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PRELIMINARY INVESTIGATIONS AND SURVEYS FOR INCREASING THE WATER SUPPLY OF THE DISTRICT OF COLUMBIA.

LETTER

FROM

THE SECRETARY OF WAR,

TRANSMITTING,

WITH A LETTER FROM THE CHIEF OF ENGINEERS, REPORT ON PRELIMINARY INVESTIGATIONS AND SURVEYS FOR INCREASING THE WATER SUPPLY OF THE DISTRICT OF COLUMBIA, AS CALLED FOR BY THE ACT OF CONGRESS APPROVED MAY 26, 1908, MAKING APPROPRIATIONS FOR THE DISTRICT OF COLUMBIA FOR THE FISCAL YEAR ENDING JUNE 30, 1909.

December 15, 1909.—Referred to the Committee on the District of Columbia and ordered to be printed, with accompanying illustrations.

War Department,
Washington, December 13, 1909.

Sir: I have the honor to transmit herewith a letter from the Chief of Engineers, U. S. Army, dated October 1, 1909, together with copy of report, with illustrations, from Maj. Jay J. Morrow, Corps of Engineers, dated July 8, 1909, upon preliminary investigations and surveys for increasing the water supply of the District of Columbia, made by him in compliance with the provisions of the act of Congress approved May 26, 1908, making appropriations for the District of Columbia for the fiscal year ending June 30, 1909.

Very respectfully,

J. M. Dickinson,
Secretary of War.

The Speaker of the House of Representatives.

War Department,
Office of the Chief of Engineers,
Washington, October 1, 1909.

Sir: I have the honor to submit herewith for transmission to Congress a report of July 8, 1909, with illustrations, by Maj. Jay J. Morrow, Corps of Engineers, on the preliminary investigations and surveys for increasing the water supply of the District of Columbia, as called for by the act of Congress approved May 26, 1908, making appropriations for the District of Columbia for the fiscal year ending June 30, 1909.

I concur in the opinion of the District officer.

Very respectfully,

W. L. MARSHALL,
Chief of Engineers, U. S. Army.

The SECRETARY OF WAR.

PRELIMINARY INVESTIGATIONS AND SURVEYS FOR INCREASING THE WATER SUPPLY OF THE DISTRICT OF COLUMBIA.

UNITED STATES ENGINEER OFFICE,
Washington, D. C., July 8, 1909.

SIR: I have the honor to submit the following report, in compliance with instructions contained in letter dated Office of the Chief of Engineers, U. S. Army, Washington, June 5, 1908, assigning to my predecessor in this office the duty of making the preliminary investigations and surveys for increasing the water supply of the District of Columbia, as called for by the act making appropriations for the District of Columbia for the fiscal year ending June 30, 1909, approved May 26, 1908:

DESCRIPTION OF PRESENT SYSTEM.

The present plant for supplying the city of Washington with water consists of a diversion dam in the Potomac River at Great Falls, a gravity conduit from Great Falls to Dalecarlia reservoir, a gravity conduit from Dalecarlia reservoir to Georgetown reservoir, a pressure conduit from Georgetown reservoir to McMillan Park reservoir, and a pumping plant at McMillan Park reservoir, lifting the water through a height of from 20 to 30 feet to the filter beds. It is then carried by gravity mains to the District's pumping station, on Bryant street, whence it is disposed of by the officials of the District of Columbia, in part by pumping for higher services and in part by gravity in lower services.

The project for the first work originated with Capt. M. C. Meigs, Corps of Engineers, U. S. Army, in 1852 and 1853, and the first appropriation was made in the act approved March 3, 1853, appropriating $100,000. Under this project it was proposed to build a dam at Great Falls, a receiving reservoir at Dalecarlia, and a distributing reservoir on the heights beyond Georgetown. The necessary legal right was given to the Federal Government by act of legislature of the State of Maryland, in May, 1853. The aqueduct, according to this project, was so far completed in 1859 that the water from the receiving reservoir was available and turned into the mains, utilizing water only from Little Falls branch. From the distributing reservoir one 30-inch and one 12-inch main were projected, being considered ample for the supply for some years after the completion of the aqueduct. As the demand increased a 36-inch main was added in 1873 and a 48-inch main in 1890. The conduit was completed and the water supplied from the Potomac in December, 1863, since which date the system has been in successful operation. In 1886 the dam at Great Falls, which had been a riprap dam, extending across the Maryland channel only, was replaced by a masonry structure which covered the entire channel, its top at a level of 148 feet above mean tide water. Finally, in 1896, this dam was raised 2½ feet. In the year 1901 there was completed a tunnel leading from the Georgetown reservoir to McMillan Park reservoir, situated between Howard University and Soldiers' Home, which reservoir was also completed in 1901. During the years 1903 to 1905 the filter beds at McMillan Park were constructed, which provide now for filtering the entire water supply of the District.

The conduit, in a general way, consists of about 15 miles of conduit and tunnel and flow through 3 reservoirs, 2 of which are provided with by-conduits. The conduit itself is a 9-foot tube, for the most part of brick masonry, but partly in its rock tunnel sections unlined, the unlined sections aggregating 3,700 linear feet, which, of course, could only be lined with extreme difficulty until a new conduit is built. There are on the line of the tunnel 26 culverts, nearly all in made ground, the failure of any one of which would break the conduit for a short period.

CAPACITY OF THE CONDUIT.

In 1896–97 a very careful study of the flow in the aqueduct was made by Capt. (now Lieut. Col.) David DuB. Gaillard, Corps of Engineers, U. S. Army, the details of which are reported in full in the Annual Report of the Chief of Engineers for 1897. Briefly stated, he found the ultimate capacity of the system at the lowest stages of the Potomac River to be about 76,500,000 gallons per day, with the water in the Georgetown reservoir standing at an elevation of 144. At that time the Georgetown reservoir was the distributing reservoir—a function now filled by McMillan Park reservoir—and Captain Gaillard's studies did not include any consideration of the maximum quantity the aqueduct would deliver with the water in the Georgetown reservoir at a lower level. A careful study has been made in the progress of the investigations just completed as to the present capacity of the aqueduct system, the details of which are given in the appendices. It suffices here to state that with levels established approximately as follows:

Manhole No. 1 (near Great Falls intake)	150.5
Dalecarlia reservoir	142.6
Georgetown reservoir	140.25
McMillan Park reservoir	137.5

a supply of 87,500,000 gallons per day was obtained, which would seem to justify the conclusion that the aqueduct system as it now stands will discharge approximately 90,000,000 gallons per day as a maximum, but that this high rate of discharge can be obtained only by the drawing down of the reservoirs to such an extent as to practically exhaust them as storage basins. The aqueduct can, however, be operated with a mean discharge of 80,000,000 gallons per day or more, leaving the reservoirs available for reserve supply.

SCOPE OF PRESENT INVESTIGATIONS.

In accordance with project approved by the Chief of Engineers, U. S. Army, June 17, 1908, to Mr. F. F. Longley, assistant superintendent of the filtration plant, was assigned the duty of making the necessary surveys, detailed studies, and plans, under the direction of this office, to carry into effect the law. Following these instructions, Mr. Longley submitted to this office a report, which is attached hereto in full with all appendices and which covers in greater or less detail the entire field, and gives studies into the advantages and disadvantages of the following projects:

First. An additional supply from the Potomac River, to be taken from the river at Great Falls, to be carried by gravity through a new conduit to McMillan Park reservoir, and then pumped to the present filter beds, in all essentials a system differing only slightly from the present supply.

Second. An additional supply from the Potomac River, to be taken from the river at Little Falls, to be delivered by pumping into Dalecarlia reservoir and carried thence by gravity through a new conduit to McMillan Park reservoir, and then pumped to the present filter beds, the construction between Dalecarlia and McMillan Park reservoirs being the same as proposed in the first project.

Third. An additional supply from the Potomac River, to be taken from the river at some point south of Aqueduct Bridge, to be delivered by pumping to McMillan Park reservoir, and then pumped to the present filter beds.

Fourth. A supply from Rock Creek, to be taken from the creek at a point just north of military road, and either delivered by conduit to the filter beds (without necessity of pumping from McMillan Park reservoir) or purified by new filter beds located in Rock Creek valley at the dam site, and delivering into the city mains at the elevation of the present flow line of the first high service.

Fifth. A supply from Seneca Creek, which flows into the Potomac River about 8½ miles above Great Falls, to be impounded in the creek at an elevation with sufficient head to allow for purification in additional filters and delivery by gravity into the city mains at an elevation at least as high as the present flow line of the first high service.

Sixth. A supply from ground-water sources, to be obtained by sinking deep wells to water-bearing strata.

Seventh. The suggested popular plan of a supply from the upper branches of the Potomac River was also briefly considered, the water to be taken from the river at a point over 100 miles above the city and delivered by a gravity conduit to the filter plant at McMillan Park.

As the work of Mr. Longley was nearing completion this office called into consultation Mr. Allen Hazen, consulting civil engineer, of great experience in work of this nature, to review the work done and suggest such modifications as to him might seem proper. His final report was submitted on June 28 and is forwarded herewith.

In addition to the projects studied by Mr. Longley, the project for obtaining a supply from Patuxent River, Maryland, a valley a few miles north of the District of Columbia, to be taken from the river at a point near the crossing of the Columbia turnpike and delivered by pipe line and conduit by gravity to the filter beds at McMillan Park, without passing through McMillan Park reservoir, was suggested in May by Mr. Hazen, and with the little time and funds at command it was briefly examined.

In addition to a study of these projects, studies were also made of the following methods for providing for increasing the capacity of the present conduit:

First. By raising the crest of the dam at Great Falls, by either permanent construction, to an additional height of 2½ feet, or by a raising only at periods of minimum discharge to an additional height of not to exceed 2 feet by the use of flashboards, designed to be carried away at freshet stages.

Second. By the construction of a pumping station at Dalecarlia reservoir, to pump the water not exceeding 6 feet in height, thus increasing the hydraulic gradient with a resultant slight increase in capacity of the present conduit.

Besides these studies looking toward an increase in the capacity of present conduit, a study was made of accomplishing much the same result by cutting off largely the waste of water by a complete and thorough application of meters to all services.

A study was also made looking toward the providing of additional storage for the water supply by the construction of a new reservoir at some point on the old or proposed new conduit. This study also included consideration of the necessity of preliminary treatment of the water by sedimentation or coagulation in both the present and the proposed new works.

