,192.79	110.34	703,360	35,590	.0506
Comparative cost of pumping same amount based upon cost per million gallons 1 foot high expected after engines are repaired and maximum capacity of engines is available......................	6,192.79	110.34	703,360	28,134	.0400

The Present Engines Are Capable of Better Economy.

Engines Nos. 1, 2, 3 and 4 in the One Hundred and Seventy-ninth Street Station were designed and installed during a period when duty of pumping machinery was receiving much attention from manufacturers and engineers in charge of water works, by reason of the high duty records made just previous to that time by sundry engines. The duty of these engines shown by tests, published in "Power," August, 1897, although 33 per cent. in excess of the contract requirements, is below the duty that this Department finds these engines are capable of making when properly adjusted and looked after. The published report above mentioned explains:

> "At the time of these tests no preliminary trial had been made, as the City engineers wished the engines started as soon as possible on account of the demand for water."
>
> The necessity of running the engines in regular commission and the manufacturer's knowledge that the terms of the contract could be fulfilled easily, are reasons probably for the low records. A comparison of proportions of the steam cylinders, of the distri-

bution of load and conditions of service does not differ very materially from the low service engines of the Metropolitan Water Works, Boston, Mass. The latter engines have some advantages by being larger in horse power about 33 per cent. and by having smaller cylinder clearances, while the engines in the One Hundred and Seventy-ninth Street Station have the advantage of 10 lbs. higher steam pressure and total lift on pumps which is favorable to higher mechanical efficiency. The revolutions per minute in either case are practically the same.

The manufacturers of these engines would to-day guarantee a duty for engines from the same patterns under the conditions existing at the One Hundred and Seventy-ninth Street Station of 150 million foot pounds of work per 1,000 pounds of dry steam consumed by the engine and its auxiliaries.

Assuming an evaporation by the boilers of 8.6 lbs. of water per pound of coal at actual temperature and pressure, the duty on 100 pounds of coal would be 129 million foot pounds. Allowing a loss of 10 per cent. in regular running, the station duty on 100 pounds of coal would be 116 million foot pounds. The estimate herein presented of the probable reduction in the cost of pumping the entire consumption with the engines in the One Hundred and Seventy-ninth Street Station is based upon a regular station duty of 115 million foot pounds per 100 pounds of coal consumed without any allowance for moisture or ash, and it is entirely reasonable to expect this with the engines maintained in good repair and with a corps of attendants no more than ample.

The Low Service engines of the Metropolitan Water Works, Boston, Mass., show an annual duty of 119.49 million foot pounds of work per 100 pounds of coal consumed, including that required to furnish steam for heating the station and consumed by an engine operating a 35 K. W. generator running 11 hours per day for supplying electric current for lighting the Low and High Service Stations.

RECOMMENDATION RELATIVE TO OPERATING ENGINES.

It is not to be expected that the engines in One Hundred and Seventy-ninth Street can be operated without occasional interruption. There may be intervals when it will be necessary to start the engines in Ninety-eighth Street Station in regular service in order to attend to small repairs. It is recommended as desirable and decidedly economical to plan on running the engines in One Hundred and Seventy-ninth Street as much as possible until the average daily consumption amounts to 63.8 million gallons.

The Metropolitan Water Board, Boston, Mass., by concentration of pumping, by the adoption of efficient equipment and careful management saved 46 per cent. of the cost of pumping during the year 1898 compared with the pumping expenses during the year 1897.

INSPECTION OF ENGINES AND RESULT OF REPAIRS.

Engines Nos. 1, 2, 3 and 4 in the One Hundred and Seventy-ninth Street Station have been running in regular service as the consumption required since 1897. The cost of repairs during this entire period is reported to have been remarkably low. On the 1st of May, 1903, in co-operation with Mr. N. S. Hill, Jr., Chief Engineer of the Department of Water Supply, Gas and Electricity, these engines were thoroughly overhauled and found to be badly in need of repairs. Tests made May 8th on the pumps showed excessive slippage or loss of action, caused principally by water valves adrift, which amounted to 60 per cent. on pump No. 2 and 65 per cent. on pump No. 4. These slippage tests were made by taking the revolutions, steam and water pressures when the engines were running in regular service and afterward the same data with the engines operating under the same conditions in regard to steam and water pressure, but with the gate valves on the discharge main closed. After each test the man-hole plates on the pumps were removed, and the openings from the discharge pipe into the pumps were inspected to detect any leakage past the gate valves. In both cases the gate valves were found tight. To determine the slippage through the pump valves and past the plungers, the displacement of the plungers represented by the revolutions of the engines while the gate valves on the discharge pipe closed, was taken.

Slippage Tests.

	Data from Tests Before Repairs were Made.		Data from Test After Repairs were Made.
	Engine No. 4 (May 8).	Engine No. 2 (May 11).	Engine No. 4 (May 11).
Revolutions per minute in regular service, gate valve on discharge pipe open	30	30	30
Steam pressure at engine, pounds per square inch	150	150	150
Water pressure by gauge on engine, pounds per square inch	45	45	45
Revolutions per minute with gate valve on discharge pipe closed	19.5	18	1.25
Percentage of loss of action or slippage	65	60	.0416

It is almost inconceivable that the pumps could have had their valves in this inefficient condition for a long period without discovery. An attempt was made to analyze the record of average pumpage as reckoned by plunger displacement for several months previous, but its incompleteness and doubts concerning its accuracy prevented.

Pumps on engine No. 4 were repaired first. To show the simple nature of the repairs it may be stated that the work was begun on May 8th, finished and pumps started in regular service, May 11th.

On account of the necessity for continuous running it was considered by the engineer in charge that engines Nos. 1 and 3 could not be stopped for a detailed test. They were, however, examined and repaired and no indication of such excessive slip found as on Nos. 2 and 4. Several of the small pump valves were, however, missing on each engine. It was therefore assumed that engines Nos. 1 and 3, after the repairs, had only 4 per cent. slip, like No. 4 engine, but that prior to the repairs the slip was somewhat greater.

The best practical test is found in the fact that two of the engines previously run were shut down after the repairs. Prior to the first of these tests five engines, including the new Worthington engine No. 6, were kept in operation in the One Hundred and Seventy-ninth Street Station and one engine in the High Bridge Station in order to supply the consumption. After the repairs were made on all pumps it was found that because of the prevention of slippage, one engine in One Hundred and Seventy-ninth Street Station could be shut down all the time and the engine at High Bridge could also be shut down the greater part of the time, while the remaining four engines, including the engine No. 6 in One Hundred and Seventy-ninth Street Station, performed all the work previously performed by the six engines.

REDUCTION IN EXPENSE FOR OIL, WASTE AND PACKING.

The cost of oil, waste and packing used by the engines in the One Hundred and Seventy-ninth Street Station during the month of May, 1903, amounting to $445 and the total pumpage 901 million gallons. During the month of August, 1903, the total pumpage was 1,045 million gallons, and the cost of oil, waste and packing $286, which is an increase in the amount pumped of nearly 16 per cent. and decrease in cost of supplies of 35.73 per cent. At the same rate for cost of supplies as during August, the yearly cost would be $3,432. The yearly pumpage at the daily rate during May, June, July and August, 1903, would amount to 11,096 million gallons. Hence it appears for pumping to the actual average height of about 112 feet in 1903, the cost of oil, waste and packing under present conditions will be about 30.9 cents per million gallons.

During the year 1902 the cost of oil, waste and packing used by the engines (one more in number than used in daily service in the One Hundred and Seventy-ninth Street Station) in the Low and High Service Stations of the Metropolitan Water Works, Boston, Mass., amounted to $1,363, as shown by the Board's annual report. The total pumpage was 38,840 million gallons, which made the cost of these supplies 3.5c. for pumping 1 million gallons to actual average height of 70 feet. Increasing this cost proportionately to correspond with the actual average head pumped against at One Hundred and Seventy-ninth Street Station gives 5.6c., or less than 1-5 the cost at One Hundred and Seventy-ninth Street Station.

Further inspection showed parts of the steam valve gear were much worn and that the larger bearings were in need of adjustment. Diagrams taken from steam cylinders June 19, 1903, before adjusting any of the parts, showed a poor distribution of steam and consequent impairment of efficiency. During the time these cards were taken the condensed steam used by the cylinders was weighed and the work performed by the engine noted. The duty shown, based upon plunger displacement, exclusive of the steam used by the jackets, was about 64 million foot pounds per 1,000 pounds of steam, and allowing for actual use of steam in jackets must have been not over 56 million foot pounds. The receivers were found in a leaky condition. Cleaning the condensers increased the vacuum 1½ inches. A gain of 1½ inches in vacuum is equivalent to an increase in efficiency of 1.6 per cent. for the High Service engines and 1.9 per cent. for the Tower engines, or, in other words, a loss of 1½ inches in vacuum is equivalent to a loss of three horse power.

The jacket system on the No. 4 engine was changed in order to have a reduced pressure in the intermediate and low pressure cylinders from that in the high pressure cylinder. On account of the limited time available for making tests and lack of apparatus, the percentage of steam used by the jackets prior to the repairs was not obtained.

ORGANIZATION.

The organization at the One Hundred and Seventy-ninth Street Station compares favorably in the number of men employed with those at similar stations in other cities. The rate of daily wages is about an average of the cases tabulated in Table No. 12. Overmanning of stations is often a cause of excessive cost of pumping, but this does not seem to prevail in the Manhattan stations.

Pumping Stations in the Borough of Queens.

There are five pumping stations owned by the City in the Borough of Queens, two in Long Island City, one in Flushing, which was known until recently as College Point, one in Bayside, recently known as the Flushing Station, and one in Whitestone. Of the stations in Long Island City, designated as Nos. 1, 2 and 3, station No. 2 has been out of commission since November 9th, 1902, on account of a boiler explosion, which wrecked the plant.

During the months of May, June, July and August, 1903, these stations pumped in the aggregate from driven wells 445 million gallons against an average head of 176 feet. The total pumping expenses during this period were $18,945, making the average cost of pumping 1 million gallons 1 foot high, $0.24 for coal, attendance and ordinary repairs and supplies, exclusive of interest and depreciation and extraordinary repairs, or Sinking Fund, which is very high compared with cost of operating similar stations in other cities, as may be seen by the table below:

Cost of Pumping, Including Labor, Repairs and Supplies, with Five Small Plants in the Borough of Queens, During the Months of May, June, July and August, 1903.

Long Island City, Station No. 1—	
Daily average gallons pumped	608,000
Head pumped against, feet	115.6
Cost of pumping 1 million gallons 1 foot high, cents	47.5
Long Island City, Station No. 3—	
Daily average gallons pumped	612,700
Head pumped against, feet	127.3
Cost of pumping 1 million gallons 1 foot high, cents	37.12
Flushing Station—	
Daily average gallons pumped	993,100
Head pumped against, feet	206
Cost of pumping 1 million gallons 1 foot high, cents	16.41
Whitestone Station—	
Daily average gallons pumped	98,344
Head pumped against, feet	175
Cost of pumping 1 million gallons 1 foot high, cents	$1.35
Bayside Station—	
Daily average gallons pumped	1,303,000
Head pumped against, feet	205
Cost of pumping 1 million gallons 1 foot high, cents	13.05

Cost of Pumping, Including Labor, Repairs and Supplies, with Small Plants, Equipped with Direct-Acting Pumps Similar to Those Used in the Pumping Stations in the Borough of Queens in Each Case for a Period of One Year.

Pittsburg, Pa., Garfield Station, During the Year 1899—

Daily average gallons pumped	410,000
Head pumped against, feet	205
Cost of pumping 1 million gallons 1 foot high, cents	15

Boston, Mass., Metropolitan Water Works (3 *Small Stations*), *During the Year* 1902.

West Roxbury Station—	
Daily average gallons pumped	352,000
Head pumped against, feet	133
Cost of pumping 1 million gallons 1 foot high, cents	30.5
Arlington Station—	
Daily average gallons pumped	315,000
Head pumped against, feet	278
Cost of pumping 1 million gallons 1 foot high, cents	14.7
Clinton Sewerage Station—	
Daily average gallons pumped	786,000
Head pumped against, feet	46
Cost of pumping 1 million gallons 1 foot high, cents	18

New York, N. Y., Borough of Brooklyn (2 *Stations*), *During the Year* 1899.

Gravesend Station—	
Daily average gallons pumped	2,355,033
Head pumped against, feet	154
Cost of pumping 1 million gallons 1 foot high, cents	11.90
New Utrecht—	
Daily average gallons pumped	1,209,596
Head pumped against, feet	200
Cost of pumping 1 million gallons 1 foot high, cents	18.17

The stations in the Borough of Queens were visited and examined in a general way after they had been partially renovated and remodeled and repairs on the engines begun in accordance with instructions of Mr. Hill, the Chief Engineer of the Department of Water Supply, Gas and Electricity. All of these Queens Borough stations, with the exception of those at Bayside and Flushing, contain antiquated machinery, some of which was erected in 1874 and is still in daily use. In each of the latter stations at Bayside and Flushing there is one engine of modern design, the economy of which, however, is not apparent on account of the practice of running alternately with other engines which are not as economical. The present intention of the Department of Water Supply, Gas and Electricity is to replace the older engines in the larger stations by modern high-duty engines, and this should result in a saving of more than 40 per cent. in fuel alone, amounting to, approximately, $6,250 per year, based upon the present rate of pumping. Beyond this replacing of engines in these small stations in Queens, there is little that can now be recommended for lessening the cost of pumping until the future source of supply for this Borough is determined.

The Present Pumping Stations in the Borough of Brooklyn.

This Department has made studies in co-operation with Mr. I. M. de Varona, Chief Engineer of the Department of Water Supply, Gas and Electricity for Brooklyn, of methods of securing greater economy in pumping at the present numerous low lift driven well plants, by operating them with electricity or other power and the centralizing of pumping. Studies have also been made in this Department concerning the operating expenses of all plants and assistance has been given upon the preparation of plans and specifications for the Gravesend Station, upon perfecting the designs for the Wantagh Station, so that the foundations and buildings first put in should be adapted for permanent use and that the motive power of the pumps may with minimum expense be changed from steam to electricity, and has advised concerning the type of engine and layout of plant for the new high service engines at Ridgewood.

Our investigations show that electricity developed at the large Millburn Station and transmitted by wire along the conduit right of way will be the best and cheapest power for pumping at all this series of comparatively small low lift plants.

SOURCE OF SUPPLIES AND QUANTITIES PUMPED WITH THE DIFFERENT PLANTS.

Of the entire supply pumped by engines in the large Ridgewood Stations, about 60 per cent. is surface water from streams and reservoirs delivered by gravity and pumped by the engines in the Millburn Station and thence pumped to Ridgewood by the engines in that, through the aqueduct and pipe lines. The balance, 40 per cent., is ground water, drawn from wells and lifted into the aqueduct by pumps in 16 small plants, shown in Table No. 15, scattered through a distance of 22.3 miles, along the line of the aqueduct in an easterly direction from Ridgewood to Massapequa.