All these matters are presented in detail in the reports of Mr. Longley and Mr. Hazen, hereto appended, with drawings.

The projects for increasing the water supply by any of the methods studied excepting by a gravity supply from Great Falls and by a gravity supply from the Patuxent River (the first and last of the projects previously enumerated) can be dismissed from consideration for reasons fully detailed in Mr. Longley's report. Briefly given, the second (pumping from Little Falls), the third (pumping from Washington Harbor), the fifth (gravity supply from Seneca Creek), and the seventh (supply from upper branches of Potomac) are rejected as showing considerably greater cost without compensating advantages. The fourth (supply from Rock Creek) is rejected because of insufficiency of supply, prohibitive value of real estate, and the opposition that would doubtless arise to the submergence of so large an area in Rock Creek Park. The sixth (ground water supplies) is rejected because it is doubtful if a sufficient supply could be so obtained, and practically certain that if it could be obtained, it would be uneconomical as compared with the other plans.

PROJECTS FOR INCREASING SUPPLY.

Of the projects for increasing the supply but two remain for favorable consideration—the first contemplating additional supply from Potomac River to be taken from the river at Great Falls, to be carried by gravity through the new conduit to McMillan Park reservoir and then pumped to the present filter beds. The Potomac River at Great Falls has a minimum flow approximately ten times as great as the present consumption of the water in the District, and the United States has a right to a large enough portion of this flow to supply more than twice the present consumption. The existing aqueduct dam holds the water at a level suitable for the supply of this additional quantity. For the most part the right of way of the old aqueduct is wide enough for the location of a new line within its limits.

The general route followed by the old aqueduct is the only surface route at the proper grade between Great Falls and Georgetown reservoir. It would be entirely feasible to locate another aqueduct parallel with the first to run almost its whole length. There can be no question but that an alternative route should be selected if feasible, in order to reduce to a minimum the chance of a single accident or hostile military operation disabling both conduits. Careful studies have been made of all possible divergent routes between the same two termini. Between Dalecarlia and McMillan Park reservoirs a new line has been found which could be recommended for economical reasons alone, being shorter than the old route, and possessing the great advantage of having all its tunnel sections at grade. But above Dalecarlia reservoir the separation of the two lines offers extreme difficulties. Above Cabin Johns a location can be found that would be shorter, but it would be considerably more expensive, being largely in tunnel. From Cabin Johns Bridge south a separate line would have to be not only wholly in tunnel but materially longer.

The proposed location of the parallel route is described as follows: From Great Falls to a point near the Anglers' Club at the head of the Conduit road, by a straight grade tunnel; thence on the south side of the old aqueduct and parallel to it to the north end of Dalecarlia reservoir, a cut-and-cover aqueduct, with one short tunnel; a by-conduit skirting the south shore of the reservoir and crossing at the narrowest point to the east end; thence a tunnel almost due east to Connecticut avenue extended; thence cut-and-cover aqueduct along the side of the valleys of the branch just north of Linnean Hill and of Piney Branch, to Fourteenth street; and thence a grade tunnel mainly under Spring road and Warder street to the north end of McMillan Park reservoir. The total length of this line, including the by-conduit around Dalecarlia reservoir, is 78,120 feet, of which 30,440 feet is in grade tunnel.

Its estimated cost, including the land, intake and outlet gatehouses, coagulating equipment for future installation, masonry aqueduct bridge in the park across Rock Creek, and all engineering expenses and contingencies, is placed at $3,879,383.

The alternative location, which might be designated as the tunnel location, follows the same route as the parallel location from Cabin Johns Bridge to McMillan Park reservoir, but above Cabin Johns diverges from the first, running directly from Great Falls to a point on the west side of the valley near Cabin Johns Bridge in grade tunnel; thence in a short section of cut-and-cover aqueduct and a siphon crossing to the east end of the valley, where it joins the line just described.

The estimated cost for this project, including the land, intake and gatehouses, coagulating plant for future installation, masonry aqueduct bridge in the park across Rock Creek, and all engineering expenses and contingencies, is placed at $4,333,686.

The details of these projects have been carefully worked out as thoroughly as is believed to be necessary at the present time, and are fully explained in the appendixes to this report, and detailed in accompanying tracings. The principal structures are a combined intake and gatehouse at Great Falls with a 48-inch drain leading to a point below the falls, which will provide for drainage at the upper end of not only the old but also the new aqueduct; a construction to provide for the crossing of the old aqueduct near the Anglers' Club; the crossing of Cabin Johns valley by an inverted siphon some 70 feet below the hydraulic grade line on a concrete masonry bridge immediately over the stream; a gatehouse at the inlet of Dalecarlia reservoir; another crossing of the old aqueduct in this gatehouse; a 48-inch drain from this gatehouse to the old diversion tunnel of Little Falls branch; a by-conduit around Dalecarlia reservoir, crossing the reservoir at the narrow neck near the south end, in a reinforced concrete section supported on piers and arches of concrete masonry; an outlet gatehouse at Dalecarlia reservoir; a masonry bridge across Rock Creek valley in the park, by an inverted siphon some 35 feet below the hydraulic grade line, the bridge to be of suitable width for a highway, to provide a high-level crossing of the valley, with suitable architectural treatment demanded by these surroundings; a 48-inch blow-off for drainage to be provided at this crossing; and a gatehouse at the north end of McMillan Park reservoir, with a small pumping equipment to provide for the final drainage of this section, which can not be economically taken care of by gravity drainage.

The principal structures on the tunnel location differ from those just described by the elimination of all constructions between the gatehouse at Great Falls and the crossing of Cabin Johns valley; the crossing of the valley would be very similar to that provided for the other location, but the structure would be located immediately under the present Cabin Johns Bridge, and at this point the old and the new aqueducts would cross each other.

It should be noted that the first-described route would fit in well with the additional storage hereinafter described, should such be deemed advisable, at the Stubblefield site. The proposed Stubblefield reservoir would lie immediately alongside both aqueducts, and could be conveniently connected with both through gatehouses, thus providing for storage of not only the new but also the old supply. This site could not, however, be utilized for the tunnel location, as the tunnel takes a more northerly route and is far removed from the Stubblefield reservoir site. The scheme, however, for storage in the reservoir at Cabin Johns valley could easily be combined with the tunnel location, but it possesses defects which have elsewhere been described. These facts are mentioned as showing that the location of the conduit paralleling the present conduit from the Anglers' Club to Cabin Johns Bridge lends itself much more easily to the extension of the reservoir system than does the tunnel location. The Stubblefield reservoir could still be constructed, however, if deemed advisable, but storage in it would have to be restricted to water supplied through the old conduit.

PATUXENT RIVER PROJECT.

The second project remaining for favorable consideration contemplates the utilization of the Patuxent River, Maryland, as a source of supply. Consideration of this supply was suggested by Mr. Hazen and was considered near the end of the investigations covered in Mr. Longley's report. The project, however, has many features which might demand its ultimate selection. Briefly outlined the project would assume the following form:

A masonry dam 70 or 80 feet high and possibly 800 feet long, founded upon rock, would be thrown across Patuxent River at some point of the gorge near the Columbia turnpike; this would form a reservoir over the Patuxent Valley of a length measured along the valley of about 9 miles, with a number of considerable branches on tributary streams, and would provide for storage sufficient to provide not less than 100,000,000 gallons of water per day, even during most unfavorable seasons. The elevation of the reservoir would be sufficient to justify the use of a smaller conduit for the same capacity than would be possible with the small head obtained at Great Falls, and at the same time the water could be delivered to the filters at McMillan Park by gravity, rendering unnecessary the pumpage which would be required for a supply from Great Falls. A tunnel approximately 3 miles long, through the ridge between the Patuxent Valley and the valley of the Paint Branch of the Anacostia would bring the water to a point from which it could be led to the filters by a direct and easy route for a steel pipe conduit, it being probable that a 6-foot conduit would suffice for more than doubling the present supply. The two great advantages of such a supply would be, first, the great advantage of having the two means of supply entirely separated, and, second, a saving of the necessity of pumping to reach the filter beds. Information at hand is not sufficient to definitely determine whether these advantages are sufficient to overbalance the known disadvantages, which are the construction of a dam, the purchase of large tracts which would be flooded in the creation of the reservoir, the diversion of sewage from some of the villages lying within the drainage area and near to the reservoir, provisions necessary to be taken to raise various roads and build bridges for them, the necessity to first obtain legal authority of the State of Maryland to utilize the water and condemn the necessary lands, and consideration of claims for lost water rights which might arise from riparian owners below the stream. It is, however, believed that the project is sufficiently promising to justify a careful study, which can be undertaken before the necessity arises for the increase in the supply. It is believed that this study should include a rough topographic survey of the valley, a study of the extent and value of the land necessary to be condemned, and an estimate of the cost of all structures required, together with a study of the comparison of the quality of the water to be obtained with the quality of Potomac water, the degree of sedimentation the reservoir may provide, and the necessity for preliminary treatment should this not be sufficient. It is estimated that these studies could be made at a cost of $3,000, and that an appropriation therefor should be made at a reasonably early date, as it should be borne in mind that should this project be adopted for ultimate construction the necessary legal preliminaries would add possibly two years to its time of completion over the time necessary to complete the work of providing a new conduit from Great Falls.

INCREASING CAPACITY OF PRESENT CONDUIT.

Referring to the additional studies made it is believed that any considerable raising of the crest of the dam at Great Falls is inadvisable. The two serious objections to this plan are the increase of pressure on the interior of the present conduit, and the raising of the water level above the dam, especially at flood stages. It is estimated that the capacity of the conduit would be increased about 10 per cent with an addition to its height of 2½ feet, and any greater increase is believed to be ill-advised. To effect this permanent increase in the height of the dam is believed to effect an increase in the supply incommensurate with the cost. The alternative plan, suggested by Mr. Hazen, of providing flashboards to be installed at low stages, raising the level of the pool above the dam by a height not to exceed 2 feet, would, however, be comparatively inexpensive, would result in no greater pressure on the conduit than it now frequently carries at medium high stages, and would not operate to raise the upper levels during flood stages, the flashboards being installed with a view to being swept away at high stages, the levels in the pool at flood stages being regulated by the permanent dam, as at present. It is estimated that an increase in the capacity of the present conduit of about 8,000,000 gallons per day could be effected with perfect safety and at small expense by this method. A maintenance charge would, however, be required, to supply an entirely new equipment of flashboards for each considerable freshet.