Table No. 15.

Locations, Capacities and Costs of Pumping with Plants (not including Millburn) Delivering into Conduits Furnishing Water to the Ridgewood Stations.

Stations.	No. of pumps.	Nominal capacity of pumps 24 hours. (Million gallons.)	Type of pumps and engines.	Average amount pumped 24 hours, when pumps were run during the year. (Million gallons.)			Number of days on which pumps were run.			Total cost of pumping 1 million gallons 1 foot high.	
				1896.	1900.	1901.	1896.	1900.	1901.	1896.	1900.
Spring Creek (Old)	3	10	Horizontal compound (two) triple (one) direct acting	4.535	4.009	3.715	365	360	346	$0.2037	$0.2978
Spring Creek (Temporary)	2	7	Horizontal simple non-condensing direct acting	2.838	3.350	2.783	277	365	355	.2290	.2216
Shetucket	1	5	Horizontal simple non condensing direct acting	.....	1.313	1.118	...	344	330	....	.6213
Oconee	1	5	Horizontal simple non-condensing direct acting	.....	1.457	1.157	...	337	311	....	.5264
Baiseleys	2	6	Horizontal compound direct acting	1.528	1.581	1.379	206	365	351	.3341	.3951
Jameco	3	17	" " " "	5.064	4.936	3.708	365	364	361	.2122	.2910
Springfield	1	5	" " " "	1.990	2.697	3.056	167	363	361	.5537	.3376
Forest Stream	2	10	" " " "	3.354	3.585	3.568	240	365	357	.2619	.2940
Clear Stream	2	10	" " " "	2.854	2.565	2.868	343	363	353	.2816	.3539
Watt's Pond	1	3	" " " "	2.097	3.170	3.892	266	363	351	.3113	.2422
Smith's Pond	2	10	" " " "	6.559	7.500	6.823	240	365	362	.2543	.2788
Agawan	2	12	Centrifugal pumps driven by belt from simple steam engines non-condensing	4.518	2.702	1.908	197	101	105	.1327	.6276
Merrick	3	15	Centrifugal pumps driven by belt from simple steam engines non-condensing. Horizontal simple non-condensing direct acting	4.693	4.227	5.378	343	188	116	.28524	.3532
Matowa	2	12	Centrifugal pumps driven by belt from simple steam engines non-condensing	4.495	2.942	1.184	99	157	185	.27705	.5388
Wantagh	3	14	Centrifugal pumps driven by belt from simple steam engines non-condensing. Horizontal simple non-condensing direct acting	3.998	3.379	3.542	169	216	187	.27744	.4412
Massapequa	3	14	Centrifugal pumps driven by belt from simple steam engines non-condensing. Horizontal simple non-condensing direct acting	5.373	3.489	3.002	263	164	153	.24288	.4236

In order to centralize pumping and reduce the cost, nine sites for pumping in the future have been suggested and the maximum daily yield at each estimated by Mr. de Varona, as follows:

Stations.	Approximate yield 24 hours, million gallons, when running full.	Suction lift feet, plus and minus.	Delivery lift feet, plus and minus.	Total lift feet, plus and minus.
Spring Creek	8	15	8	23
Oconee	10	15	8	23
Springfield	15	15	8	23
Watt's Pond	14	15	8	23
Smith's Pond	14	15	8	23
Millburn	11	15	8	23
Merrick	12	15	8	23
Wantagh	12	15	8	23
Massapequa	17	15	8	23
Total	113	....	....	....

INFILTRATION SYSTEM AND PROPOSED MACHINERY FOR PUMPING PLANTS.

Mr. de Varona proposes that the present method of collecting ground water by means of driven wells be largely replaced by one based on the use of an infiltration gallery composed of a long line of large vitrified clay pipes varying from 20 to 36 inches in diameter, buried about parallel to the present aqueduct and at a sufficient depth below the water table to intercept the ground water and conduct it to a collecting well midway of the gallery, from which it is to be lifted by pumps into the aqueduct. The vitrified clay pipes are to be laid with joints slightly open and are to be covered over with a layer of gravel so as to allow water to enter them freely. The first plant of this kind in the Brooklyn system is now being constructed at Wantagh under the designs, specifications and supervision of Mr. de Varona. The type of pump called for by these specifications is substantially the same as that installed at the Brooklyn driven well stations in 1896 for experimental purposes during the development of the new watersheds, being of the centrifugal type, operated by belt connections from non-condensing steam engines. He proposed, however, to regard these pumps as temporary and to replace them by something better after the first year or whenever the infiltration gallery has passed beyond the experimental stage and its capacity and requirements have been proved.

The cost of pumping with these small plants equipped with this class of machinery ranges from 28.5c. per 1 million gallons 1 foot high under favorable conditions and constant operation to $1 per 1 million gallons 1 foot high under intermittent running and at least three times the cost really necessary at scattered plants of this size.

Therefore, it is recommended by this Department that the specifications for the Wantagh plant be changed so as to embody the latest design of centrifugal pump having the highest efficiency and adapted for driving by an electric motor; so that whenever the time comes to change the motive power from steam to electricity, the additional cost of equipment will be only that of the motors and their installation.

By the addition of condensers to the temporary engines, which the contractor for the Wantagh infiltration gallery is called on to furnish under the terms of his contract, the City would save about 25 per cent. of the fuel required for the operation of the plants of the character called for by the specifications. A further ultimate saving of several thousand dollars could be effected by building a permanent brick station instead of a temporary wooden building to be soon torn down and replaced by a permanent brick station after the gallery has been proved by experience.

The type of pump recommended by this Department for all such permanent low lift plants is the centrifugal, operated by an electrical motor directly connected, the current for which is to be supplied by a central plant, for which the Millburn site offers the greatest advantages in first cost and in efficiency of the transmission line.

The Cost of Pumping, Actual and Estimated.

By the construction of modern plants of the type just mentioned at all of the present driven well stations all of these plants of the present wasteful type may be superseded.

This Department estimates the cost of pumping in the proposed stations with pumps driven by electrical motors, supplied with current from a central power plant, based upon efficiency guarantees made by manufacturers of the machinery and the prevailing rate of wages, need not exceed 8½c. per 1 million gallons 1 foot high. The average cost of pumping the same amount, based upon the cost and total pumpage during the year 1896, with the pumps in the present plants, was 27c. These low lift plants are many of them subject to intermittent running, governed by the conditions of the rainfall, drought and water consumption. When the supply of surface water from the watersheds delivered into the conduits by gravity is large, following rainy weather, the pumping of ground water is regulated to make up only the amount necessary to supply the daily consumption.

The total pumpage with these small plants during the year 1896 was 16,747 million gallons against a total head of about 30 feet. During this period the aggregate cost of pumping at these small stations amounted to $138,786, of which $63,487 was for labor. The balance includes the cost of fuel, supplies, current repairs, interest and sinking fund charges.

The cost of pumping varies, of course, from month to month and year to year. with the number of men employed, the rate of wages and the cost of fuel and supplies. The coal strike in the year 1902 advanced the price of coal, and it is not fair to compare the cost of pumping during such extraordinary periods of unsettled prices with average years. For this reason, and because more recent records were not available in convenient form, the year 1896 has been taken as demonstrative of average conditions.

Importance of Having Efficient Machinery and Favorable Conditions in Order to Operate Plants at Reasonable Cost.

The importance of having efficient machinery and favorable conditions for pumping is apparent when one considers the number of times this present Brooklyn supply must be pumped before reaching the consumer. While some of the water is pumped but once, much is pumped three times and a portion four times, thus: Water from the driven wells on the easterly side of Millburn, namely, Agawan, Merrick, Matowa, Wantagh and Massapequa, is pumped from the wells into the new conduit, and thence flows to the engines in the Millburn Station. by which it is pumped to the Ridgewood Stations, and there pumped into the Ridgewood Reservoir, from which a part of the water is pumped by the engines in the Mount Prospect Station into either the Mount Prospect Reservoir or the Tower. Water so pumped costs for each 1 million gallons 1 foot high for the first pumpage with the low lift plants, about 27c.; for the second pumpage, with the Millburn plant 6½c.; for the third pumpage, with the Ridgewood plants, 5c., and for the fourth pumpage, with the Mount Prospect plant, 11c., making a total of 49.5c.

All of these costs of pumping can be reduced either by improving the efficiency of the machinery, reducing the number of men employed. or by a reduction in wages, of which the first seems to be the best way. The general line of development is so far fixed by existing structures that little can be done to lessen the number of times that these several portions of the water are pumped. The feasibility of greatly reducing the cost of pumping lies principally in the construction of new machinery to supersede the present wasteful pumping machinery in the low lift plants and in centralizing the generation of power for pumping at the scattered small low lift plants. There can also be a substantial saving made by centralizing and combining the pumping now done at Mount Prospect with that at Ridgewood.

ESTIMATED COST OF CONSTRUCTING PROPOSED PLANTS.

It is estimated by this Department that the ultimate cost of new boilers, generators, transmission, motors, pumps, buildings and accessories for pumping into the aqueduct from all of the present ground water supplies and from such surface water supplies as lie at elevations below the aqueduct, and having an aggregate daily capacity of the maximum estimated yield of these present sources, viz.: 113 million gallons daily, could be constructed for $332,000.

These estimated costs include enlarging the Millburn Station to receive the power engines and the necessary boilers for furnishing the electric current for operating pumps in the low lift stations. Nine brick stations equipped with centrifugal pumps. induction motors, transformers, switch devices, transmission line from the central plant, and either turbo alternators or generators operated by reciprocating engines installed complete with all station appurtenances and transformers.

This equipment would provide for a pumpage of 113 million gallons per day, which, if combined with the minimum yield of surface from the watersheds, is more than the present conduits can convey; so while it may not be necessary to expend so large an amount of money as this, $332,000 on the first installation, it would doubtless be best to provide space in the buildings to accommodate without future enlargement machinery for pumping the full yield of the sources and to provide at first only sufficient power and pumps to deliver say 72 million gallons daily. The estimated cost of this construction if carried out under proper designs and careful supervision. is $282,000.

The estimated saving in fuel, supplies and other expenses in pumping with the proposed plants, based upon a daily average pumpage of 45.9 million gallons against a total head of 30 feet at 8½c. per million gallons 1 foot high, would amount to $42,704, against a cost under similar conditions of $138,786 during the year 1896, which is a saving of $96,092 per year, or 69 per cent. This amount. $96,092, would pay about 30 per cent. per annum interest on the proposed expenditure.

The estimated time to complete these works is eighteen months. The power plant in the Millburn Station and the pumping plants at Merrick, Wantagh and Massapequa could be installed within one year from date of signing contract.

Gravesend and New Utrecht Plants.

The advantage of consolidating the Gravesend and New Utrecht plants was mentioned by Mr. De Varona in the report of the Department of Water Supply, Gas and Electricity, for the quarter ending September 30, 1902, and an appropriation of $100,000 was granted later in the same year to complete this work. A draft of specifications for the engines, boilers and connections for the proposed station, together with the architect's preliminary plans for the building, was submitted to this Commission on Additional Water Supply in July and turned over to this Department for inspection. These specifications and plans were returned on August 26th, 1903, with amended specifications for engines, boilers, economizers, piping and appurtenances, also preliminary drawing showing the proposed arrangement of machinery recommended by the Department Engineer of the Commission on Additional Supply.

Actual Cost of Pumping with the Present Plants at Gravesend and New Utrecht.

Year.	Station.	Average Amount Pumped, per Million Gallons, 24 Hours.	Head Pumped Against, Feet.	Cost of Fuel Delivered per Ton 2,240 Pounds.	Total Cost of Pumping.	Cost of One Million Gallons 1 Foot High.
1896	Gravesend	1.884	132.5	$3.33	$12,139	$0.1328
	New Utrecht	1.025	208.8	3.37	12,668	.1617
1899	Gravesend	2.355	154	3.64	13,861	.1190
	New Utrecht	1.209	200	3.49	13,903	.1817
1902	Gravesend	2.875	....	....	......	.1085
	New Utrecht	1.468	....	....	......	.1144

The maximum daily pumpage with engines in Gravesend and New Utrecht Stations during the year 1902 was 5.424 million gallons and the average daily pumpage 4.343 million gallons. The proposed engines for the plant to supersede these stations, each have a nominal capacity of 6½ million gallons daily, which may be increased to 7½ million gallons, Mr. de Varona's estimate of the maximum daily yield of ground water at this point.

The following estimates of cost are based on pumping 6 millon gallons daily, the probable daily consumption in the near future. For the present it does not seem necessary or advisable to purchase duplicate high duty engines for the proposed station. The specifications suggested include one triple expansion fly wheel engine capable of maintaining the highest station economy, and as an auxiliary to run in case of emergency, a new triple duplex direct-acting engine has been recommended. The estimated cost of the latter engine, erected in the proposed station, is the same as that for removing the compound direct-acting engine from the existing station at Gravesend and installing it in the proposed station suggested in the draft of specifications furnished by Mr. de Varona. The saving in fuel possible with a new auxiliary engine would be about 50 per cent. of that used by the existing compound direct-acting engine.

Estimated Cost of Pumping with Proposed Plant at Gravesend.

Average Amount Pumped, 24 Hours, Million Gallons.	Head Pumped Against, Feet.	Cost of One Million Gallons 1 Foot High.	Cost of Fuel per Ton 2,240 Pounds.	Total Yearly Cost of Pumping.
6	200	$0.0371	$4 00	$16,245

In these estimates 3 1-3 men are allowed on each eight hour watch for one engine, or 10 men in all, and the average rate of wages is $2.75 per day on each watch. The cost of coal is assumed at $4 per ton. These estimates are higher both in regard to number of men employed and in cost of coal than the costs found in regular service at sundry stations reported on in Table No. 12, being so assumed for the purpose of a conservative estimate.

The estimated saving by superseding the existing plants and centralizing the pumping for New Utrecht and Gravesend is as follows:

The combined average pumpage with the engines in the existing plants during the year 1899 was 3.564 million gallons daily, and the cost of pumping $27,764. The average pumpage for the proposed plant is taken at 6 million gallons daily and the estimated cost of pumping at $16,245, which is a saving of $11,519 per year, notwithstanding it proposes an increase of 38 per cent. in the amount of water pumped daily. The loss per day by operating the existing plants compared with the estimated cost of operating the proposed plant is $31.50.

MILLBURN PUMPING STATION.

The Millburn Station is located in the village of Baldwin, Long Island, 15 miles east of the Ridgewood plants. It contains five triple expansion direct acting engines working under an average lift of 50 feet, each having a daily nominal capacity of 10 million gallons. and two triple expansion direct acting engines, capable of working under a lift of 76.5 feet, each of 12 million gallons nominal capacity, capable of being increased to 15 million gallons. The supply of surface water from the watersheds and the pumpage from the low lift stations at Agawan, Merrick, Matowa, Wantagh and Massapequa is all pumped by these engines to the Ridgewood plants.

The average cost of pumping 1 million gallons 1 foot high with this plant is found to be 6½c. With the engines installed this year (1903), it is expected under the careful management of this station, that there will be no trouble in reducing the cost of pumping 20 per cent. A further saving in the operation could be made by providing more efficient means for heating the feed water and for furnishing dry steam to the engines. There is a strong probability of making as good a record on cost of pumping at this station as is practicable with engines of the direct acting type under similar conditions.

THE RIDGEWOOD AND MOUNT PROSPECT PUMPING STATIONS.

There are two Ridgewood plants known as the Old Station and the New Station, one on either side of Atlantic avenue, at Richmond street, in that portion of the Borough of Brooklyn known as "East New York." The old plant, constructed in 1859, was equipped with beam engines that remained in regular service until replaced in 1897 with modern engines. This station now contains pumps having an aggregate capacity of 90 million gallons daily. The new plant, started in regular service in 1891, contains pumps of 57.5 million gallons daily capacity. All of the Ridgewood pumps deliver their water into Ridgewood Reservoir at an elevation of 170 feet above tide.

The water pumped at these two Ridgewood stations comes to them through the long eastern conduits partly from the Millburn pumps and partly by gravity from the original watersheds, while a considerable portion is pumped into the conduit from the driven wells of the original watershed.

The Mount Prospect plant, located on Underhill avenue and Prospect place, Borough of Brooklyn, contains four pumps of 14.5 million gallons daily aggregate nominal capacity. These are all supplied with water from the Ridgewood Reservoir. The two larger pumps of 9 million gallons nominal aggregate daily capacity deliver into the Mount Prospect Reservoir at an elevation of 198 feet above tide and the two smaller pumps of 8 million gallons nominal aggregate daily capacity deliver into the Mount Prospect Tower at an elevation of 278 feet above tide.

COST OF REPAIRS, RIDGEWOOD AND MILLBURN PLANTS.

The costs of making repairs is high at the Ridgewood plants for both materials and labor. So far as possible, these repairs are made by employees of the Department. The organization of the pumping station forces is composed of four shifts of men, three shifts standing watches of eight hours each through the twenty-four hours, while the fourth shift works by day in the capacity of a repair force. These shifts alternate at regular intervals one with the other, the repair force changing to the operating force. This is an expensive way of attending to repairs and is less effective than if regular mechanics were employed to attend to such work. It is natural that men employed upon the repair jobs should desire to finish the work they have begun, and it is better to have them do so, in order to reduce the chances of errors and to avoid the division of responsibility.

The writer when managing pumping stations has found it more satisfactory to keep a small force of mechanics especially for repairs. These men become, by reason of their service, familiar with the pumps, boilers and miscellaneous machinery in the different plants and often prove good men to select from when needed to fill vacancies in the fire and engine rooms.

Cost of Boiler Repairs at Ridgewood and Millburn Plants During the Years 1900, 1901 *and* 1902.

	Number of Boilers.	Year Installed.	Rated Boiler Horse Power Combined.	1900.	1901.	1902.
Ridgewood (old) Plant..	8	1884	800	$5,188	$5,247	$4,845
	6	1886	600			
	10	1897	2,000			
Ridgewood (new) Plant.	6	1890	600	10,605	8,694	5,194
	4	1894	800			
Millburn Plant.........	10	1894	800	978	630	399
	2	1903	400			

At all three of the above plants the same type of boiler is used. The great difference in cost of repairs between the Millburn and Ridgewood plants is due largely to the water used in the boilers. The analysis of the water by Mr. Geo. C. Whipple, Director of the Mount Prospect Laboratory, shows that the water used for feeding boilers in the Ridgewood plants contained elements known to be detrimental to boilers, mainly chlorine from the sea water that reaches certain of the driven wells, while at Millburn the water is soft and free from deleterious ingredients. All sorts of compounds and devices for keeping the boilers from pitting and scaling have been tried at Ridgewood and the expert mechanical and chemical advice obtained, but nothing seems yet to have been found to neutralize permanently these corrosive properties. Water from Millburn, the same that is successfully used in the Millburn boilers, is delivered to the Ridgewood plant through the 48-inch pipe ending at the Ridgewood New Station and could with very small expense be substituted for the hard water now used, and this would doubtless prevent this pitting of the boiler shells, furnaces and tubes and save these expensive repairs.

COSTS OF PUMPING WITH THE RIDGEWOOD PLANTS.

Cost of Pumping 1 Million Gallons 1 Foot High, Including Fuel, Labor, Repairs, Supplies, Interest and Sinking Fund Charges.

Stations.	1899.	1900.	1901.
Ridgewood (old)	$.04607	$.04672	$.05780
Ridgewood (new)	.06583	.07597	.08030

During the years 1897 and 1898 the triple expansion high duty direct acting engines were installed in the old plant and operated in regular service. This resulted in reducing the cost of pumping about 28 per cent., compared with the cost of pumping with the beam engines during the previous year. This cost included interest and sinking fund charges amounting approximately, to $.0125 per million gallons pumped 1 foot high. Deducting this from the cost of pumping during the year 1899 shows a cost of $.03257, which is about the same as the cost of pumping with the same type of engine having the same capacity under less advantageous conditions in regard to pressure pumped against, in the Springfield Avenue Station. Chicago, Ill., during the year 1902. The increase in the cost of pumping since these engines were first installed in the Ridgewood (old) plant may be accounted for partly by increase in the wages of employees and partly by the advance in cost of coal and supplies. It is not likely that this machinery under the efficient management of the station and care it receives has deteriorated in this short time so as to cause necessarily any material difference in the efficiency of the plant. The practice of alternately operating the No. 3 beam engine in this plant reduces the station duty and consequently increases the cost of pumping. It is apparently necessary to operate the beam engine, so that the only relief is in the substitution of a new engine. Similar statements may be made in regard to increase in cost of pumping with the engines in the new Ridgewood plant. These engines are of the compound high duty direct acting type; they were installed in 1891 and 1894 and have been in regular service as required since. These engines are not of the most economical type as shown by the cost of pumping in the table. Later estimates are given showing the possible saving by superseding these engines.

MOUNT PROSPECT PLANTS.

The two beam engines in the Mount Prospect Station on the Reservoir Service are not economical and cannot be made so. The two direct acting engines on the Tower Service are delivering water as cheaply as can be expected with engines of this type. This Mount Prospect pumping plant as a whole is expensive to operate, and should be abandoned or new engines of the best modern type be provided as early as practicable.

ESTIMATED SAVING BY CHANGING PRESENT METHOD OF PUMPING.

The increased consumption in the High Service district, which includes the Reservoir and Tower Service supplied by the Mount Prospect plant, together with the wasteful type of engines now in use, make it, as suggested by Mr. de Varona, of importance both in regard to pumping the increased consumption and in due economy in cost of pumping, that new engines be provided in the present station or that the station be abandoned and the pumping done with new engines installed at Ridgewood. Mr. de Varona, in his report for the year 1902, estimated it would soon require 12 million gallons daily to supply the High Service district. Assuming this amount of water to be pumped, he estimates the saving by superseding the Mount Prospect plant, and the cost of constructing the proposed works, as follows:

Estimated cost of altering and extending the Old Ridgewood Station to receive new engines and boilers...............	$150.000
Estimated cost of two high duty engines of 15 million gallons daily capacity each, with boilers and appurtenances, for the High Service installed in the Old Ridgewood Station	210.000
Total estimated cost of altering the Old Ridgewood Station and installing new machinery specified above	$360.000
From this amount deductions are made which are chargeable to Ridgewood to offset expenses otherwise necessary at this plant within the next few years consisting of the cost of new engines for the Low Service, boilers, appurtenances and alterations to building amounting to................	$142.500
Further deductions are made for the cost of new engines required at Mount Prospect if that station were continued, and assets represented by the value of the Mount Prospect property chargeable to transfer of High Service pumping to Ridgewood amounting to......................	147.500
Making the total deductions from the cost of constructing the proposed plant at Ridgewood	$290.000

Leaving an excess of cost by making all the changes at Ridgewood and thus improving both the Low Service and the

High Service above the cost of improving the Mount Prospect plant and retaining it where it now is and installing engines at Ridgewood to provide for the increasing low service consumption.......................... $70,000

The estimated yearly saving in fuel, operating expenses and supplies by centralizing pumping at Ridgewood is estimated by Mr. de Varona as $40,610 for new high service and improving low service, which would net more than 11 per cent. annually on the estimated cost of the changes on high and low service.

Another method of changing the present system which seems to offer more advantage and proves by the estimated cost to be a better investment, would be to transpose the present new Ridgewood plant into the proposed plant by installing two 15 million gallon high duty engines for the High Service in the space now unoccupied, and extending the boiler house to receive the necessary boilers.

It is then proposed gradually to replace, as may be found necessary, the present five vertical compound engines of 10 million gallons daily capacity each by modern high duty engines of 20 million gallons daily capacity each, thus providing for future consumption in the district supplied by the Ridgewood Reservoir by engines capable of maintaining the highest station economy.

The cost of pumping with these proposed new engines of 20 million gallons daily capacity is estimated at $.045 per 1 million gallons 1 foot high, including interest and sinking fund charges, while as previously shown the costs of pumping with the present engines in the new Ridgewood plant during the years 1899, 1900 and 1901 were $.06583, $.07597 and $.08030, respectively, per million gallons 1 foot high. The average cost for these three years was $.074 per 1 million gallons 1 foot high. At this rate, assuming the daily average pumping to be 40 million gallons, which would require four engines in operation, the total average yearly cost of pumping would be $173,468. With engines of 20 million gallons daily capacity, it would be necessary only to operate two in order to supply 40 million gallons daily. The estimated total cost of pumping at the rate of $.045 per 1 million gallons 1 foot high is $110,090, which is a saving of $63,378 per year over the cost of pumping at the average rate for the years 1899, 1900, 1901.

To show the cost of remodeling the new Ridgewood plant, installing engines, boilers and appurtenances to supersede the Mount Prospect plant, and two of the present 10 million gallon engines, the following estimates have been prepared:

The estimated cost of two vertical triple expansion high duty crank and fly wheel engines of 20 million gallons daily

capacity each for the Ridgewood Reservoir Service, with boilers and appurtenances erected complete ready for operation, is	$280,000
The estimated cost of foundations, connections and miscellaneous work in removing old machinery, etc.	75,000
Total cost	$355,000
To this add the cost of two vertical triple expansion engines of 15 million gallons daily capacity each, for the High Service, boilers, appurtenances and necessary alterations to the old Ridgewood Station estimated by Mr. de Varona. These estimates are conservative for the cost of the proposed changes in the new Ridgewood Station, which will require less alterations to provide space for the new machinery	360,000
The estimated total cost of centralizing pumping at Ridgewood, now done with the Mount Prospect plant, improving the Low Service by substituting two triple expansion high duty engines and necessary boilers for two existing compound direct acting engines and their boilers and alterations to building, all complete in readiness for regular operation..	$715,000

Estimated yearly saving by this project:

By centralizing High Service pumping at Ridgewood (Mr. de Varona's estimate)	$40,410
By substitution of new engines for the Low Service in the new Ridgewood Station	63,578
Total saving	$103,988

This sum, $103,988, would pay 14½ per cent. interest annually on the estimated cost of completing the new works.

There would be a greater saving, which has not been considered in these estimates, in the cost of maintenance by the reduced expenses in labor and the smaller amount of fuel and supplies necessary in order to operate two proposed engines instead of four existing engines.

The following tables, Nos. 16, 17 and 18 show the principal dimensions of engines, type of boilers, individual capacities and pressures under which they work in the several larger stations in the Borough of Brooklyn:

Table No. 16.

Principal Dimensions of Pumping Engines, Capacities and Pressures.

New York City—Brooklyn Supply.

Ridgewood (Old).

Engine No.	Type of Engine.	Diameter of Steam Cylinders, Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger, in Inches, Double Acting.	Stroke of Steam Piston and of Pump Plunger, Inches.	Year Installed.	Manufacturer.	Steam Pressure, Lbs. Per Square Inch, Gauge.	Revolutions Per Minute for Nominal Capacity.	Nominal Capacity, 24 Hours, Million Gallons.	Total Lift, Feet.	Service Supplied.
1	Vertical triple expansion high duty direct acting........	23	36	66	33½	60	1897	Henry R. Worthington.	135	15.5	20	185	Low Service District from Ridgewood Reservoir. Elevation 170 feet above tide.
2	Vertical triple expansion high duty direct acting.........	23	36	66	33½	60	1897	"	135	11	20	185	
3	Vertical triple expansion high duty direct acting.........	23	36	65	33½	60	1899	"	135	11	20	185	
3	Vertical simple beam crank and fly wheel............	85	..	..	40 and 50½ differential.	120	1869	Hubbard & Whittaker.	20	15.5	15	174	
4	Horizontal compound direct acting....................	26	..	48	24	36	1884	M. T. Davidson........	48	20	7.5	168	
4	Horizontal compound direct acting..................	26	..	48	24	36	1884	"	48	20	7.5	168	
	Total capacity, nominal..........										90	..	

Boiler equipment, eight return tubular externally fired boilers, in brick settings, sixteen marine corrugated furnace, return flue internally fired boilers.

Ridgewood (New).

1	Vertical compound and high duty direct acting..........	25	..	50	28	48	1891	Henry R. Worthington.	110	14	10	170	Low Service District from Ridgewood Reservoir. Elevation 170 feet above tide.
2	Vertical compound and high duty direct acting.........	25	..	50	28	48	1891	"	110	14	10	170	
3	Vertical compound and high duty direct acting.........	25	..	50	28	48	1894	"	110	14	10	170	
4	Vertical compound and high duty direct acting.........	25	..	50	28	48	1894	"	110	14	10	170	
5	Vertical compound and high duty direct acting.........	25	..	50	28	48	1894	"	110	14	10	170	
6	Horizontal compound direct acting.....................	29	..	50½	22	48	1892	"	110	17.5	7.5	170	
	Total capacity, nominal..............................										57.5	..	

Boiler equipment, four return tubular externally fired boilers, in brick settings, four marine corrugated furnace, return flue internally fired boilers.

Table No 17.

Principal Dimensions of Pumping Engines, Capacities and Pressures.

New York City—Brooklyn Supply.

Mt. Prospect Station.