The study as to the insertion of a booster pumping station at Dalecarlia has shown that the plan would have less effect on increasing the capacity of the present system than it would have on regulating the levels of the three existing reservoirs, all of which lie below the site of the proposed pumping station. This is due to the fact that the pumping station would have no effect on increasing the capacity of the conduit above the station except such slight effect as would result from a drawing down of the level for a short distance back from the station, the effect of a steeper gradient being quickly nullified by the decreased capacity of the portion of the aqueduct which would be flowing only partly full. The principal value, however, of such a station would be in regulating the levels of the reservoirs to provide for the excessive consumption which is demanded on rare occasions, and these advantages might at some future date justify the construction of this plant. Its cost as estimated by Mr. Longley, with the necessary machinery, is $65,000, with an annual maintenance charge estimated at $3,000. Mr. Hazen, however, suggests a modification in Mr. Longley's plan, which would considerably reduce the estimate for first installation.

INSURANCE AGAINST ACCIDENT TO CONDUIT.

A study as to the necessity for providing additional supply from the viewpoint of insurance against risk of failure of the present aqueduct system shows the following conditions to be found:

In the unlined sections, which aggregate nearly 4,000 feet, seams varying in thickness up to 4 inches, and some disintegration of the surface, have been found, so that at every cleaning fragments of rock are found, which are broken up and carried out of the tunnel. These sections are inspected on every occasion when the conduit is drained, and have all been personally inspected by me. The worst points can and will be gradually lined, the work being done with considerable difficulty, due to the short and infrequent periods available. It is not believed there is any danger of a fall of rock large enough to cause an interruption of the water supply, but what danger there is can not be remedied until these unlined sections can be lined.

On the line of the aqueduct there are twenty-six culverts over streams of greater or less size. Over each culvert the masonry tube is built upon filled ground. Certain portions of the aqueduct, resting on some of these artificial embankments, have become considerably deformed in their fifty years of service, and it is doubtless due only to the extreme foresight of Captain Meigs that these deformations have not resulted in the failure of the aqueduct at several of these points during its earlier years of service. It seems now, however, probable that all such deformations occurred soon after the aqueduct was built and that they have stood practically unchanged for many years. It is certain that practically all of those that are now in evidence were noted in the examination heretofore referred to, made by Captain Gaillard twelve years ago. This office has now instituted the practice of a careful and detailed examination of all critical sections upon every occasion when the aqueduct is drained, which occurs on an average of three or four times per year, and it is believed that no serious threat exists at these points, especially as, the conduit being under pressure of not above 2 or 3 feet head, any such washout could be restored by a temporary flume on a timber trestle within the storage period provided for by the reservoirs, leaving the permanent construction to be subsequently undertaken.

It is believed that the consideration of the stability of the structures of the old aqueduct system fails to show any defect or weakness which threatens to interrupt the water supply of the District of Columbia to a sufficient extent to warrant the expenditure of the large amount necessary to provide a complete new aqueduct system before such new works would be required by reason of the inadequacy of the supply.

ADDITIONAL STORAGE.

The study as to the necessity for providing for additional storage capacity is so intimately related to that for preliminary treatment by sedimentation or coagulation that the two can best be handled as a single study. The existing aqueduct system includes three reservoirs (Dalecarlia, Georgetown, and McMillan Park) with a total storage area of about 125 acres and a total storage capacity from their bottoms to their flood lines of approximately 600,000,000 gallons. As the reservoirs can not be filled to their flood lines when the aqueduct is being used to anything approaching its full capacity, and as they can not be drawn to their bottoms, only a part of this total, estimated at 300,000,000 gallons, can be utilized. This quantity provides for a period of effectual storage for the present average consumption of about five days. These reservoirs provide for a natural purification by sedimentation of considerable value not only in the removal of turbidity but in the attendant reduction of bacteria. The degree of natural purification is, of course, reduced by any increase in the rate of flow through the reservoirs; but, more important, the degree of natural purification will also be reduced as the draft on the system increases, by the necessity of keeping the conduit open during periods of excessive turbidity in the Potomac water at times when, with the present consumption, the conduit can be kept safely closed.

In the two projects remaining for favorable consideration, viz, a gravity supply from the Potomac at Great Falls to McMillan Park reservoir and a gravity supply from Patuxent River direct to the filter beds, two sites have been considered, either of which could be adapted for use as a reservoir of large capacity; both of these are on the line of the first-mentioned conduit. The necessity of a reservoir other than the one created in the Patuxent Valley would probably not be necessary in case that route were adopted, as the reservoir itself would provide large storage, with attendant purification, and the use of the water from that supply would make it possible to exclude the turbid water of the Potomac, ordinarily high in bacteria in periods of excessive turbidity, for longer lengths of time than is possible under the present operation of the water-supply system. The two reservoir sites investigated are, respectively, in Cabin Johns Valley and the site known as the Stubblefield site, a comparatively flat area of about 180 acres, lying between the old aqueduct and the Chesapeake and Ohio Canal, about 4 miles below Great Falls. The former of these two sites—the valley of Cabin Johns Creek—could be converted into a reservoir by the construction of a dam immediately above Cabin Johns Bridge. Unless it were intended to utilize the water of Cabin Johns Creek for the supply, a condition which would become less and less desirable with the growth of the population of the District of Columbia, expensive diversion works would be required to conduct and to carry flood discharge of this stream around the reservoirs. The size of a possible freshet flow of 4,000 cubic feet per second seriously complicates the plans for its diversion and the expense would be absolutely prohibitive. The project, however, has been given a further study and a detailed scheme worked out, providing for the storage and subsequent diversion of ordinary freshets—a scheme which at very infrequent intervals would fail of total exclusion of the waters during high and prolonged floods, but which brings the cost within figures which render the work practicable.

The study of the Stubblefield site shows that it would be possible to construct at that point an artificial reservoir, not complicated with any questions of floods from feeding streams, with a maximum available storage capacity of about 425,000,000 gallons, and a total capacity of 850,000,000 gallons, at an estimated total cost of $1,380,588. As this cost figure is considerably less than the figure of cost of the Cabin John site the details of the latter project are not presented with this report, but are filed in this office for future reference. The details of the Stubblefield reservoir site are, however, submitted with this report.

Additional storage besides the apparent advantage of providing a reserve available for supply in the event of an interruption of the flow in the aqueduct above the point of storage, and the equally apparent advantage of providing a desirable flexibility to the water system for an occasional peak in the draft, due to conditions of use above the average capacity of the supply, possesses a very important advantage, not so apparent to the layman, of improving the quality of the water physically and bacteriologically, both by increasing the period of sedimentation and lengthening the periods during which undesirable water may be excluded from the conduit. It might well be that a system designed to attain these first two objects should fail in the third, and in such a system it might be discovered that another means could be found to attain the third desired result, and at a cost which would commend it over the project to provide for more storage. This is believed to be actually the case in the Washington supply.

NECESSITY OF IMPROVING CHARACTER OF RAW WATER.

The operation of the filtration plant was started in October, 1905, and has provided a most satisfactory effluent, so much so that it may be assumed that any additional supply that may be provided will have to be filtered. The question naturally arises as to whether the present plant will be sufficient for a large increase in the supply. The filtration plant was designed for a rate of filtration of 3,000,000 gallons per acre per day.

At the time of its design it was in accordance with the most approved practice. Experience since that time, however, has shown that the plant can under favorable conditions of the raw water be operated at a rate higher than 3,000,000 gallons per acre per day, without any deterioration in the quality of the effluent, the increase in the rate being abundantly sufficient to provide for a much greater consumption than the District of Columbia will demand for a great many years to come. There are, however, at the present time some conditions which will require improvement in order to obtain such results. In order to attain any such high rates of filtration it would be necessary to supply the raw water to the filters in at least as favorable a condition as it is now applied under ordinarily favorable conditions; in other words, the water must be either excluded at the inlet to the conduit during periods of excessive turbidity, or, at such periods, a preliminary treatment must be applied. The exclusion of the water is practically impossible without a large increase in the storage. Experiments conducted by this office in recent years with preliminary treatment by coagulation have shown this to be the only method that will give unfailing results in this character of the raw water during periods of such turbidity. This process possesses great flexibilty and could be applied to whatever extent might be indicated by the results of filtration operations.

Besides providing for the filtration of all water demanded by the growth of the city to even twice its present consumption of water, without any increase in the size of the filter beds, such a plant would simplify enormously the present operation of the filters. The turbidity of the water at the present time furnished to the filter beds frequently causes great reductions in the capacity of the plant, requiring efforts lasting many days to furnish the quality of water demanded, and frequently without success. Coagulation will give with certainty the objects desired by effecting the sudden and immediate precipitation of a large percentage of bacteria in any quantity in which they are likely to enter the system. It could, moreover, do this with more effectiveness and more dependency than any system of reservoirs feasible to construct as a part of the system. It would be necessary to coagulate the water only during periods of high turbidity and under conditions and during periods of greatly increased consumption.

Even at the increased capacities required a coagulating plant could be installed and the Georgetown reservoir remodeled in connection therewith, at a cost of $130,000, with a maintenance and operating cost, depending largely upon the frequency and duration of the periods of excessive turbidity, which would probably not exceed $15,000 per year. Consideration of these facts, together with the fact that the coagulating plant already recommended by this office has received the unqualified approval of the Board of Consulting Engineers and the indorsement of the medical society, justifies the assumption that coagulation may be considered an assured adjunct to the aqueduct system and filtration plant in the future, and that after its installation, which should be promptly provided for, there is no argument which demands the construction of an additional reservoir in connection with either the present or an aqueduct system providing for a large increase in the supply.

WASTE PREVENTION.

A study looking to the reverse side of the question, viz, the proposition to reduce largely the waste of the water, is carefully gone into in the appendixes of this report, and justifies the statement that it is possibly the most important part of the report. The present maximum capacity of the Washington Aqueduct is believed to be about 90,000,000 gallons per day. The present average consumption demanded per day is slightly less than 60,000,000 gallons. Of this amount a large part is undoubtedly wasted, the amount wasted being, however, considerably reduced within the past three years.

The abnormal consumption of water which occurred during the years 1905 and 1906 is responsible for the introduction of the system of metering private services, which was inaugurated three years ago. The work has now, however, been nearly halted by the lack of funds. There are now, out of about 60,000 service connections, a little less than 13,000 meters in service, or about 21 per cent of all. The funds are not more than sufficient to keep up with the new services, so that there will probably continue to be in the neighborhood of about 47,000 unmetered services in the District unless money is provided for their installation. The cost of purchasing and installing meters has been about $16.50 each, at which rate it would cost about $775,000 to equip every private service with a meter.