Engine No.	Type of Engine.	Diameter of Steam Cylinders, Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger, in Inches, all Double Acting.	Stroke of Steam Piston and of Pump Plunger, inches.	Year Installed.	Manufacturer.	Steam Pressure, Lbs. Per Square Inch, Gauge.	Revolutions Per Minute for Nominal Capacity.	Nominal Capacity, 24 Hours, Million Gallons.	Total Lift, Feet.	Service Supplied.
1	Vertical compound beam crank and fly wheel.......	26	..	18	24	42	1890	Wright...............	130	21	5	70	High Service District from Mt. Prospect Reservoir. Elevation 198.5 feet above tide.
2	Vertical simple beam crank and fly wheel............	27	..	..	23	39	1886	"	25	20	4	70	
3	Horizontal triple duplex direct acting.............	8	14	24	14	24	1894	M. T. Davidson........	130	29	2½	162	High Service District from Mt. Prospect Tower. Elevation 278.4 feet above tide.
4	Horizontal triple duplex direct acting..............	8	14	24	14	24	1894	"	130	29	2½	162	
5	Horizontal triple single direct acting..............	11½	20	24	21	24	1898	"	130	30	3	162	
	Total capacity, nominal....................................										17	..	

Boiler equipment, three marine corrugated furnace, return tubular internally fired boilers.

New Lots Station.

Engine No.	Type of Engine.	Diameter of Steam Cylinders, Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger, in Inches, all Double Acting.	Stroke of Steam Piston and of Pump Plunger, inches.	Year Installed.	Manufacturer.	Steam Pressure, Lbs. Per Square Inch, Gauge.	Revolutions Per Minute for Nominal Capacity.	Nominal Capacity, 24 Hours, Million Gallons.	Total Lift, Feet.	Service Supplied.
1	Horizontal duplex direct acting........................	18	..	32	16	24	1884	M. T. Davidson........	60	26	3	175	High Service District direct pumping. Elevations lower than Mt. Prospect Reservoir. 198.5 feet above tide.
2	Horizontal duplex direct acting	16	..	30	16	24	1896	"	60	30	3½	175	
	Total capacity, nominal....................................										6½	..	

Boiler equipment, four return tubular, externally fired boilers, in brick settings.

TABLE NO 18.

Principal Dimensions of Pumping Engines, Capacities and Pressures.

New York City—Brooklyn Supply.

Millburn Station.

Engine No.	Type of Engine.	Diameter of Steam Cylinders, Inches. High Pressure.	Diameter of Steam Cylinders, Inches. Intermediate Pressure.	Diameter of Steam Cylinders, Inches. Low Pressure.	Diameter of Pump Plunger, in Inches, All Double Acting.	Stroke of Steam Piston and of Pump Plunger, Inches.	Year Installed.	Manufacturer.	Steam Pressure, Lbs. Per Square Inch, Gauge.	Revolutions Per Minute for Nominal Capacity.	Nominal Capacity, 24 Hours, Million Gallons.	Total Lift, Feet.	Service Supplied.
1	Horizontal triple direct acting	11½	20	36	36	36	1892	M. T. Davidson	125	22	10	56	Water from this section is all pumped to the Ridgewood Station.
2	Horizontal triple direct acting	11½	20	36	36	36	1892	"	125	22	10	56	
3	Horizontal triple direct acting	11½	20	36	36	36	1892	"	125	22	10	56	
4	Horizontal triple direct acting	11½	20	36	36	36	1892	"	125	22	10	56	
5	Horizontal triple direct acting	11½	20	36	36	36	1892	"	125	22	10	56	
6	Horizontal triple expansion direct acting	13	21	34	30	24	1903	Henry R. Worthington.	125	30–37.5	12–15	76.5	
7	Horizontal triple expansion direct acting	13	21	34	30	24	1903	"	125	30–37.5	12–15	76.5	
	Total capacity, nominal									74–80	....	....	

Boiler equipment, twelve marine corrugated furnace, return flue internally fired boilers.

TABLE No. 18—*Continued.*

New Utrecht Station.

Engine No.	Type of Engine.	Diameter of Steam Cylinders. Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger in Inches. All Double Acting.	Stroke of Steam Piston and of Pump Plunger. Inches.	Year Installed.	Manufacturers.	Steam Pressure, lbs. per sq. in. Gage.	Revolutions per Minute for Nominal Capacity.	Nominal Capacity 24 hours. Million Gallons.	Total Lift. Feet.	Service Supplied.
1	Horizontal compound direct acting	15	..	30	15	18	1885	Henry R. Worthington.	70	27	2	200	High Service District direct pumping. Elevations lower than Mt. Prospect Reservoir. 198.5 feet above tide.
2	Horizontal compound direct acting	15	..	30	15	18	1885	"	70	27	2	200	
3	Horizontal non-condensing single direct acting	18	..	..	12	24	1885	Knowles	70	45	1½	200	
	Total capacity, nominal										5½	..	

Boiler equipment, three return tubular externally fired boilers, in brick settings.

Gravesend Station.

Engine No.	Type of Engine.	Diameter of Steam Cylinders. Inches. High Pressure.	Intermediate Pressure.	Low Pressure.	Diameter of Pump Plunger in Inches. All Double Acting.	Stroke of Steam Piston and of Pump Plunger. Inches.	Year Installed.	Manufacturers.	Steam Pressure, lbs. per sq. in. Gage.	Revolutions per Minute for Nominal Capacity.	Nominal Capacity 24 hours. Million Gallons.	Total Lift. Feet.	Service Supplied.
1	Horizontal compound direct acting	12	..	22	14	18	1890	Henry R. Worthington.	70	30	2	158	Low Service District direct pumping. Elevations lower than Ridgewood Reservoir. 170 feet above tide.
2	Horizontal compound direct acting	16	..	30	19	24	1892	Dean, Holyoke, Mass.	70	32	5	158	
	Total capacity, nominal										7	..	

Boiler equipment, three return tubular externally fired boilers, in brick settings.

APPENDIX IX.

Water Waste Investigations.

Appendix IX.

WATER WASTE INVESTIGATIONS.

In brief outline, the method followed in these investigations consisted in measuring the rate of draft of water at every hour day and night for a period of about a week, in each of twelve carefully selected typical districts, averaging not far from one-quarter to one-half a square mile in area, and meanwhile making a house-to-house inspection within the district for leaks of plumbing fixtures.

The water supply pipes of this district under test were meanwhile cut off so far as possible from the pipes of the adjacent territory. This was accomplished by closing the gate valves in the streets along the border line of this district so that the water could enter the district under examination only by a single pipe: or if so complete a cut-off was impracticable, by reason of main arteries passing across the district or from any other cause, the number of lines of pipe left open to feed the district was made the smallest possible. On each open pipe was placed a metering instrument called a pitometer, by which the rate of delivery of water into this district was measured and recorded continuously hour by hour and minute by minute. The flow thus measured comprised both the use and the waste. By comparing the night flow with the day flow, and granting that under ordinary conditions little water is really used between 2 A. M. and 4 A. M., an inference can be drawn as to the proportion of use and waste. To further separate the waste from the use a house-to-house inspection of leaky plumbing fixtures was made and the rate of each leak found was measured.

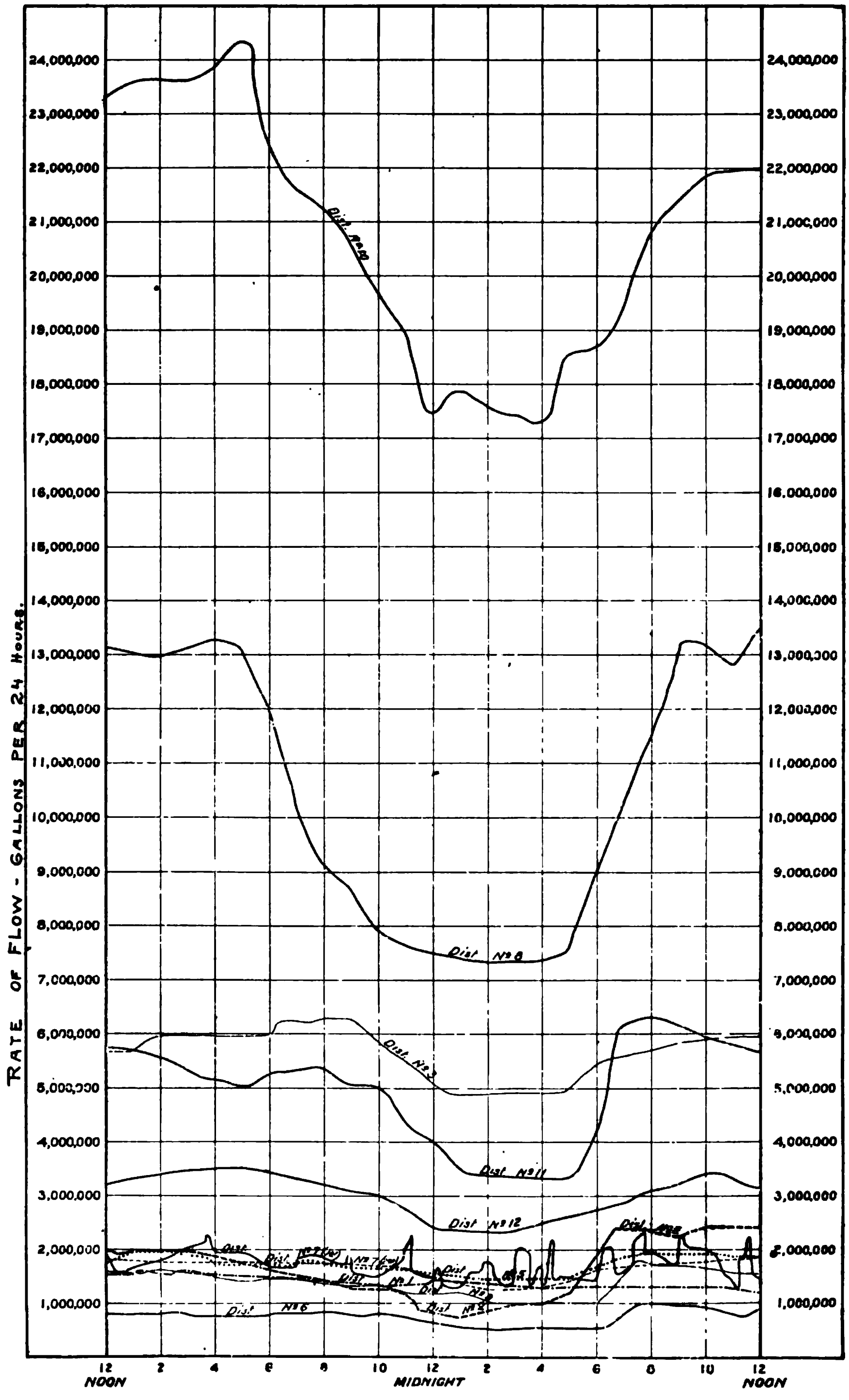


PLATE 1. APP. IX.

Typical Curves showing hourly variation in Rate of Consumption in Various Districts. From pitometer measurements; exclusive of Sundays.

Concerning the Field Work and Force.

This work was planned in outline in November, 1902, by N. S. Hill, Jr., Chief Engineer of the Department of Water Supply, Gas and Electricity. The field work of pitometer measurement began in December, 1902, under the general supervision of Edward S. Cole, Civil Engineer, inventor of the pitometer, and the computations were kept well up to date by the observers devoting their time to this work in the intervals between the field measurements and while pipe gangs were preparing new districts.

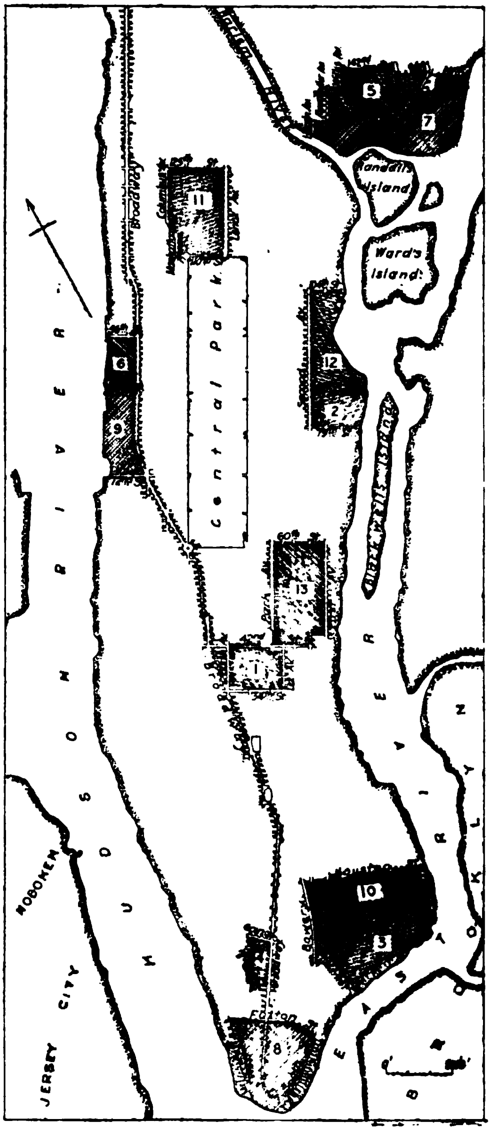
The force consisted of the "floating pipe-repair gang No. 2" of the Water Department, which comprised about eight men under an experienced foreman, who has worked for 30 years on the distribution system and in nearly all parts of Manhattan. This gang was under the supervision of Assistant Engineer John E. Deignan, of the Water Department, who has had experience in charge of repairs and shut-offs for more than 10 years. These men set the pitometer taps and the street boxes; repaired and replaced valves; made shut-offs, and inspected sewers at night in connection with the water waste investigation. These men also carried on repair work of the Department, which sometimes required their absence from the pitometer work for several days at a time.

The house-to-house inspection of fixtures and the measurement of leaks was made by a force of from 10 to 20 men, detailed from the office of the Water Registrar, most of whom were new men taken on under Civil Service rules for this work. The Registrar's office also supplied as required three or four "meter readers," who made night readings of several of the large service meters, commonly at from 12 to 20 typical places in each district.

The statistics of frontage rates, metered water, number of families, etc., were compiled and furnished by the regular forces of the Water Registrar's office.

After a district had been marked out on the map, the first work was to examine the valves on the border line, to see if they were in working condition and to set new valves or repair defective valves. This work, as stated above, was done by members of one of the "floating gangs" ordinarily devoted to emergency repairs. Meanwhile another portion of the pipe-gang prepared the place for setting the pitometer.

A gang of about four men could uncover the pipe and set a gauge pit consisting of a 4-foot cubical box of 2-inch plank, and tap the pipe, in from one to two days. Two experienced pitometer observers could set up and adjust four or more pitometers in a day. A barricade about 8 feet square was set around the pit. The pit box was protected by a 2-inch cover, which was kept shut and locked, except while the pitometer observers were at the instrument. In the most crowded streets a watchman was kept stationed


HUDSON RIVER
Central Park
Ward's Island
JERSEY CITY
HOBOKEN
EAST RIVER
BROOKLYN
Broadway
1
2
3
5
6
7
8
9
10
11
12
13

at the barricade around the pit all of the time during the day while the instrument was in use.

The pitometer, when once set up and adjusted, was maintained, taking a continuous record of the flow into the district for nearly a week.

After the close of the week's measurement in a district the pits were immediately filled up and the paving replaced.

In general, in a district where the gate valves were found in fairly good order, from one to two weeks' time would be occupied in preparing the pits, tapping the pipe, and inspecting and closing the gates around the border, so that, including the time required for adjusting and observing the pitometers, from two to three weeks would be expended in the measurements over one district.

Selection of Districts Metered.

Much careful investigation had to be devoted to selecting these districts and to marking out their border lines. The effort was to select districts having a fairly uniform class of buildings and occupancy, in order that the results might be representative and capable of intelligent application to other large areas of similar occupancy.

One district comprised several of the principal hotels, and had a large transient population; in another district large quantities of water were drawn for railroad use. Another comprised a down town business district teeming with life in office buildings and commercial establishments by day, but comparatively deserted by night; one district was supplied by a comparatively recent system of street mains, and another comprised many of the oldest water mains in the City, some of them being uncoated pipes laid in low, wet ground near salt water, where the largest amount of corrosion and leakage would naturally be expected. Of the residence districts examined two were chiefly occupied by very expensive residences, while two of the other districts embraced chiefly the poorer east side tenements.

Much difficulty and delay were sometimes involved in working out the practical lines of shut-off because this necessitated knowledge of the location of all gate valves along the border, the repairing of any gates found defective, and in many instances the isolation of the district required the cutting in of new gates. In one of the districts selected for study (No. 4), measurements had to be abandoned because of the large number of water gates found broken. Outside screw gates with iron screws have been largely used in the distribution pipe system of Manhattan. The most of these gates are now old, and it is not strange that many were found with their wrought iron screws so rusty as to be inoperative.

The Work So Far Accomplished.

The 12 districts investigated cover in the aggregate nearly two square miles and comprise nearly 12 per cent. of the entire area of Manhattan and The Bronx, exclusive of the sparsely settled territory in the northern portion of Bronx Borough.

The results of these measurements are presented in the following table and are instructive notwithstanding that they leave the questions concerning the reasons for the large night draft, and where it goes to, without a definite and conclusive answer.

The cut immediately following the table expresses graphically the relative quantities of metered water, unmetered water and fixture leakage, as stated in the table:

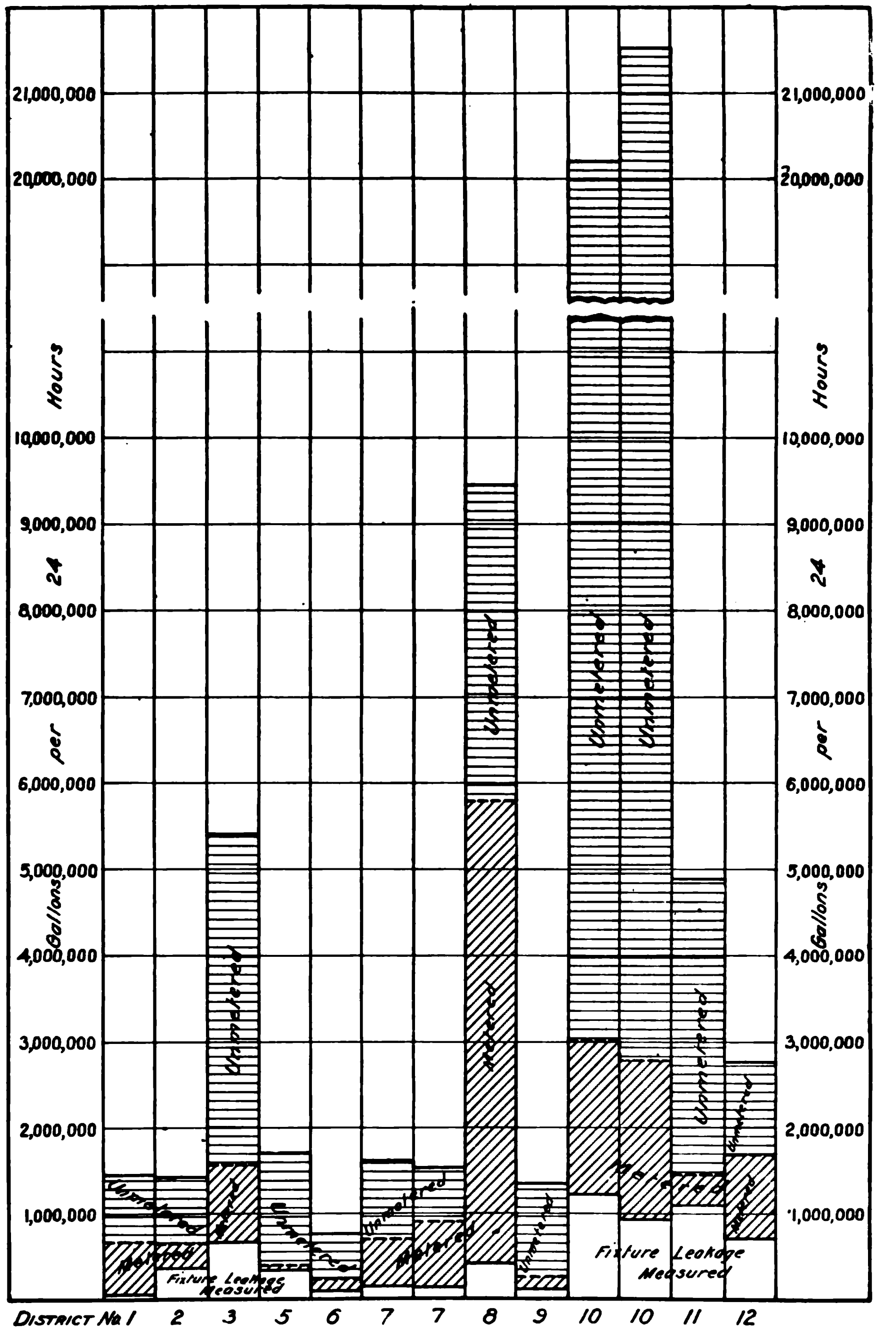


PLATE II. APP. IX.

Relative Proportions of Water supplied through Service Meters and the Unmetred Supply—also of the total quantity of fixture leakage found in the house-to-house inspection, in the several Typical Districts Investigated.

Notes Upon Completeness of Cut-off at Boundary of District.

The boundary line of the average district was perhaps two miles in length, and a water main ran through nearly every cross street that this boundary intersected, and thus from ten to fifty or more of these cross mains, according to the size of the district, had to be cut off by closing their gate valves before the isolation of the district was complete.

Obviously it was important to be certain that all of these valves were shut tight, save those of the mains on which the pitometers were set. Under the peculiar conditions found in Manhattan it was not deemed prudent to make a test of tightness of this cut-off *as a whole*, according to the method commonly practiced in connection with district metering, which consists in also closing the feed gate for a few moments after midnight, meanwhile noting the rate of drop of pressure within the district and perhaps meanwhile opening a hydrant on high ground to make sure that the water is not standing in the house supply risers under a head higher than the street level.

Along the border line of the district the completeness of closing of those gates having outside screws was determined by counting the turns on the scew, and noting if its top stood flush with the nut when the gate was turned down hard. Where gate was of the inside screw pattern the inspector also temporarily closed the gate next farther inward and tested an intermediate hydrant for drop of pressure while the gates were both shut, and the same test was also applied to a majority of the outside screw gates on the border line. Some gates were found with stems broken off so as to indicate " shut " while gate was open, and some the reverse of this, but with outside screw gates obviously no gate could be open while the screw was down.

It is stated that all of this work of cutting out the districts was under the excellent supervision of an Assistant Engineer who has had more than ten years' experience in looking after pipe repairs in Manhattan, assisted by a pipe repair foreman who has had thirty years' experience on the Manhattan pipes, and that the gates were closed by experienced men under the direct charge of a foreman and that in any case of doubtful working the gate was opened and reseated several times.

While it might perhaps be claimed that there was no absolute test of the completeness of the isolation of any district, Mr. Hill, Mr. Cole, Mr. Deignan and others in direct daily contact with this work, express their personal confidence that the cut-off was substantially complete at every known water gate around the boundary line and nothing has so far appeared in the discussion of the tests which discredits this view.

Comparisons of Night and Day Pressures in Waste Districts, Manhattan and The Bronx, December, 1903.

District Number.	Location.	Lbs.					
1..	S. W. corner 35th street and Park avenue	31	2.35	A. M.	17	2.45	P. M.
	S. E. " 38th street and Park avenue	23	2.42	"	15	2.42	"
2..	S. E. corner 84th street and Avenue A	21½	1.25	"	19	1.25	"
	S. E. " 83d street and Second avenue	28	1.40	"	21	1.40	"
3..	S. W. corner Rutgers street and East Broadway	29	1.07	"	23	1.07	"
	S. E. " Jackson and Grand streets	27	1.17	"	20	1.17	"
4..	S. E. corner Reade street and West Broadway	32½	12.35	"	out of service.	12	"
	S. S. Beach street, opposite St. John's lane	37	12.45	"	30	12.45	"
5..	N. S. 138th street, east of Southern Boulevard	36½	12.05	"	35	12.05	"
	W. S. St. Ann's avenue, south of Southern Boulevard	34½	12.30	"	36	12.36	"
	N. S. Southern Boulevard, between Willis avenue and Brown place	35	12.50	"	27	12.50	"
6..	N. E. corner 89th street and West End avenue	41	11.40	"	36	11.40	"
	W. S. Broadway, between 92d and 93d streets	38	11.51	"	34	11.51	"
7..	N. W. corner 136th street and Willis avenue	24½	11.12	"	20	11.05	"
	N. E. " " "	24½	11.15	"	20	11.15	"
	N. E. corner 142d street and Willis avenue	34	11.34	"	30	11.35	"
	W. S. St. Ann's avenue, south of 142d street	33	11.40	"	30	11.40	"
8..	S. W. corner Broadway and Liberty street	26½	11.45	"	17	11.45	"
	W. S. State street, south of Bridge street	35½	11.55	"	24	11.55	"
9..	W. S. Broadway, between 81st and 82d streets	43½	11.20	"	31	11.20	"
	E. S. West End avenue, between 82d and 83d streets	47½	11.26	"	41	11.28	"
10..	S. E. corner Forsyth and Canal streets	22	1.00	"	16	1 00	"
	W. S. Cannon street, between Brown and Delancey	33	1.25	"	25	1.25	"
	N. W. corner Houston street and Second avenue	25	1.43	"	18	1.45	"
11..	N. E corner 111th street and Manhattan avenue	28½	12.10	"	27	12.07	"
	N. E. " 116th " "	33½	12.24	"	32	12.20	"
	N. W. " 124th street and Eighth avenue	38½	12.30	"	38	12.30	"
	N. W. " 123d street and Lenox avenue	37½	12.40	"	36	12.40	"
12..	N. E. corner 103d street and Second avenue	38½	1.07	"	25	1.00	"
	N. E. " 86th street and First avenue	25	1. 5	"	22½	1.15	"
13..	N. W. corner 45th street and Third avenue	29	2.55	"	25	2.55	"
	N. S. 57th street, between Lexington and Third avenues	29	3.05	"	26	3.05	"
14..	S. E. corner Eighth avenue and 15th street	35	2.10	"	28	2.10	"
	N. W. " Seventh avenue and 28th street	32	2.25	"	26	2.25	"

Difference in Pressure on the Two Sides of Boundary Line of District.

While this was not observed with great fullness of detail or with great precision the notes set forth in the preceding and following tables show the general relation to have been as follows:

The pressure within a district was commonly smaller than without, because of the cutting off of so many feed lines; but this relation often varied in the same district at different parts of the border line and varied at different hours of the day. The actual difference of pressure inside of the district during the test as compared with the water pressure in the adjacent territory outside the district is seen to have been commonly not more than one or two pounds per square inch. In two or three districts the pressure inside the line of shut-off may have been three to five pounds per square inch less than outside. During the test in District No. 1 the inside pressure was slightly *higher* than in much of the adjoining territory, by reason of the temporary diversion of a supply that ordinarily passed through it to a district beyond, and the same was true of District No. 3.

PITOMETER BOX

AT BROADWAY AND FULTON STREET.

In general, this difference of water pressure on the two sides of the boundary line of the districts was so small that the possible flow of water through any closed but leaky gates along this border line must have been comparatively small.

Day Pressures—Before and After Closing Districts.

District.	Before Closing.	After Closing.
1 W. S. Madison avenue, between 37th and 38th streets	5¼ lbs.	9 lbs.
2. S. E. corner 84th street and Avenue "A"	19½ "	19½ "
3. N. E. corner Market and South streets	30½ "	28½ "
South street, west of Pike street	29½ "	31 "
Pike street, north of South street	29 "	30 "
Rutger street, north of South street	29½ "	30½ "
Rutger street, south of South street	28¾ "	29½ "
Jefferson street, north of South street	29 "	30 "
5. St. Ann's avenue, south of 141st street	24 "	27 "
136th street and Willis avenue	22 "	24 "
137th street, between Willis avenue and Brown place	19½ "	21 "
6. Broadway and 92d street	29 "	26 "
7. 138th street, east of Southern Boulevard	35 "	35 "
St. Ann's avenue, south of Southern Boulevard	29½ "	31 "
8. Cedar street, east of Broadway	18 "	18 "
9. N. E. corner 75th street and West End avenue	23¾ "	23 "
10. N. E. corner Cannon and Grand streets	18¾ "	16 "
Cannon street, between Rivington and Stanton streets	24 "	21 "
Mangin street, between Grand and Broome streets	20¼ "	25¼ "
11. N. W. corner 124th street and Seventh avenue	38½ "	38½ "
S. E. corner 124th street and Seventh avenue	35 "	34 "
St. Nicholas avenue, between 123d and 124th streets	37¼ "	34 "
111th street, between Seventh and Eighth avenues	29½ "	24 "
N. E. corner 111th street and Seventh avenue	33 "	28½ "
12. 104th street and First avenue	33 "	28½ "
13. 56th street and First avenue	20½ "	20 "
45th street and First avenue	24¾ "	25 "
Second avenue and 43d street	18¾ "	17 "

Possibility of Undiscovered Open Pipes.

Considering the incomplete system of pipe plans and records prevailing heretofore for many years, and the frequent changes of pipes and services required with the rapid growth and rebuilding of the city, there may be a remote chance in one or more of the districts that an old and forgotten so-called "temporary" connection, interfered with the completeness of the cut-off.

In a few of the districts the opportunity for small undiscovered connections exists through large buildings near the border lines which have double service connections from two streets into a single house system, without check valves. These double services are rare except in case of factories and large buildings in the down-town districts.

Effect of Flow Across the District Boundary Through Leaky Gates or Open Pipes.