In addition to this good start in the work of metering services, the water department of the District of Columbia, about three years ago commenced the work of its pitometer division, which has been pursued continuously since that time in a survey of the waste in the distribution system, and has produced excellent, even remarkable, results. The work of the pitometer surveys has covered possibly two-thirds of the area of the District of Columbia, and it is probable that the work over the other third will cut off as large a waste in proportion to the area, and probably a little larger, after which time the investigations are expected to be continued as long as they show efficiency in the suppression of waste. The amount of leakage detected and cut off by this service and by such meters as have been installed in the two and one-half years of operation is equal to nearly 12,000,000 gallons per day. For this work it would be impossible to give too much credit to the efforts of Mr. W. A. Mac-

Farland, superintendent of the water department of the District of Columbia. The combined result of these measures for suppression of waste is shown markedly in the decrease in daily per capita consumption since 1906 and in the fact that the average daily consumption now is less than it has been at any time within the past five years, despite the increase in house services following the growth of the city.

A careful consideration of the data contained in this study, all of which is detailed at length in the appendixes of this report, would seem to indicate that a continuation of the work of the pitometer survey of the District water department, and the completion at an early date of the work of installation of meters on house services, would result in a cutting off of the unnecessary waste of water which was occurring three years ago in the District of Columbia by not less than 24,000,000 gallons per day. If this saving could have been effected instantly, at the time of the beginning of measures of waste preventions, the average daily consumption at that time would have been approximately 135 gallons per day per capita, which is the figure assumed as a reasonable average consumption per capita for all necessary purposes, including a liberal allowance for waste which can not reasonably be prevented. This same figure is deduced independently by Mr. Longley in his report, and seems to be entirely reasonable and one which universal metering may hope to attain. It is a curious fact that the figure deduced by Mr. Longley, of 90 gallons per capita per day, to which is added a 50 per cent allowance for unpreventable waste, is the exact total figure used by the original designers of the Washington Aqueduct, and was placed at that figure by them in excess of any allowance that had previously been made for any public water supply.

The use of meters on house services does not imply a desire upon the part of the officials to restrict even the lavish use of the water, but merely to provide a means for placing upon the consumer the burden of any extravagant or useless waste that may be found upon his individual premises. The meters are intended more for the detection of leaks in mains or service pipes on the premises, and are intended to place upon the consumer the pecuniary responsibility for any flagrant waste from faucets, hose, etc., or of any waste caused by a deliberate neglect of any defective plumbing in the house.

In the studies made as to the consumption of water in the District of Columbia it is necessary to carefully consider not only the mean daily demand, but the question of peak loads, or excess in the rate of consumption which may occur in periods of prolonged extreme cold weather, and on occasions in the summer time due to periods of prolonged heat and drought. This maximum draft to meet such peaks in cold weather has been as high as 45 per cent, but it is certain that the means recommended for a restriction of waste should tend to reduce this, the most serious, overdraft. There remains, however, to be considered the summer peak, which represents an extra use of water for cooling streets and watering lawns, which doubtless will continue at more or less frequent intervals even after the installation of the measures recommended. It is believed that the figure suggested by Mr. Hazen, viz, 30 per cent above the annual average rate, is ample to cover these summer peaks, and that this figure is more than ample to cover the overdraft which may occur during the winter peaks, and that the figure assumed by Mr. Hazen, viz, an annual average consumption of 65,000,000 gallons per day, can be safely taken as the figure at which the average annual consumption per day of the present system may be placed without any additions to the system, except the universal installation of meters, the continuation of the pitometer surveys, and the addition of the coagulating plant for preliminary treatment of the water supply; and that this mean average consumption provides for sufficient expansion in the system to meet all unusual demands.

This figure, on the assumption of a reduction of the daily per capita consumption to the figure of 135 gallons, would place the date at which the present conduit will be insufficient to meet demands at the date when the population of the District of Columbia shall have reached 480,000. A careful study of Mr. Longley's data shows that there appears no reason to believe that the mean per capita consumption can not be reduced to this figure.

It can not be too insistently urged, however, that the probability of having to provide only this quantity of water is contingent solely upon the reduction of waste, which can not be accomplished except by the extension of the meter system to cover all services. It is suggested that an appropriation to this end to provide the water department with these funds should be made in the next District appropriation act, to provide for approximately one-third of the necessary work in the fiscal year 1911, to be followed in each of the two succeeding years by an approximately equal appropriation, with the provision that funds are to be repaid from the revenues of the water department in equal annual installments covering a sufficiently long period until completed. Should this be done, it is the belief of this office that the necessity for providing for an increase in the volume of water supplied to the District could be safely postponed for at least twenty years.

The question of metering the supplies used in the buildings and grounds owned by the United States has also been studied. The Federal Government is a large consumer of water in the District of Columbia, and it has been difficult, especially on the part of the District officials, to convince the federal officials having charge of the various buildings and grounds that all extravagant waste could be cut off. Not only have large leaks been frequently discovered, but the use of the filtered water for operating condensing plants, even where a plant had been installed which would enable Potomac water pumped direct from the river at small expense to be used instead, has been frequently protested against, but without avail in all cases. The argument which is frequently made is that the United States furnishes water free to the District of Columbia, and the District of Columbia should not object to any quantity of waste on the part of the federal officials. It is believed that the necessity for metering of all supplies to government buildings and grounds is equal to the necessity of metering supplies for private consumers of the same quantity of water; these meters should, however, be installed at the expense of the United States, and preferably under the direction of the officer in charge of the Washington Aqueduct, who should also be charged with the duty of reading the meters and taking such steps as might be necessary to restrict waste. It is believed that this treatment of the question would remove all chance of friction between the

District officials and the federal officials, and would result in a considerable saving in water and consequent lengthening of the period at the end of which the supply will have to be increased. This office has made estimates as to the cost of this installation, at $50,000, and an item to effect this installation should be included in the District appropriation act for the fiscal year 1911.

It remains then to endeavor to forecast a date at which the present water supply will be insufficient. Mr. Longley has made studies as to the growth to be expected in the population of the District of Columbia in the coming years, has entered on this study with great care, and seems to have considered all factors which might enter. According to his studies it is deduced that the population of the District of Columbia will reach the figure of 480,000 at a date not far removed from the year 1930. It seems safe to accept this estimate, although it may be that the rate of growth of the city will increase to some extent in the coming years, as there seem to be indications justifying such an assumption. The date fixed is, however, but about twenty years from date, and as there remain two important factors of safety which at small expense and at short notice can be made to increase to a considerable extent the capacity of the present works it is believed that this office is safe in reporting that, with these adjuncts, there will be no necessity for the completion of the construction of a new conduit until about the date mentioned. The two expedients referred to are those heretofore outlined, viz, the use of temporary flashboards on the dam at Great Falls and the construction of a booster pumping station at Dalecarlia reservoir. It is believed that the first-mentioned expedient can be made to add to the capacity of the aqueduct about 8,000,000 gallons per day, and that the booster station at Dalecarlia, while not adding greatly to the capacity during periods of normal consumption, would operate in times of peak loads to provide for an increased flow in the aqueduct below Dalecarlia reservoir, making it safe to reduce the allowance of 30 per cent, suggested by Mr. Hazen, and previously referred to, as a reserve supply to meet the excess demand during these periods of overdraft. It is believed that these expedients would provide for the safe management of the aqueduct to meet the demands that would be made upon it by a population of about 530,000, which figure of population, it is believed, can be safely predicted will not be reached by the District of Columbia in less than twenty years' time. At the risk of repetition it should be again stated that these figures depend for their justification upon the early installation of the measures herein recommended for the reduction of waste and for the preliminary treatment of the supply.

It should be stated here that upon the installation of all meters, as recommended, and the completion of the waste survey, this office will become possessed of data which will enable a more reliable figure for the future per capita consumption to be deduced than the office is now justified in assuming.

CONCLUSIONS.

As a result of these investigations the following conclusions are arrived at:

First. The efforts of the water department of the District of Columbia of the last three years, looking to a suppression of waste, have produced such remarkable results as to imperatively demand their continuance and extension by rapidly covering all services, both private and public, in the District of Columbia by meters.

Second. As an alternative to providing for the construction of an additional storage reservoir, which will become more necessary as the demand for water increases and to provide for the more efficient working of the present filtration plant during periods of excessive turbidity in Potomac water, the construction of a coagulating plant and remodeling of Georgetown reservoir for use in connection therewith is imperatively demanded as a necessary adjunct to the present system, and should be at once begun.

Third. Contingent upon the adoption of these measures, there can be no doubt that the consumption and waste of water in the District of Columbia in the next few years will be far enough below the safe working capacity of the existing aqueduct to make it safe to postpone new construction until fuller and more definite results are at hand to predict accurately the date at which such construction must be completed.

Fourth. There appears to be no justification for an increase in the supply through fear of failure in any of the structures of the existing system.

Fifth. When the necessity arises for an increase in the supply, there appear to be three projects, any of which would give a satisfactory supply at least as great as the present supply and at reasonable cost. From Great Falls an aqueduct with all necessary appurtenant structures could be constructed, with such slight variations from plans which have been worked out in considerable detail as might be deemed necessary by advances in the art of providing public water supplies, at a cost of $3,900,000, and the work could be done in from four to five years' time, of which at least a year would be consumed in the necessary work of acquisition of title to lands necessary. On another route from Great Falls, withdrawn from the line of the existing aqueduct as far as topography will permit, an aqueduct with all appurtenant structures could be constructed at a cost of $4,350,000, and in about the same length of time. From the Patuxent Valley an aqueduct with all necessary appurtenant structures could be constructed in from four to six years' time. Sufficient data as to cost of this development is not, however, at hand, and a known additional obstacle appears to its adoption, as the power to enter the State of Maryland for this purpose must first be obtained from that State. The project, however, offers known advantages which would justify its adoption as against the Great Falls project, even at an increased cost of nearly $1,000,000. These advantages justify a careful study at an early date, for which the sum of $3,000 should be appropriated. Until the completion of this investigation it is unnecessary to inquire further into the merits of the three routes from which selection will have to be made.

Sixth. Contingent upon the construction of the coagulating plant recommended, no additional storage capacity need be provided, even when the additional conduit is constructed, nor will any addition be required to the present filtration plant beyond slight modifications in the arrangement of ducts, even with a demand for twice the present maximum consumption.