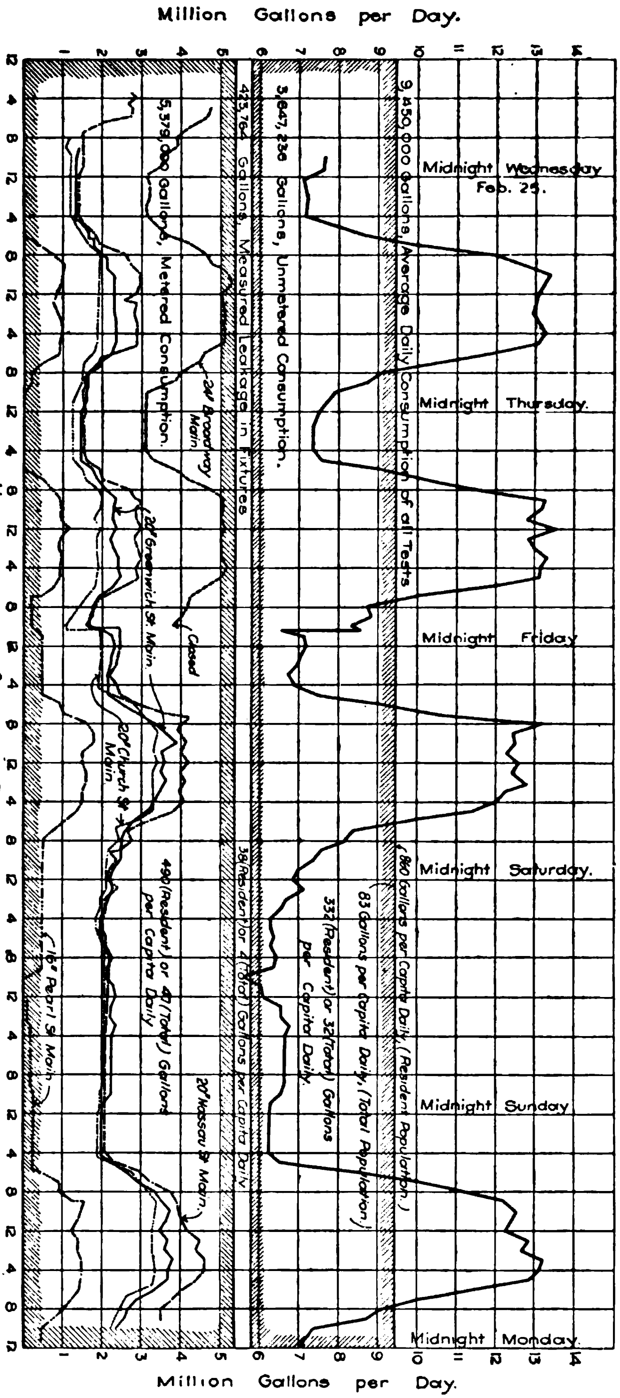
While in considering the degree of certainty afforded by these measurements it has appeared best to discuss the effect of any possible undiscovered open pipe, it should be distinctly understood that it is highly improbable that any such existed, save perhaps some rather small double service connections in District No. 8.

The effect of any undiscovered open pipe entering the district under test would be simply that of an unmetered feed pipe, and if such existed in any district where there was a lower pressure inside than outside its boundary line, the total consumption in that district as computed from the pitometer observations is too small by the amount of this inflow. In any case where the inside pressure was the higher, as in District No. 1, this condition is reversed, and if there was any undiscovered open pipe the unrecorded total consumption was too large.

Any such undiscovered opening would seldom largely modify the relation between the rate of flow at 4 A. M. and that at 10 A. M., but would tend toward equalizing the curve for the district in question with that of the surrounding territory, and would also tend to cause some underestimate of the leakage. For example, within District No. 8, after isolating a sub-district along portions of Liberty street, West street and Washington street, in order to determine if there was an excessive night flow such as might be caused by leaks from these very old street mains and the old service pipes connected with them, it was found that the excess of the pitometered night flow over that accounted for by the house meters was very small, and the inference from this is that these old mains are substantially tight. If, however, there was some undiscovered open connection this may have let in water sufficient to supply whatever leakage there was from these mains.

Save where there was some abnormal draft immediately outside the district and near to the assumed undiscovered open pipe, the probability is that with two channels open, one being the pitometered channel, and the other an assumed undiscovered channel, the rate of flow in both would follow substantially the same curve from hour to hour, and it is probable that the two supplies would increase and decrease proportionally to each other, and this being so, the curve recorded by the pitometer in the feed pipe would correctly indicate the relative hourly variation in flow for the whole district.

This relation is illustrated by the series of curves presented below taken from the several pitometers used simultaneously in supplying District No. 8. It is seen that the rate of delivery of most of the different inlets from hour to hour varies proportionally, but that this is not an absolute rule is illustrated by the curve for the 16-inch Pearl street main, in which there was almost no



RESULTS OF WATER WASTE INVESTIGATION IN DISTRICT NO. 8.

velocity at night, although it showed a large flow by day, and is also illustrated by the 12-inch main to District No. 10, which had a flow in opposite directions at different hours of the twenty-four.

It is plain that undiscovered connections across the boundary would in general tend to smooth out the characteristics of the curve of hourly variation of consumption for a given district and to bring it toward the average of the surrounding territory, and, because of the pressure commonly being smaller inside than outside the district the tendency of an undiscovered opening ordinarily would be to cause the measurement by a district meter to underestimate the consumption.

Notes on the Method of District Metering.

Having a district isolated, the method of investigation began in a way somewhat similar to that followed in the water waste investigations made by the aid of the Deacon meter in Liverpool, England; Boston, Mass., and elsewhere; but for reasons to be stated later the present measurements in New York had to be less complete. As already stated, the method consists in measuring the rate of flow of water into this district continuously throughout the 24 hours and continuing this for about a week if practicable, thus obtaining the rate of consumption of this particular district in the most quiet hours of the night for comparison with that in the busy hours of the day, and obtaining by the week's run the rate on Saturday and Sunday for comparison with the rate of consumption on other days. The metering instrument makes a record in the form of a chart, showing this rate of delivery of water, from which many inferences as to the relative proportions of consumption and leakage can be derived when this curve is interpreted by experience and knowledge of the general habits of the consumers, especially so if it be granted that the real use of water occurs mainly during ordinary working hours, and that the flow measured between 3 and 4 A. M. consists mainly of leakage.

The summation of the average daily rate of flow for each hour shown by this chart gives the total volume delivered into the district in gallons per 24 hours.

Unfortunately for the work of waste detection in New York by any form of district meter there are four important details of the local conditions in water service pipes and plumbing which differ from what is found elsewhere and interfere with the location and measurement of the leakage.

1st. The universal absence of curb stop cocks.

2d. The large size of the house tanks.

3d. The frequent absence of any ball cock from the house tank.

4th. The inability to shut off all inflow to small districts at night from the fear of collapsing some of the water heaters used for bath and laundry purposes, or causing other damage to those who have to use water at night if the pressure were shut off temporarily after midnight for an hour or so from a city block, in order to note the effect of the closing and opening of this pipe upon the chart recorded by the district meter, and thereby measuring the flow and waste through such individual main pipe or in this block.

Absence of Curb-Stop Cocks Lessens Utility of Method.

It was the absence of the curb-stop cock, we are told, that interfered with the use of the Deacon meter purchased many years ago by the New York Department of Water Supply for use in waste detection. In Liverpool and Boston, where such excellent work has been done in the past with the Deacon meter, and in Terre Haute, Indiana, where the practical value of the pitometer was first demonstrated, the curb-stop proved an important adjunct, for by shutting off the service pipes along a street after midnight, one after another, keeping note of the time at each, and then later opening one after the other at stated intervals, a comparison of these times of shut-off with the time of change in rate of flow shown by the autographic chart of the district meter serves to identify those times when a service pipe was closed or opened and locates it for further investigation and house inspection. The use of a "waterphone" attachment to the valve wrench aids in distinguishing those services through which water waste or night supply is passing.

The Chief Engineer of the Department of Water Supply has recently begun the work of putting in curb-stop cocks.

The Refilling of House Tanks Tends to Obscure Indications of District Meter.

The refilling of house tanks in New York after midnight obscures the night leakage to an extent which it is extremely difficult to estimate.

Were it not for this possibility that an uncertain number of house tanks were still in process of being replenished it would be practically certain that by far the greater part of the night flow measured into the ordinary resi-

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The following case illustrates waste through the overflow pipe of a house tank. Some years ago a meter was first attached to the Engineers' Club at No. 374 Fifth avenue, and the water consumption found surprisingly large notwithstanding that the plumbing fixtures were found tight. A further investigation was then made which showed that leakage through the tank overflow had been going on doubtless for years. On stopping this the consumption shown by the water meter was immediately reduced to about one-third its former monthly rate.

dence district by the pitometer or other district meter from 3 A. M. to 4 A. M. was leakage, because of the well-known fact that less than one in twenty of the population is working or using water at these hours, and that the great suburban population which makes serious demands on the water supply during the day is then absent.

An effort was made by Mr. N. S. Hill, Jr., Chief Engineer, to obtain some estimate of the effect of these tanks upon the night draft. In the course of the house-to-house inspection nearly all of the tanks in each district were inspected and measured. It was obviously impracticable to inspect the height of water in any large number of these tanks by night, to see whether or not they were still refilling after midnight.

The regular day inspectors were instructed to look for a water line at the overflow level, and in general these water marks were found there, thus plainly showing that waste occurs. A ball cock properly set would shut off all farther inflow at several inches below the level of the overflow pipe.

This extensive use of house tanks was formerly encouraged by the Department of Water Supply, as a result of the failure of the City pressure to reach the upper stories during the day, particularly during those periods prior to the completion of the new Croton aqueduct, where the pressure had to be throttled to check consumption, and again, when because of failure to provide high service pumps of capacity sufficient to keep pace with the remarkable growth of population and increased height of buildings in up-town residence districts, so that the pressure by day fell one or two stories, and again, during a period of outgrown main arteries to the down-town districts prior to the laying of additional mains in 1897-8.

The aggregate tankage reaches a surprising amount. The average size for dwellings and tenements appears to be about 1,500 gallons per building, and as the average consumption for these buildings is less than 4,000 gallons per day, it will be seen that the average tank holds 40 per cent. of a day's full supply. If all tanks were nearly emptied by day and refilled by night, this would account for a large night draft; but this refilling *late at night* probably takes place at only a small proportion of all the tanks.

A partial inspection of the thousands of record sheets turned in by the house-to-house inspection shows that in general the tanks were found not more than one-quarter to one-third empty when inspected in the afternoon, and we may confidently assume that in the majority of cases, the conditions of draft, the size of the service pipe, and the pressure on the City pipes was sufficient to cause these to refill before midnight.

The police patrol are said to have in sundry cases reported sound of flow at night in the rain water leaders from the roof, which probably came from tank overflow.

For obtaining a more precise conception of that hour in the twenty-four at which the refilling of most of the tanks will be complete it will be convenient to group these tanks into four classes.

(*a*) The gravity tanks set just below the night water level, and in a portion of the City where pressure is largely drawn down by day so that they cannot refill until the pressure rises after the heaviest rate of draft is over.

(*b*) The gravity tanks which set low enough so that the City water pressure can refill them at any hour of the day.

The chief purpose of these tanks is to supply water during a brief period in larger volume than the city service pipe will deliver it. As soon as the excessive rate of draft stops the tank begins to refill and nearly all such tanks probably refill before midnight.

(*c*) Tanks in dwellings set above the height to which the city water will rise, and filled by small house pumps of the hot air or the electric type. These commonly will be refilled during working hours and the pump shut down before the household retires or before midnight.

(*d*) Tanks in factories and large office buildings. The great majority of these are probably filled during ordinary working hours.

The tanks most likely to be refilling late at night are the house tanks set close to the level reached by the night pressure and are in sections of the City where the day pressure in the street mains is below the tank level.

On seeking to consult an hourly curve of pressures for each pitometer district in order to learn the hour when high pressure was restored in each district, it was found these pressures had not been measured as is customary because of the gauge spring furnished with the instrument not having happened to be well adapted for the range of pressures in New York.

The figures on numbers of house tanks given in the table happen to have been made up without distinguishing between gravity tanks and pump tanks, and the present data are insufficient for distributing the tank capacity according to the groups just noted.

Absence of Ball Cocks.

The absence of ball cocks on the house tanks also works against the precision of estimation on constant leakage by means of a measurement of the flow into a district found at say 3 to 4 A. M.; for obviously waste caused by the absence of a ball cock on a house tank begins only after the tank has become refilled, and is not substantially uniform throughout the twenty-four hours, like leakage from defective plumbing fixtures, or like leaks from a bad joint in street mains, or like the leaks resulting from electrolysis.

Conditions of waste at tanks supplied by gravity from City pressure direct will be different from those with tanks supplied by house pumps. There are said to be more than 8,000 small house pumps in use in Manhattan, mostly of the hot air type. These are used chiefly for supplying stories above the level of the City pressure, and for these tanks it is customary to use a tell-tale consisting of a small lead pipe leaving the tank at a point commonly a few inches below the level of the overflow pipe. This tell-tale pipe leads to some convenient sink, or drain, near the pump, and when water runs from it, the janitor is supposed to stop the pump.

In another class of house tank the filling is done under gravity pressure through a pipe the valve of which is operated by hand. Some of these are fitted with tell-tales of the type just described.*

The Pitometer.

The instrument selected for use as the district meter in all of these investigations was the Cole-Flad Pitometer.

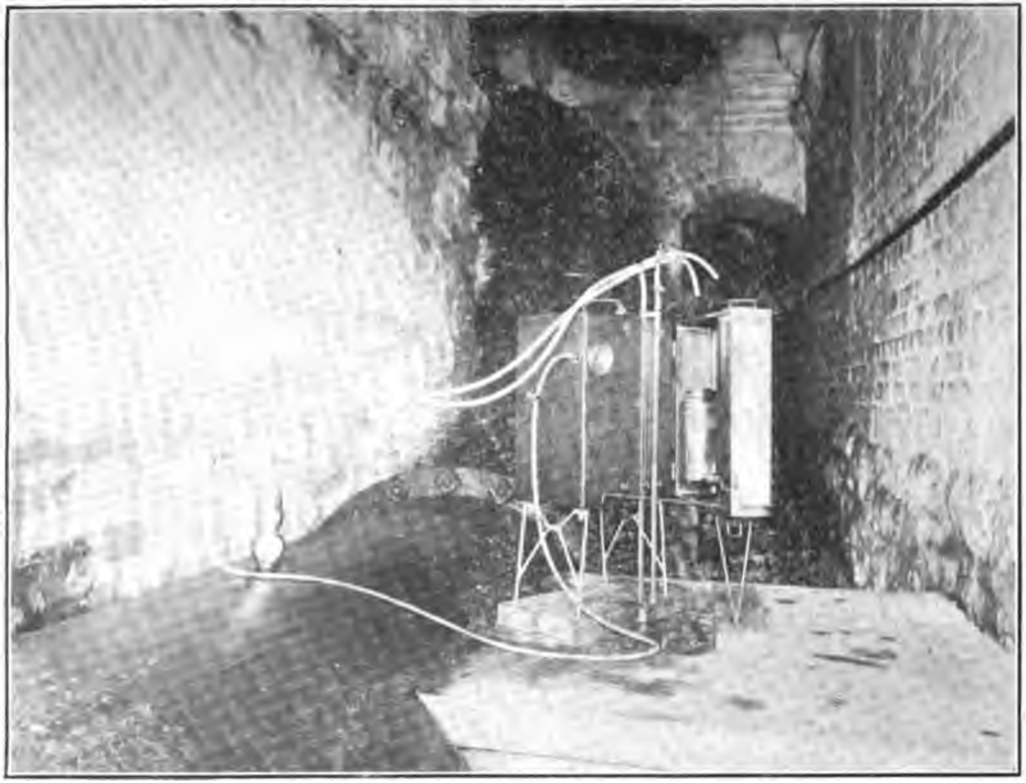
Its low cost of installation as compared with a Deacon meter or Venturi meter and its extreme portability, and the ease and quickness with which it can be attached to any water main, make it valuable when in expert hands, for temporary work of this kind.

The instrument has proved satisfactory in these New York tests. From three to six pitometers have been in regular use upon the water waste surveys in Manhattan and The Bronx much of the time during the past year, and four in Brooklyn during the past six months, all these pitometers being leased temporarily from the inventor and operated under his personal supervision.

A photograph of the instrument is shown above.

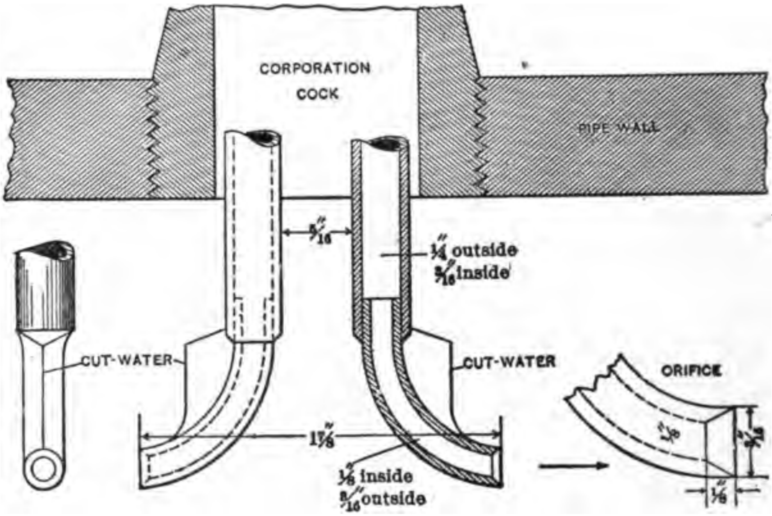
This meter works on the well-known principle of Pitot's tube and consists in fact of a pair of Pitot's tubes, which can be inserted in the street water main through an ordinary one-inch corporation cock. The pressure within these tubes is communicated to a glass U tube and recorded photographically by appropriate attachments.

* It is understood that an order has been issused by the Water Department to householders, requesting that ball cocks be placed at all places where they were found lacking in the course of a house-to-house inspection.



THE PITOMETER ON 36-INCH MAIN IN CHICAGO.
FOURTEENTH STREET PUMPING STATION.

The corporation cock for introducing the tubes can be quickly attached to a water main under pressure, by the ordinary service tapping machine.



Details of Pitometer Orifices.

The tubes are of brass ¼-inch outside diameter, 3-16-inch inside diamter, with an orifice at the end ⅛-inch diameter. One tube of the pair points directly upstream, and the other directly downstream.

The velocity of the water in the street main by impinging against the upstream tube tends to increase the pressure in that branch of the pitometer while it tends to lessen the pressure in that branch turned downstream, and the difference in pressure in the two tubes being proportional to the square of the velocity serves to measure this velocity, the coefficint of the instrument having been previously determined. Tests have shown the actual velocity to be very nearly 80 per cent. of the theoretical velocity corresponding to these differences of head between the tubes.

Since with a small velocity this difference in head if measured by a water column would be inconveniently small for precise and rapid observation, the ingenious expedient is adopted of connecting the two Pitot tubes by short, upward-sloping rubber tubes to the two branches of a glass U tube partially filled with a liquid heavier than water. Carbon tetrachloride of about specific gravity 1.5 is commonly used, and is diluted to specific gravity 1.25 by gasoline, or some other hydrocarbon. The water from the rubber connecting tubes, pressing on top of this, forces the line of demarcation between the two liquids up or down according to the pressure, and if liquid of

1.25 specific gravity is used, it multiplies the range of motion to four times what it would be if water and air were used in the glass tubes for measuring the pressure.

The first set of measurements taken with the pitometer after it has been set up and any air bubbles blown out from the connecting tubes, and the whole apparatus properly adjusted, is a determination of the distribution of velocities across the diameter of the pipe, by inserting the point of instrument to varying depths and noting the velocity at each point. From a plotted curve of these velocities across the section the relation of mean velocity to the maximum velocity is determined.

Throughout the subsequent observations the point of the instrument is set at the position of maximum velocity and maintained there. This point of miximum velocity is commonly found to coincide with the center of the pipe. Typical curves of distribution of velocity found in the street mains through which several of the districts were fed are presented below, the curve of observed velocity heads and the curve of distribution of velocity deduced therefrom being given, also the limits of the rings into which the area of cross section of pipe was divided for integration of the curve to obtain the total quantity flowing and the mean velocity of the cross section.

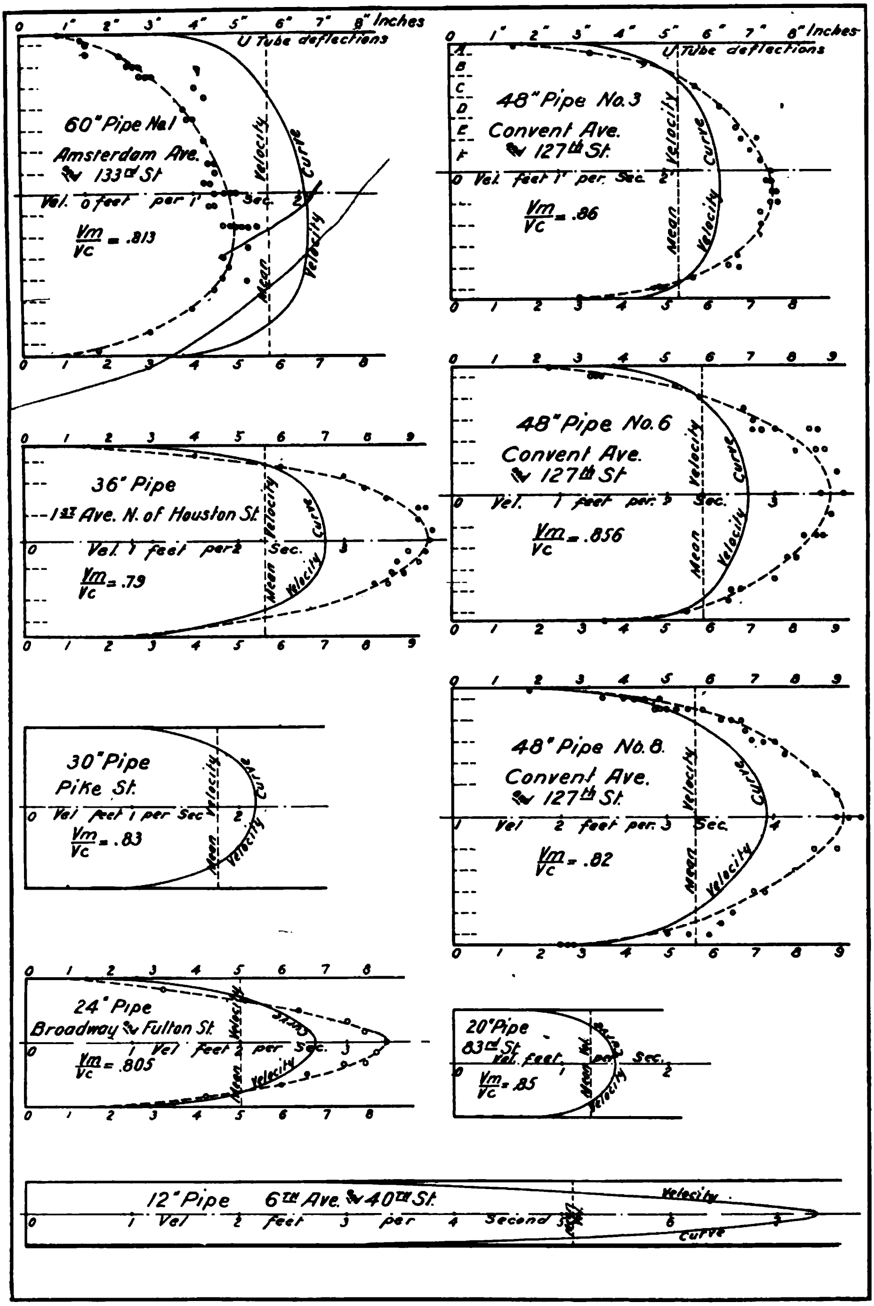


PLATE III. APP. IX.

Typical Curves showing Distribution of Velocity in Cross Section of Pipe.

The full-line curves show velocities, the dotted line curves show the Pitometer U-Tube deflections.

The ratio of mean velocity to maximum velocity found at the different stations was as follows:

Velocity Ratios Obtained by a Pitometer Traverse at Each Supply Pipe.

District No.	Location of Pitometer.	Direction of Flow "In" or "Out."	Nominal Size of Main.	Approximate Date Laid.	Ratio of Mean Velocity to Maximum Velocity by Pipe Traverse.
			Ins.		
1	Fortieth street west of Sixth avenue	In	12	1873	.70
2	Eighty-third street and Second avenue	"	20	New.	.85
3	Pike street west of East Broadway	"	30	1878	.83
5	One Hundred and Thirty-eighth street west of Southern Boulevard	"	12	1881	...
6	Ninety-sixth street and Broadway	"	12	1879	.79
7	One Hundred and Thirty-eighth street east of Southern Boulevard	"	12	1831	.75
7	Lincoln avenue and Southern Boulevard	"	12	1885	.75
8	Church and Fulton streets	"	20	1876	.81
8	Broadway and Fulton streets	"	24	1841	.80
8	Nassau and Fulton streets	"	20	1876	.80
8	Pearl and Fulton streets	"	16	1843	.79
8	Greenwich and Fulton streets	"	20	1898	.77
9	Eighty-sixth street west side of Broadway	"	12	1879	.82
10	Pike street (see above)	"	30	1878	.83
10	Canal street east of Bowery	In and Out.	20	1882	.80
10	First avenue north of Houston street	In	36	1878	.79
10	Avenue A north of First street	"	30	....	.80
11	One Hundred and Twenty-fourth street and Lenox avenue	"	12	....	.84
11	One Hundred and Twenty-fourth street and Seventh avenue	"	12	....	.85
11	One Hundred and Twenty-fourth street and Eighth avenue	"	12	....	.76
12	Second avenue south of Eighty-sixth street	In (N.)	12	....	.81
12	Second avenue and 104th street	Out and In.	12	....	.81

Since many of the pipes are obstructed and reduced in area by an incrustation of tubercles, the actual diameter of the pipe was measured so far as practicable by noting the distance on the instrument tubes when gently pushed against the side opposite from the corporation cock, and again when withdrawn until the "cutwater" was in contact with the surface of the pipe at the corporation cock.

With a pipe badly tuberculated, the general tendency of this measurement would be to slightly overestimate the net effective area, because of the end of the measure falling between the tubercles at the opposite side, and also because any tubercle close to the corporation cock would naturally be detached in the operation of tapping. This margin of uncertainty is fortunately small, because of the questionable area being at the ring of least velocity. An error of ¼-inch in the diameter of a 12-inch pipe would cause an overestimate of quantity of only about 2½ per cent., and in general the possible error from this cause must have been smaller than this.

Districts Nos. 1, 2, 5, 6 and 9 were each fed by a single 12-inch pipe.

District No. 7 was fed by two 12-inch pipes.

District No. 11 was fed by three 12-inch pipes.

District No. 8 was fed by three 20-inch and one 16-inch.

District No. 10 was fed by two 30-inch, one 36-inch, while one 20-inch ran at times to supply territory beyond and at other times fed in.

District No. 12 was fed by one 12-inch, and a 12-inch which sometimes ran outward, although most of the time feeding inward.

District No. 3 was fed by a single 30-inch pipe.

In case of negative flow, or reversed motion, the instrument records and measures with equal accuracy, and in District No. 10, one of the 12-inch pipes sometimes gave an inward flow and sometimes an outward flow.

The Continuous Record of Rate of Flow.

One of the most novel and ingenious features of the pitometer is its recording apparatus. A photograph of a typical chart made by the instrument is presented herewith.

All friction and all back lash of mechanism for recording the velocity head is avoided by application of the principle of photography. A sheet of ordinary " Velox " sensitized photo print paper is slowly revolved by clockwork on a drum behind one leg of the U tube gauge, through which a thin beam of light is projected from a lamp. The heavy liquid in the bottom of the U tube is rendered opaque by coloring matter while the water above it remains transparent, and thus the line of demarcation between the liquids in the U tube is traced on the paper by the beam of light, needing only the ordinary process of photo-print development to bring it out and record it permanently.

A scale of U tube deflections is marked autographically on the chart by notches in the shield, and a paper scale is readily prepared, by which the velocity or rate of discharge in gallons can be read off directly from any part of this curve.