Seventh. For reasons outlined in the report of Mr. Hazen, the officials of the District of Columbia should make arrangement to cover the present filtered-water reservoirs at Reno and Brightwood at as early a date as will be permitted by funds at their disposal.

It is a matter of no small gratification to this office to be able to make this report, which is made possible only by the excellent results which have been obtained by the introduction of such meters as have already been installed and the thorough and efficient work in the suppression of waste in the distributing system. Especially is this so because the great consumption of water of from three to five years ago justified the officials having charge of the water supply and of the management of the affairs of the District of Columbia in the assumption that additional works would be urgently needed, possibly within the period required for good construction work, and the investigations entered upon under this appropriation were approached by all in the belief that the result of the investigations would show the necessity for early construction. It is further gratifying because it can be demonstrated, as suggested in Mr. Hazen's report, that the installation of all the measures recommended for immediate adoption can be effected at only a fraction of the cost of interest charges on the outlay necessary for new works, which interest charge will be a direct saving for so much time as the construction of the additional works can be postponed.

This office has therefore to make the following recommendations:

1. That the sum of $50,000 be requested of Congress in the District appropriation act to provide for the expenses of the fiscal year 1911 for the installation of meters on all federal supplies, the sum to be appropriated entirely from United States funds, to be disbursed under this office, the legislation to provide for the reading of the meters also by this office.

2. That the appropriations previously asked for by this office of $130,000 for the construction of a coagulating plant and for remodeling the Georgetown reservoir, for use in connection therewith, be included in the District appropriation act for the fiscal year 1911, the sum to be payable one-half from the revenues of the District of Columbia and one-half from United States funds.

3. That there be included in the same appropriation act the sum of $250,000, and in the appropriation acts for two ensuing years an equal sum, to be increased or reduced in the third year by such sum as the experience of the first two years may indicate, in order to provide funds for the extension of the meter system to all private services in the District of Columbia, these appropriations to be made payable from United States funds, with provision for their entire repayment to the United States, with interest charges, over a period of about twenty years' time, as has been done in cases of like nature in the past.

4. The inclusion in an early District appropriation act of an appropriation of $3,000 to provide for complete investigation of the project heretofore briefly described for increasing the water supply of the District of Columbia from the Patuxent River.

In closing it is desired to place upon record an appreciation of the work of Mr. Longley upon this project. His thorough and painstaking report, with all appendixes, will bear close examination and repay careful study on the part of all engineers interested in the important questions related to supply and purification of water for large municipalities.

Very respectfully,

JAY J. MORROW,
Major, Corps of Engineers.

The CHIEF OF ENGINEERS, U. S. ARMY.
(Through the Division Engineer, Eastern Division.)

REPORT OF ASSISTANT SUPERINTENDENT FRANCIS F. LONGLEY.

WASHINGTON, D. C., *May 1, 1909.*

SIR: The act making appropriations to provide for the expenses of the government of the District of Columbia for the fiscal year ending June 30, 1909, contained the following:

"For preliminary investigations and surveys for increasing the water supply, ten thousand dollars."

This was made upon the repeated recommendation of the officers in charge of the Washington Aqueduct. The following project was approved for the expenditure of the funds provided by this appropriation:

"The above sum of ten thousand dollars, or so much thereof as may be necessary, is to be applied to a study of the available sources of additional water supply and the means of bringing this water to the city; to making surveys, plans and estimates, and to such other engineering and office expenses as may be necessary for completing the work; to defraying transportation or other expenses of employees properly chargeable to the work, and to the securing of a review and expert opinion upon the completed project."

In accordance with the verbal instructions of the officer then in charge of the Washington Aqueduct, I took charge of this work on July 1, 1908, and I now have the honor of submitting the accompanying report, which sets forth in detail the procedure of the work, the general conditions affecting it, brief consideration of all the various possibilities for additional supply which have been investigated and rejected, a more complete consideration of those possibilities which seemed favorable, together with preliminary designs and estimates of cost thereof, and lastly, the conclusions reached and recommendations made upon the entire investigation.

The view of the expert employed for a review and opinion upon this report will shortly be presented.[a]

THE PRESENT WATER SUPPLY OF THE DISTRICT OF COLUMBIA.

The water supply of the District of Columbia is obtained from the Potomac River. The existing works were constructed largely before the civil war. They consist in a general way of about 15 miles of conduit and tunnel and three reservoirs. The intake is just above the Great Falls of the Potomac on the Maryland side of the river. The conduit follows generally parallel to the river and to the Chesapeake and Ohio Canal discharging into the first or Dalecarlia reservoir located just above the District line and about 9 miles from Great Falls; thence through another 2-mile section of conduit to the second, or Georgetown reservoir; and thence through about 4 miles of tunnel under the city to McMillan Park reservoir, adjoining which the filtration plant is located.

The capacity of this system has been the subject of a careful study which is presented as an appendix to this report (Appendix D). The point in which we are interested in considering the present water supply resources of the District is the limiting quantity that the system will discharge continuously from the river at Great Falls to the pumping station at the filtration plant. This quantity is 90,000,000 gallons per day. The city can not, however, count upon drawing this quantity day after day throughout the year. If the draft on the system—that is, the quantity of consumption and waste—were absolutely uniform, it could be done, but this is not so. For well understood reasons, the daily draft in almost every city is subject to wide fluctuations. The maximum variation that has been recorded in this city of the consumption for a day from the mean daily consumption for the year was about 45 per cent. The necessity for maintaining a reserve capacity of this magnitude fixes the "safe annual average" that can be drawn without danger of too serious depletion of the reservoirs under abnormal conditions at about 62,000,000 gallons per day.

The studies elsewhere described, that were made some twelve years ago upon the flow in the aqueduct, indicated a discharge, in round numbers, of 75,000,000 gallons per day with the reservoirs at levels which had been shown by experience to give adequate storage and fair pressures in the city. This quantity has commonly been stated as the "nominal capacity" of the system. It would represent the "safe annual average" if, by the introduction of measures referred to later, the 45 per cent maximum excess draft could be reduced to about 17 per cent.

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[a] See Mr. Hazen's review and opinion accompanying.

With the water at the levels required for the flow of 62,000,000 gallons per day through the conduit, the capacities of the three reservoirs above the lowest point to which they can be drawn are as follows:

	Gallons.
Dalecarlia reservoir	141,000,000
Georgetown reservoir	133,000,000
McMillan Park reservoir	162,000,000
Total	436,000,000

This quantity may not all be considered as available storage because the rate at which it would be drawn would diminish rapidly as the water levels approached their lowest points. From 300,000,000 to 350,000,000 gallons could be drawn from the reservoirs under the conditions assumed above, if the supply from the river were shut off. This reserve is used freely for the purpose of excluding muddy and bacteria-laden water during freshets, thereby improving the quality of the supply. Its important functions from the point of view of the capacity of the system are two, namely, (1) to maintain a continuous supply to the city for a time in the event of an accident which might interrupt the flow through the conduit, and (2) to supply the excess if at a time of abnormal consumption the demand should exceed the limiting capacity of the system.

OBJECTS OF INCREASING THE WATER SUPPLY OF THE DISTRICT OF COLUMBIA.

There are in general two objects to be attained in increasing the water supply of the District of Columbia. They are (1) to provide an additional supply to meet the increasing demands of the city, and (2) to provide positive insurance against the risk of a disastrous water famine in the event of an accident to the present system at some of its weak points.

ADDITIONAL SUPPLY TO MEET INCREASING DEMANDS.

The mean annual consumption of water in the District for a number of years past has been:

[From Annual Report of the Chief of Engineers for 1906, p. 2092, and subsequent reports.]

Fiscal year.	Total consumption per day.	Per capita, daily consumption.	Fiscal year.	Total consumption per day.	Per capita, daily consumption.
	Gallons.	*Gallons.*		*Gallons.*	*Gallons.*
1890	35,500,000	149	1900	48,500,000	164
1891	38,600,000	158	1901	50,700,000	169
1892	41,200,000	165	1902	56,000,000	183
1893	46,700,000	183	1903	58,300,000	187
1894	49,200,000	189	1904	63,000,000	199
1895	47,200,000	177	1905	70,600,000	218
1896	44,100,000	162	1906	67,700,000	207
1897	45,300,000	163	1907	66,900,000	203
1898	47,300,000	167	1908	64,900,000	191
1899	50,100,000	173			

The safe annual average consumption which could be depended upon without danger of shortage at times of abnormal draft is about 62,000,000 gallons per day. The mean annual consumption has for a number of years been approaching this safe limit at an alarming rate. This has been evident to the several officers who have been in charge of the Washington Aqueduct from year to year. As early as 1896 attention was called to the necessity for providing an additional supply in the then near future. (Report of the Chief of Engineers for 1896, p. 3966.) Since that year this has been repeatedly urged, and accompanied by recommendations for an appropriation for the preliminary steps leading up to a new supply.

In the year 1904, the consumption for the first time exceeded the safe annual average and in February, 1905, the capacity of the aqueduct was stretched to its limit and the reserve storage drawn alarmingly low. The consumption during the three years since 1905 has not been quite as high as that year, but it has been above the safe annual average. The need for a remedy for these conditions is one of the factors that urged the consideration of means for increasing the water supply.

Insurance against shortage of water due to accident to present system.—The question of insuring the District against risk of disaster due to the failure of some part of the present aqueduct system was forcibly set forth by Col. Smith S. Leach in his report on the Washington Aqueduct for 1905, an extract of which is here given:

"Attention is invited to the danger of an interruption of the supply by an accident to the conduit. This structure has stood for nearly half a century, and without interruption in its use other than to empty it periodically for cleaning. This fact is no guarantee that it will not be interrupted in the future.

"It includes six tunnels aggregating 3,700 linear feet in seamy rock, and unlined. They can not be lined until a new conduit is built. At every cleaning fragments of rock are found to have been dislodged from the roof. There is an appreciable risk of more or larger pieces falling in, sufficient to block the tunnel for a considerable time.

"There are 26 culverts, nearly all in made ground, the failure of any one of which would break the conduit. They are of massive construction, but equally strong ones have been washed out, and these may be.

"The Dalecarlia reservoir is formed by an earthern dam across a valley. In this dam is the by-conduit. If this dam should break, the by-conduit would be destroyed and the supply of the District completely cut off.

"The statement is justifiable that notwithstanding its fifty years of uninterrupted use, the Washington Aqueduct is more vulnerable than the average of similar structures and that there is risk of an accident to it which would cut off the supply for a period long enough to cause a water famine, which would involve a cancellation of all fire insurance and a partial depopulation of the city, besides other and more calamitous consequences. This risk can be underwritten by the construction of another conduit, and in no other way."

NECESSITY FOR INCREASING THE SUPPLY.

The necessity for increasing the water supply of the District of Columbia, from a consideration of the objects outlined above, depends in each case upon certain conditions and assumptions that must be presented and considered in detail.

From the consideration of increasing consumption.—The consumption of water in the District has been for several years in excess of the safe annual average. If the tendency were now toward a still further increase in total consumption there would be absolutely no question as to the necessity for providing an additional supply with the least possible delay. Whereas three years ago the rapid and unretarded rate of increase of the consumption would have made such a recommendation imperative, conditions of water consumption have arisen during those three years which introduce a question of reasonable doubt as to the urgent necessity for increasing the supply at the present time to meet increasing consumption.

Alarmed by the rapid increase in total consumption, as already pointed out, which seems largely chargeable to useless waste of water, the officials in charge of the water department of the District began in 1905 or 1906 an active campaign against waste. The details of this work are given as far as the data are available in Appendix A. As there stated, the waste of water has been so reduced that the per capita daily consumption has been lowered from 207 gallons in 1906 to 191 gallons in 1908, with a corresponding reduction in the total mean daily consumption from 67,700,000 to 64,900,000 gallons per day. Those in charge of the work of waste prevention believe that these measures will still further reduce the per capita daily consumption, and to a degree sufficient to cause a material reduction in the total amount of water required. If their judgment in this question is not in error and they should effect a considerable reduction in the total consumption, the argument of rapidly increasing consumption, which seemed so unmistakably potent three years ago would lose its force and would not at the present time justify the expenditure of the large amounts necessary for providing an additional supply.

The question of the use and waste of water in the District of Columbia and the reduction in consumption through the efforts aimed at the suppression of waste are considered at length elsewhere in this report (Appendix A). The conclusions thereon may be summed up briefly as follows:

(1) A per capita quantity of 135 gallons of water per day should be ample for all the legitimate needs of the District and for a generous allowance for unpreventable waste.

(2) A consideration of the results so far effected by the investigations for the detection and suppression of waste lead to the certain conclusion that the per capita consumption can be considerably reduced and should be reduced to 135 gallons per day, provided the water department be given the necessary funds for this work.

If this reduction can be effected without unreasonable delay, the total consumption will be greatly reduced and should not exceed the safe limit of the existing aqueduct system, according to the present rate of increase in population of the District, until some time after 1930. Obviously, then, there is no necessity at the present time, from the point of view of increasing demand for water, for the construction of new works, provided the District water department is given full support in the prevention of waste.

From the consideration of insurance.—The necessity of providing an additional supply of water at the present time from the consideration of insurance against risk of failure of the present aqueduct depends chiefly upon the stability of the structures thereof, especially at the weak points. These weaknesses have been investigated in all the detail possible. Personal trips of inspection have been made through the aqueduct by the officers in charge, accompanied by the assistants in local charge and those engaged upon this investigation. From a critical examination of the weak points the following statements may be made which are concurred in by those who were engaged in that examination:

(1) The present aqueduct system includes about 4,000 feet of unlined rock tunnel. The rock itself is durable, but the whole mass is intersected by numerous seams of comparatively soft material. The seams vary in thickness up to 3 or 4 inches or more, and in many places the material in them has disintegrated to a very considerable depth. At every cleaning fragments of rock are found to have been dislodged from the roof or sides of the section. These are not of great size, and are broken up and carried out of the tunnel. It is not believed that there is any danger of a fall of rock great enough to cause an actual interruption of the water supply. A remedy for this condition would lie in the complete lining of all the tunnel sections, especially where the soft seams are most in evidence. This is practically impossible, since the tunnels can not be drained for a period longer than about three days. No real danger is anticipated from this source before new works will be required by reason of increasing consumption.

(2) On the line of the present aqueduct there are twenty-six culverts, which carry the drainage of considerable watersheds on the north side of the line. Over each culvert a fill of earth was made and the aqueduct built upon this fill. There is no record of any of these embankments having been endangered by freshets, but this is of course within the range of possibilities. This condition is guarded against by careful inspection and proper cleaning of the culverts, and there is believed to be no real danger due to the flow of storm water through them under the aqueduct.

(3) Certain portions of the aqueduct resting upon some of the artificial embankments described above have become badly deformed in their fifty years of service, due presumably to the settlement of the embankments and consequent change in direction and intensity of earth pressures about them. The most noticeable deformation is over culvert No. 20, where the aqueduct has settled about 5 inches. It has flattened at this point so that its horizontal diameter has become from 8 to 12 inches greater than its vertical diameter. It seems probable that such deformations as this occurred soon after the aqueduct was built and that they have stood for many years in their present condition. The deformation at culvert No. 20 was noted, but not measured, as far back as 1896. If it be true that the deformation occurred when the masonry was green, and that the section is not undergoing any further change of shape, then there is probably no weakness inherent in the deformation, as the strength of the structure is so largely dependent here as elsewhere upon the support of the surrounding earth. A continuing series of observations is to be instituted upon the shape of the aqueduct section over culvert No. 20. If there is no change in shape, the structure is quite safe from danger due to this defect.

(4) Attention has been called to the condition of the brickwork of the aqueduct. The mortar is inferior to the first-class Portland cement mortar that would be used to-day in such work. This is most noticeable in the invert, in which the brick have been loosened in many places by the occasional passage of men for inspection and repair. In the entire length of the aqueduct, however, there is no place where a fall of brick has occurred, and in the total absence of any unusual forces acting upon the brickwork, and with systematic inspection each time the water is drained off, there is no reason for apprehending danger from this source.

(5) In the tunnel between Georgetown and McMillan Park reservoirs there is a portion just east of Foundry Branch having a section vertically elongated in order to bring the invert down to a grade which permits proper drainage. The brick side walls lining this section are straight and have no arch action to support them. As a result they have separated from the wall in two places and bulged toward the interior of the tunnel. The maximum movement has been about 5 inches and the length of wall affected about 15 feet in each place. These two existing defects have been held against further movement by the use of adjustable struts made of heavy 4-inch pipe. No further danger of this kind threatens, though it is realized that bulging might occur at other points of this elongated section. Even the complete collapse of a section of this lining, however, would not be a serious accident, though it could not be repaired

until after a new aqueduct is built, for it would not interrupt the flow of water through the tunnel.

(6) The earthen dam forming Dalecarlia reservoir has been mentioned as one of the vulnerable points of the system. It is true that the failure of the dam would destroy the by-conduit and cut off the supply. But the dam has stood half a century, and, unlike a brick-masonry structure, the lapse of time tends to strengthen rather than weaken it. The reservoir is not subject to freshets. In view of these considerations, this can not be seriously regarded as a point of weakness.

Stated briefly, the consideration of the stability of the structures of the old aqueduct system fails to show any defect or weakness which threatens to interrupt the water supply of the District of Columbia. It is confidently believed that no real danger of this sort need be apprehended in the near future which would warrant the expenditure of the large amount necessary to provide a complete new aqueduct system before such new works will be required anyway by the increasing consumption in the District.

POSSIBLE SOURCES OF ADDITIONAL SUPPLY.

While it is an unexpected and most important conclusion that no new works are needed at present for the extension of the water supply, and while it will be welcomed by Congress, still it was the intention of that body in appropriating money for this investigation to secure a broad view of the problem of additional supply for the District of Columbia, and, as far as possible, detailed presentation of the most favorable possibilities. The surveys originally intended have therefore been carried out, all possible sources given consideration, and general designs and estimates prepared for those which seemed to present advantages that would give them any chance for serious consideration in the future.

The possible sources of additional supply of water for the District of Columbia are given below. Remarks are appended to indicate approximately the quantity that might be developed from such a course, as compared with the quantity the city will need during, say, the next fifty years.

Source.	Comparative quantity available.
Potomac River at Great Falls	Unlimited.
Potomac River at Little Falls and at the tidal basin	Do.
Rock Creek	Relatively small quantity.
Seneca Creek	Ample for many years.
Ground water	Indeterminate.
Potomac at the upper branches	Unlimited.

Brief consideration has been given also to the possibility of increasing the supply by raising the dam at Great Falls, by the construction of a low-lift pumping station at Dalecarlia reservoir, and by a separate unfiltered supply for industrial purposes and fire protection.

CONSIDERATIONS AFFECTING THE CAPACITY TO BE PROVIDED FOR IN A NEW SYSTEM.

From the standpoint of design, the capacity to be provided for in an additional supply of water for a city such as this will depend upon one of the following considerations:

(1) If a source be selected which will yield a comparatively limited quantity, provision may properly be made for the full capacity of that source.

(2) If a source be selected which will yield a quantity far in excess of the city's needs, provision may be made for an estimated consumption for an arbitrarily assumed period of years into the future.

(3) Or, from a large source like the one just mentioned, the quantity may be determined by some special consideration, such as a legal decision, duplication of existing capacity for some justifiable reason, etc.

From the Potomac at Great Falls.—The minimum flow of the Potomac at Great Falls is approximately ten times the present consumption of water in the District of Columbia. The capacity of a new system from that point can not therefore be made to depend upon the total quantity of water available. There are two factors, however, that have a bearing upon the point important enough to justify their use in determining the capacity of a gravity system from Great Falls.

A corporation known as the Great Falls Power Company holds title to part of the lands adjoining Great Falls, and, as far as has been determined by the courts, the title seems to include a portion of the water rights. The government dam at Great Falls was raised in 1895–96 from elevation 148 to elevation 150.5, which resulted in submerging some of the lands belonging to the above-named company. Following upon a suit for damages in the United States Court of Claims, the Great Falls Power

Company, for certain considerations named, on May 10, 1902, signed a quitclaim deed, an abstract of which follows:

"There is also hereby conveyed and released to the United States, as against any ownership by said company of land or water rights at or near the said Great Falls of the Potomac, whether above or below the said government dam, the right on the part of the said United States to take and divert from the said Potomac River from above said government dam for the water supply of the city of Washington an amount of water equal to 153,000,000 of United States gallons in twenty-four hours, which amount is now estimated to be double the capacity of the present aqueduct, and all claims for damages present or prospective on the part of this grantor or its successors or assigns on account of the taking of water to that amount are hereby forever released."