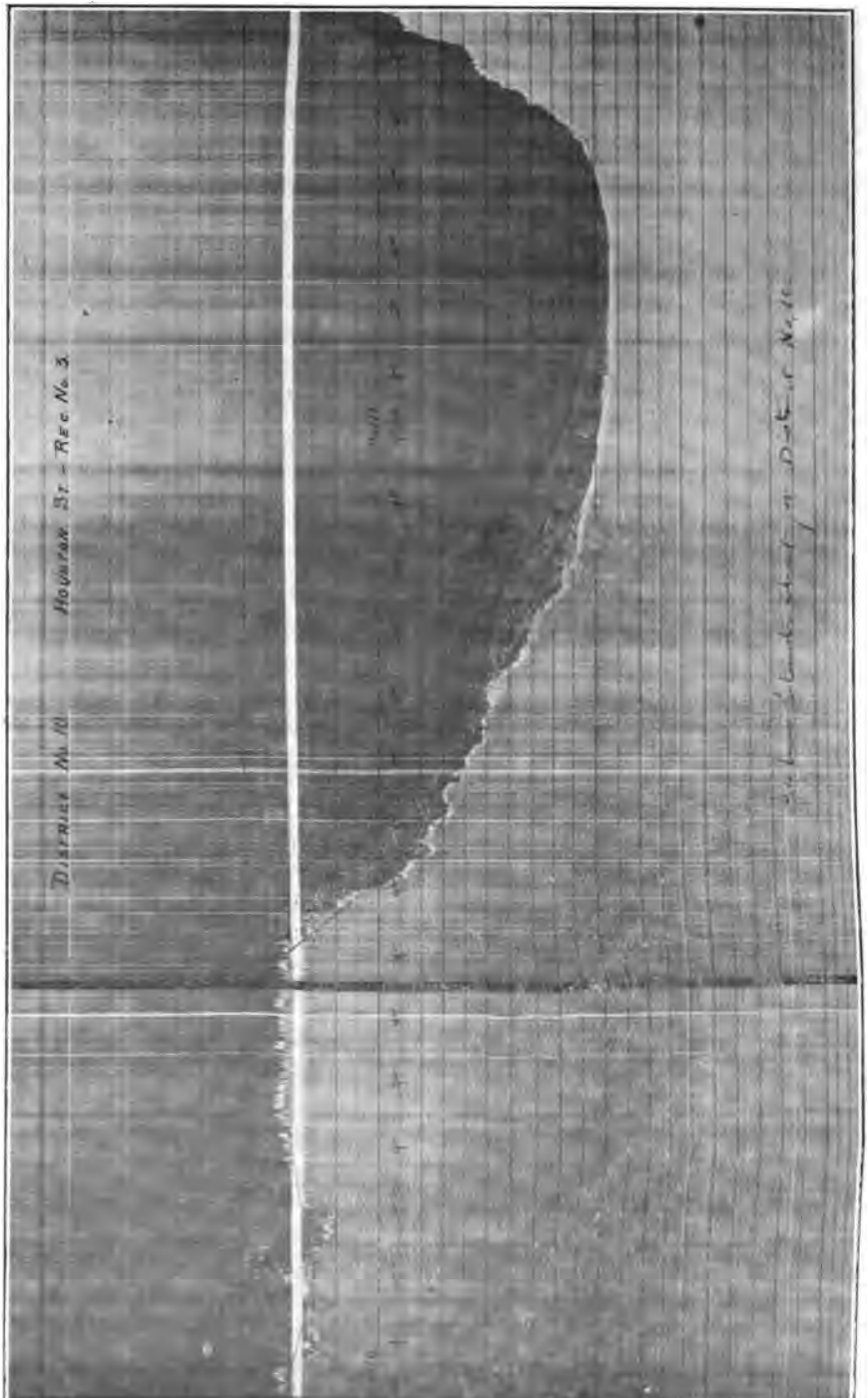
Another gauge index is so arranged as to record the pressure in pounds per square inch existing in the pipe by a line upon the same chart.

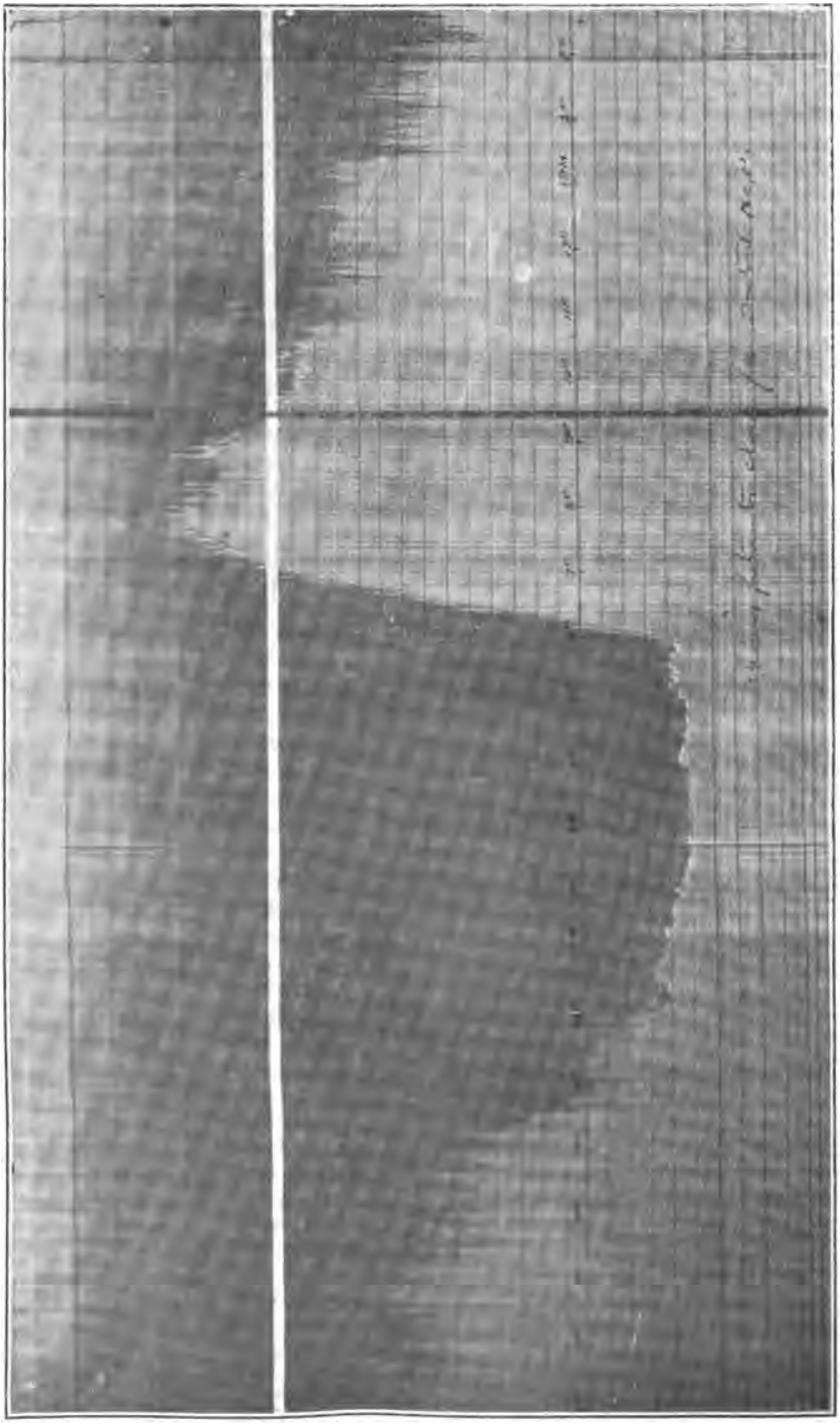
From this known velocity in a pipe of given size the rate of flow in gallons per minute, or per twenty-four hours, is readily computed.

A typical chart of velocity from hour to hour for District No. 11 is given here in addition to that shown for District No. 10.

House-to-House Inspection.

The inspectors went through each house in the district looking for obvious leaks at each sink, water closet and bath room; measuring each so far as practicable by catching the water leaking in a half-pint cup while counting the seconds and estimating the leaks that could not be caught.


District No 10
Rec No 3



Every leak found was measured or estimated and recorded. These inspectors also measured the size of the house tank and noted the presence or absence of a ball cock upon it. If the tank was sufficiently accessible they noted if there was a water-mark around the tank at the level of the overflow, and noted how far below the overflow the water in the tank was at the hour of inspection. They also noted if the tank was fed by a " goose-neck " over the top, or by a pipe entering the bottom, and noted the presence or absence of a house pump, and in one district, No. 8, they counted the number of fixtures and made a special census of the occupancy. The most of these statistics are presented in the table below.

They did this work faithfully and well for new men, but they cannot be expected to have had all the shrewdness in ferreting out obscure leaks that comes after long practice, or the skill in quickly discovering by-passes that would be laid by an experienced plumber. The Superintendent of Water Works in a city not far from New York, where remarkable results in lessening the water waste have been accomplished states that " it takes a year of training to make a good water-waste inspector."

Sewer Inspections.

In the effort to account for the night flow where the sewer itself was too small to be entered, or the flow of water too large to permit passing through it, lanterns were lowered into the next manhole beyond, so that a view could be had from one to the next. On the main sewers the manholes are said to average only about 100 feet apart, and on the pipe sewers only about 50 feet apart, and the house spurs enter the sewer above the center, thus affording a good opportunity for observation. The sewers in each district under test were entered after midnight and, so far as practicable, an examination was made of the amount of water entering from each house connection. In each district every manhole was entered. This branch of the field work was under the supervision of Mr. John E. Deignan, whose efficiency is so highly commended by Mr. N. S. Hill, Jr., Chief Engineer, that there is no reason to think that this unpleasant branch of the work was shirked. In some districts bordering the docks the tide-water prevented a complete traverse of the sewers.

Along those sewers which could be entered the effort was to inspect every house spur at its entrance to the street sewer at some time during the three or four hours after midnight, and to record all noticeable flows, and to locate the spur showing leakage by measurement from the nearest manhole. In general, each building has one spur and there are few cases where two buildings are drained by the same sewer spur. Obviously, no precise estimate of the volume of these leaks was practicable, and, as stated above, not all sewers could be traversed. In every case where a sewer could be entered a count was made of the number of spurs found leaking, but no count was made of the number not leaking. While large flows were found in some of the main sewers at night, it happened that these sewers had their origin outside the district, and that the flow appeared to come from outside the territory under special investigation.

District No. 1, the Murray Hill section, was almost the only one in which summits of main sewers were found or which did not receive sewage from points outside the district. In the residential portions of No. 1 the sewers were found almost dry after midnight.

The general impression gathered by Mr. Deignan, the Assistant Engineer in charge of this inspection, was that the volume of leakage found in the sewer spurs of the residence districts at night was small, and the inference would be that the large night flow measured by the pitometers went largely into refilling tanks, but this cannot yet be accepted as conclusively demonstrated.

It would have been interesting to select a few typical districts in which the summits and course of the sewers would permit making the limits of a sewer district coincide with those of a water pipe district, and where a thorough inspection of the sewers was practicable and then to gauge the sewer flow continuously over a weir with a recording clock gauge coincidently with the pitometer measurement of the flow of water into the district. but there has so far been no opportunity for this.

Block by Block Shut-offs.

This was attempted only in the eastern part of District No. 1 on eight residential streets, each for one block in length. The method followed was to select blocks just inside the boundary of the district, and on one at a time shut the gate at the inward end, one block away from the closed gate, forming a point on the boundary line. Men stationed at this outer gate opened it a moment after the inner gate had been seated, thus permitting only a very brief drop of pressure and not inviting the collapse of any house boiler or other damage from depriving a house of water. This work was done after 1 A. M., and in no case did the closing of the inner gate cause any noticeable drop in the rate of flow into the district, and after the entire group of blocks had been shut out the pitometer chart shows the same rate of night flow as before. This indicates that this group of houses draw little or no water for any purpose at this hour, and that their tanks had previously become full. Other evidence that the street mains and service pipes of this portion of this district are tight is found in the fact that an inspection of the sewers of the immediate vicinity is said to have shown them almost dry.

A Sunday inspection of a few typical house tanks on high ground in District No. 1 was made in order to see if they had become refilled. In a number of instances they were still in process of filling—and apparently some of them have their top so near the night hydraulic grade line, if not above it, that it is doubtful if they ever become filled.

In the two districts, Nos. 7 and 8, which are almost wholly occupied by buildings of character requiring meters under the present rules and laws, the service meters account for only about one-half of the flow measured into the district by the pitometers. This can only be explained in two ways, namely, a large amount of leakage from mains and service pipes outside the meters, or a large use of water surreptitiously through services which should be metered and are not. Probably a part of the discrepancy is due to each cause. The existence of defective meters which underregister may also help to explain it.

Finally, it must be stated that the investigations thus far made are not complete enough in their details to afford a satisfactory explanation of where a majority of the large night flow goes to, and the present data for determining what goes into refilling tanks after midnight does not yet warrant saying that half of this goes into tanks, and does not yet successfully dispute the claim that much more than half of this night flow may not be leakage.

APPENDIX X.

Organization and Force Employed.

Appendix X.

ORGANIZATION AND FORCE EMPLOYED.

The personnel of the office organization of the Commission and of the six Engineering Departments, including only the Department Engineers, the Principal Assistant Engineers and Assistant Engineers, was the following:

OFFICE.

George E. Perrine, Engineer-Secretary.
Ralph F. Nye, Clerk.

AQUEDUCT DEPARTMENT.

E. G. Hopson, Department Engineer.
F. E. Winsor, Principal Assistant Engineer (Field).
Fred. F. Moore, Principal Assistant Engineer (Office).
Chas. E. Trout, Assistant Engineer.
W. H. Herschel, Assistant Engineer.
J. L. Davis, Assistant Engineer.
Wm. M. Stodder, Assistant Engineer.

CATSKILL DEPARTMENT.

Walter H. Sears, Department Engineer.
D. W. Cole, Principal Assistant Engineer.
A. D. Nickerson, Assistant Engineer.
H. E. Abbott, Assistant Engineer.
Geo. C. Mills, Assistant Engineer.
Sidney K. Clapp, Assistant Engineer.

FILTRATION DEPARTMENT.

Wm. B. Fuller, Department Engineer.
John H. Gregory, Principal Assistant Engineer (Office).
T. H. Wiggin, Principal Assistant Engineer (Field).
G. D. Holmes, Assistant Engineer.
George E. Howe, Assistant Engineer.
A. W. Tidd, Assistant Engineer.
A. U. Whitson, Assistant Engineer.

CHEMICAL AND BIOLOGICAL DEPARTMENT.

George C. Whipple, Department Engineer.
George A. Johnson, Principal Assistant Engineer (Field).
Langdon Pearse, Principal Assistant Engineer (Laboratory).
R. R. Bradbury, Assistant (Field).
George A. Shute, Assistant (Field).
Daniel D. Jackson, Chief Chemist.
P. Schuyler Miller, Chemist.
Luther R. Sawin, Bacteriologist.
Edward P. Walters, Bacteriologist.

LONG ISLAND DEPARTMENT.

W. E. Spear, Department Engineer.
W. W. Peabody, Principal Assistant Engineer.
Geo. L. Hosmer, Assistant Engineer.
Roy S. Barker, } Superintendent Well Borings (successively).
Edward A. Clark, }

DEPARTMENT OF PUMPING.

Will J. Sando, Department Engineer.

The average total force employed by the Commission during the summer of 1903 was as follows:

6	Department Engineers.
8	Principal Assistant Engineers.
14	Assistant Engineers.
25	Draughtsmen and Computers.
9	Transitmen.
10	Levelers.
13	Rodmen.
12	Chainmen.
12	Axemen.
8	Test Well Foremen.
23	Laborers.
6	Stenographers and Typewriters.
4	Chemists.
6	Biologists.
5	Inspectors.
39	Sample Collectors and Gauge Readers.
200	