There is then no apparent legal restriction to prevent the United States providing works to take an additional quantity equal to the normal capacity of the present system, which may be taken as 75,000,0000 gallons per day.

The present aqueduct system is half a century old. It is very much in need of repair at many points. These repairs can not be made under existing conditions, which require the system to be in practically continuous service. For this system to fulfill its proper functions for a long period into the future it must be thoroughly repaired. The completion of another project equal in capacity to the present one would enable this to be done properly and economically before the needs of the city had grown to a point where they demanded the continuous service of both the old and the new systems. The increased cost and the depreciation of a project for 75,000,000 gallons per day, over one for say one-half that quantity, will be relatively small, especially in view of the appropriation of most favorable sites and locations for the first construction.

Governed by these factors the Great Falls gravity projects have been worked out on the basis of a nominal capacity of 75,000,000 and a maximum capacity of 90,000,000 gallons per day, which is equal to the capacity of the existing system.

From the Potomac at Little Falls and at the tidal basin.—In the consideration of the projects for an additional supply from Little Falls and from the Potomac at the tidal basin, the normal capacity ultimately to be provided for has been assumed as 75,000,000 gallons per day, or equal to that of the Great Falls gravity project.

From the upper branches of the Potomac.—Because of the small consideration given to a project for development of an additional supply from this source, no assumption was made as to the quantity to be developed.

From Seneca Creek.—In order to facilitate the direct comparison of costs, in the brief consideration given this project, the nominal capacity was assumed at 75,000,000 gallons per day, equal to the Great Falls gravity project.

From Rock Creek.—The total quantity that might be developed by impounding from Rock Creek, according to the data at hand, and after providing for maintaining a constant and sufficient flow in the stream below the dam, is about 28,000,000 gallons per day. The capacity for this project has therefore been assumed at that figure.

From ground water.—Because of the slight consideration given this source, no assumption has been made as to the quantity to be developed.

TREATMENT OF ADDITIONAL SUPPLY.

The active satisfaction that the people of the District of Columbia have felt over the condition of the water supply since the filtration plant was started in October, 1905, clearly justifies the assumption that any additional supply of water from the Potomac River must be purified. The question that naturally arises is whether new filters will be required for this purpose or whether the capacity of the present plant will be sufficient for the increased supply.

The filtration plant used for the present supply was designed for a rate of filtration of 3,000,000 gallons per acre per day. This was in accordance with the most approved practice at that time in Europe and in the United States; and any efforts to design the plant for rates higher than that would no doubt have met with vigorous opposition as being radical and unwarranted.

With the filtering area varying inversely with the rate adopted, and consequently the cost of construction varying nearly in that ratio, the consideration of the allowable rate of filtration for the large projects developed in the last few years has become of great importance. This has resulted in the recommendation and adoption of rates very much higher than formerly. For the new additional water supply of the city of New York, the consulting engineers, Messrs. Allen Hazen and Geo. W. Fuller, have approved the preliminary steps leading to a design which will involve rates of at least 6,000,000 gallons per acre per day for the entire flow of the new Catskill Aqueduct. This rate was most prominently mentioned in their communications, but they expressed their belief in the possibility of rates even somewhat higher.

Studies have been made and information obtained at the filtration plant in this city during the three years it has been in operation which indicate conclusively that it can be operated at a rate higher than 3,000,000 gallons per acre per day without any deterioration of the quality of the effluent. Filters Nos. 1, 2, 3, 4, and 5 were run at rates approximating 4,500,000 gallons per acre per day from December 14, 1906, to July 1, 1907. The remainder of the plant, twenty-four filters, was run during that period at a 3,000,000 gallon rate. The monthly averages of bacterial counts and turbidity for these two groups are given in the table below:

Date.	Filters 1 to 5, inclusive, rate 4,500,000 gallons per acre per day.		Filters 6 to 29, inclusive, rate 3,000,000 gallons per acre per day.	
	Bacteria per cubic centimeter.	Turbidity.	Bacteria per cubic centimeter.	Turbidity.
December 14–31, 1906	54	3	79	4
January, 1907	65	6	70	8
February, 1907	51	3	35	2
March, 1907	65	5	56	4
April, 1907	17	2	17	2
May, 1907	27	1	26	1
June, 1907	15	1	15	1
Average	42	3	43	3

Except for the different rates at which they were operated, the conditions influencing the two groups were identical. As far as bacterial efficiencies and turbidity results are concerned, the filters operated at a rate of 3,000,000 gallons per acre per day do not show any advantage over those operated at the rate 50 per cent higher.

During the month of September, 1908, certain experiments were started at the filtration plant with an equipment of small experimental filters for the express purpose of studying the effects of various rates of filtration upon the efficiencies of the process. It is intended to carry on this work for several years, in order to cover all possible conditions of temperature and of bacterial and turbidity contents of the Potomac water. General conclusions as to the laws governing the efficiency of filtration can not be drawn from the data so far obtained, but they do serve clearly to indicate that within a certain limited range the rate of filtration at the Washington plant may be increased without any deterioration in the quality of the effluent.

In the following table is given a summary of the results of operation of three of these experimental filters, by runs:

Summary of results of experimental rate studies for rates of approximately 3,000,000, 6,000,000, and 10,000,000 gallons per acre per day.

Date.	Days.	Rate.	Turbidities.		Total quantity per acre.	Bacteria.		Per cent of bacteria removed.
			Applied.	Filtered.		Applied.	Filtered.	
Filter No. 2, nominal rate, 3,000,000 gallons per day.								
Sept. 9 to Oct. 21, 1908	42	3.16	15	0	132.6	88	28	68.2
Oct. 23, 1908, to Feb. 3, 1909	104	3.39	12	0	352.5	3,325	30	99.1
Feb. 10, 1909, to date	(a)	3.20	33	5	....	837	92	89.0
Filter No. 3, nominal rate, 6,000,000 gallons per day.								
Sept. 10 to Sept. 24, 1908	15	6.24	14	0	93.6	....	....	....
Sept. 27 to Nov. 1, 1908	36	6.86	15	0	247.0	150	24	84.0
Nov. 4, 1908, to Jan. 18, 1909	76	6.71	10	0	510.0	4,250	48	98.9
Jan. 20, 1909, to date	(a)	7.30	30	4	....	570	75	86.8
Filter No. 4, nominal rate, 10,000,000 gallons per day.								
Sept. 10, to Sept. 24, 1908	11	8.6	15	0	94.4	....	....	....
Sept. 26 to Oct. 19, 1908	24	10.2	15	0	245.5	1,373	14	99.0
Oct. 22 to Dec. 6, 1908	46	10.7	10	0	492.0	6,695	29	99.6
Dec. 12, 1908, to Mar. 13, 1909	92	10.5	20	3	968.0	380	47	87.6

a Unfinished.

The averages indicate the effluent of No. 4 filter, operated at approximately a 10,000,000-gallon rate to be equal in quality to the effluent of either of the lower rate filters. The numbers of bacteria in the effluent during the several runs were no higher, and the percentage efficiencies were generally as great for the high rate as for the lower ones.

The range of conditions so far met in the experiments does not afford data for a comparison of results under conditions any more unfavorable than those shown in the above summary. It is believed that a water containing much greater numbers of bacteria than are normally found in the water applied to the Washington filters would be affected to a greater extent by the increase of the rate from 3,000,000 to 10,000,000 gallons per acre per day. But in view of the results of these experiments, and the tendency toward the use of higher rates in practice, the conclusion is entirely warranted that the Potomac water, in the condition in which it is applied to the filters during the greater part of the year, can be satisfactorily filtered at a rate of 6,000,000 gallons and probably at 10,000,000 gallons per acre per day. The present plant operated at the lower of these two rates would yield 150,000,000 gallons per day; and the maximum combined capacity of the old and proposed new aqueduct systems would necessitate rates not exceeding 7,500,000 gallons per acre per day.

Requisite conditions.—In order that the area of the present filtration plant may serve to purify this greatly increased quantity of water, attention must be particularly directed to certain interfering conditions which demand a remedy. It has just been stated that the rate of filtration could safely be increased providing the quality of the water as applied to the filters was as good as that now reaching the filters under ordinarily favorable conditions. This provision demands artificial improvement of the water in the reservoir system at those times when water of high turbidity and bacteria is unavoidably admitted to the reservoirs. With the existing reservoir capacity this necessity will increase as the consumption increases. The experiments conducted in 1907–8 upon the preliminary treatment of the Potomac water showed coagulation to be the only method that gave unfailing success in this improvement. Coagulation must therefore be considered an essential factor in adapting the present filtration plant to the higher rates. The process is entirely flexible and could be applied to whatever extent might be indicated by the results of filter operation. It does not involve any great expense. A project for this improvement has already been submitted to Congress, and has received the indorsement of the public health authorities.

The greatest physical difficulty in the operation of the filters at the present time is the abnormal shortening of the runs at certain times of the year due to the presence of large numbers of micro-organisms in the applied water. This causes sudden and uncontrollable reductions in the capacity of the plant, requiring heroic efforts lasting for many days to furnish the quality of water demanded by the city, sometimes at some risk to the high standard of quality that is so easily maintained under normal conditions. This difficulty likewise will increase with the rate of filtration. The logical remedy to apply is the elimination of these troublesome micro-organisms from the reservoir system. The trouble is believed to be due principally to one predominating form, Melosira. Treatment with copper sulphate is the common and most effective way of getting rid of such growths, and Melosira is quite sensitive to its action. With careful study and persistent effort this trouble can be avoided. This must be regarded as essential to the operation of the filters at the higher rates proposed.

Another physical difficulty in the operation of the filters arises from the abnormal fluctuations in the city's consumption during periods of severe cold weather. This is referred to at greater length elsewhere in this report. (See "Waste of water in winter of 1904–5.") The remedy, as there stated, is the application of meters to all services in the city, which will not only produce greater uniformity of draft, but will have the effect of increasing the working capacity of the filtration plant and the entire aqueduct system.

The filters, as stated, were designed for the normal rate of 3,000,000 gallons per acre per day. In order that they might be operated at the higher rates, certain changes would have to be made in the regulator houses and piping to adapt them to the new hydraulic conditions.

POINT OF DELIVERY OF ADDITIONAL SUPPLY.

In consideration of the conclusion just stated, the logical point of delivery of an additional supply of water is the McMillan Park reservoir adjoining the present filtration plant. The only exception to this would be in case an additional supply could be developed at a level high enough to deliver by gravity to the first high service of the city, which is now supplied by pumping. This case is considered in the Rock

Creek and the Seneca projects. In all the other projects studied it is assumed that the new supply will be delivered at McMillan Park reservoir.

In the case of the Great Falls gravity projects, the conditions controlling the hydraulic gradient and certain other features of the plan are therefore determined by the present normal water levels at Great Falls and McMillan Park reservoir.

SUPPLY FROM THE POTOMAC AT GREAT FALLS.

The Potomac River at Great Falls has a minimum flow approximately ten times as great as the present consumption of water in the District. The United States has a right to a large enough portion of the flow at that point to supply more than twice the present population of the District. The existing aqueduct dam at Great Falls holds the water at a level suitable for an additional supply from that point. The right of way of the old aqueduct is for the most part wide enough for the location of a new line within its limits. An additional supply from Great Falls would have the benefit of storage in the existing reservoirs. As already stated under "Treatment of the additional supply," a considerable part thereof could be filtered at the existing filtration plant without exceeding the limit of its proper capacity. In view of all these facts, the Potomac at Great Falls is a most logical source to consider for an additional supply of water for the District of Columbia.

Conditions affecting the general location of a new aqueduct from Great Falls.—The general route followed by the old aqueduct is the only surface route at the proper grade between Great Falls and Georgetown reservoir. About 5,400 feet of this is in tunnel. It would be entirely feasible to locate another aqueduct alongside the old one with but little more tunnel than that. In the Report of the Chief of Engineers for 1905, page 2613, Col. Smith S. Leach, then in charge of the Washington Aqueduct, advocated the choice of a new location separated from the old one. He said:

"With the idea of insurance paramount, the new conduit should not be built alongside the present one, but should follow a radically different course to reduce to a minimum the chance of a single cause disabling both. For this reason all possible alternative routes should be examined."

This paragraph has been frequently quoted, and the arguments implied therein clearly warranted the study of such a route.

Because of the fact stated in the first sentence of the above paragraph, any other location than that parallel to the present aqueduct would have to be largely in tunnel, at a considerably increased cost. Between Dalecarlia and McMillan Park reservoirs there are conditions, however, that render the separation of the old and the new lines an economical advantage. The total length of the old aqueduct system, from the inlet to Dalecarlia reservoir to the discharge into McMillan Park reservoir is about 37,500 feet, of which 20,700 feet is a pressure tunnel underneath the city. This length of pressure tunnel could not be avoided nor shortened in a parallel location. Furthermore, Georgetown reservoir is far removed from the direct line between Dalecarlia and McMillan Park reservoirs, and a much shorter line can be found than the old one. The new location proposed between these two points has a total length of 30,750 feet, of which 19,400 feet is in tunnel. Its total length is thus less than the other by 6,750 feet, and the length in tunnel less by 1,300 feet. As an additional advantage, the tunnel is all grade tunnel.

The separation of the two lines between Cabin Johns valley and Dalecarlia reservoir offers difficulties. From Great Falls to Cabin Johns valley a tunnel location is shorter than a location parallel to the old aqueduct; but from Cabin Johns Bridge to Dalecarlia a line separated from the present one would have to be not only wholly in tunnel, but materially longer. As this seems, on the whole, a reasonably safe section of the line, and as a consideration of the relative advantages of the two locations between Great Falls and Cabin Johns valley will be sufficient for Congress to determine upon a policy in regard to this point, but one location is given from Cabin Johns to Dalecarlia, and that one parallel to the old aqueduct. Between Great Falls and the Anglers' Club, a distance of about 2 miles, there are several places where the proximity of the Chesapeake and Ohio Canal would render impracticable the construction of a new aqueduct on the south or west side of the old one. There are but few places in this distance where construction on the side away from the canal would not be in tunnel. The parallel location is therefore shown as a straight grade tunnel from Great Falls to a point near the Anglers' Club.

For much of the distance between the Anglers' Club and Dalecarlia reservoir there would be but little difference in cost of construction on the north or south sides of the old line. There are several stretches, however, aggregating a good many thousand feet, in which the old location hugs the precipitous hillsides, which would make a high cost of construction on the north side. This location is therefore shown closely parallel to and on the south side of the old aqueduct.

Proposed locations for new aqueduct from Great Falls.—The proposed location designated herein as the "parallel location" is as follows: From Great Falls to a point near the Anglers' Club, at the head of the Conduit road, a straight grade tunnel; thence on the south side of the old aqueduct and parallel to it, cut-and-cover aqueduct, with one short tunnel, to the north end of Dalecarlia reservoir; a by-conduit thence, skirting the south shore and crossing at the narrowest point to the east end of the reservoir; thence a tunnel almost due east to Connecticut avenue extended, thence cut-and-cover aqueduct along the side of the valleys of the branch just north of Linnean Hill and of Piney Branch, to Fourteenth street; and thence a grade tunnel mainly under Spring road and Warder street to the north end of McMillan Park reservoir. The total length of this line, including the by-conduit around Dalecarlia reservoir, is 78,120 feet, of which 30,440 feet is in grade tunnel.

The proposed location designated herein as the "tunnel location" is as follows From Great Falls to a point on the west side of the valley near Cabin Johns Bridge, a grade tunnel; thence a short section of cut-and-cover aqueduct and a siphon crossing to the east end of the valley; from that point to McMillan Park reservoir the location is the same as already described. The total length of this line is 75,924 feet, of which 50,240 feet is in grade tunnel. These general locations are shown on sheet No. 1.

Grade of the new aqueduct.—The proposed Great Falls projects are designed to take water from the river at Great Falls and deliver it into McMillan Park reservoir. The hydraulic gradients at these two points are fixed by existing conditions in the old aqueduct system. Considerable change in these elevations could be made only at great expense, and no advantages are suggested which would warrant such changes. The elevation of the invert of the proposed new aqueduct has therefore been fixed for these two terminal points, as follows:

The depth of the aqueduct section it is proposed to use is 8.75 feet. The depth of the section of maximum discharge may be taken without much error to be 8.50 feet. At Great Falls the crest of the dam is at elevation 150.5 and the lowest recorded stage of the river is 150.7. The condition for maximum flow through the conduit at this point will be fulfilled if the invert be placed at such an elevation that the upper line of the section of maximum discharge coincides with the lowest recorded stage of the river. This fixes the invert at Great Falls at elevation 142.2.

At McMillan Park reservoir under existing conditions, the normal water level for the maximum capacity of 90,000,000 gallons per day is about 137.5. The conditions for maximum flow at this point will be fulfilled if the invert be placed 8.5 feet below this, or at elevation 129.0.

The elevation of intermediate points upon the systems proposed, depends upon a number of conditions. In the old aqueduct the invert at the outlet of Dalecarlia reservoir is lower than at the inlet by an amount sufficient to make the slope uniform and continuous through the main conduit and by-conduit. For the condition of maximum flow through the new system a similar design would not be advantageous. This condition may always be anticipated some time before maximum draft actually occurs, and the reservoir held in service. The hydraulic gradient across the reservoir will then be flat, and the inlet and outlet elevations of the invert may be the same. This assumption is an advantage. It reduces the total length to which the available fall must be apportioned, and thus permits the use of a steeper slope with a consequent diminution in the size of the section required.

The inlet and outlet gatehouses at Dalecarlia reservoir have therefore been assumed at the same elevation. The proposed project for additional storage at the Stubblefield site introduces the same question which can be determined only after a decision has been reached as to the adoption of that project.

No attempt has been made in this investigation to adjust the grades of the tunnel and cut and cover sections at different slopes for the maximum economy in construction. A study of this point before contracts for construction are let may result in a slight reduction in cost. In the projects submitted herewith, the total fall has been apportioned uniformly to the total lengths of the lines, excluding the by-conduits around Dalecarlia reservoir and around the Stubblefield reservoir, if provision is made for storage therein.

The length of the lines to the several gatehouses proposed are given below for the three conditions to be considered:

Length of the proposed lines.

	Parallel location.		Tunnel location.
	Without storage.	With storage.	Without storage.
	Feet.	*Feet.*	*Feet.*
Great Falls	0	0	0
Stubblefield reservoir:			
Inlet		17,700	
Outlet		21,800	
Dalecarlia inlet	47,370	47,370	45,174
Dalecarlia outlet	50,320	50,320	48,124
McMillan Park reservoir	78,120	78,120	75,924
Dalecarlia by-conduit	2,950	2,950	2,950
Stubblefield by-conduit		4,100	
Total deductions	2,950	7,050	2,950
Length to which the total fall of 13.2 feet is apportioned	75,170	71,070	72,974
Slope per 1,000	0.176	0.186	0.181

The uniform apportionment of the available fall to these several lengths gives elevations as follows for the gatehouses of the different projects:

Invert elevations at gatehouses.

	Parallel location.		Tunnel location.
	With storage.	Without storage.	Without storage.
	Feet.	*Feet.*	*Feet.*
Great Falls	142.20	142.20	142.20
Stubblefield reservoir:			
Inlet		138.91	
Outlet		138.91	
Dalecarlia reservoir:			
Inlet	133.88	134.16	134.03
Outlet	133.88	134.16	134.03
McMillan Park reservoir	129.00	129.00	129.00

Aqueduct sections.—The design of surface conduits of the class to which the proposed new aqueduct belongs has in recent years tended unmistakably toward the so-called "horseshoe section," as combining the advantages of economy in construction and good hydraulic efficiency. The question of the design of aqueduct sections was given careful consideration in the report of the commission on additional water supply for New York City in 1903, and they recommended sections of this general type. This recommendation was adopted, and is now being carried out in the construction of an aqueduct some 90 miles long and more than four times as large in sectional area as the one proposed for this city.

The tendency in the design of tunnels for this purpose has been to approach a rectangular-shaped section; or rather, a section of proper arch design which fits into an approximately rectangular tunnel excavation. This type of tunnel, too, has been adopted for the extensive New York work just referred to.

It is proposed to build both the cut-and-cover aqueduct and the tunnel sections of concrete masonry. This is to be quite generally of a single specified proportion. With the low velocities of the water in the conduit, the slight pressure, and with proper attention to the density of the concrete, no trouble need be apprehended either from wear or leakage. The requisite smoothness of the interior surface may be obtained in general by the proper troweling of the invert; by the use of metal forms of approved design for the entire interior surface above the invert, and by the careful spading and working of the freshly placed concrete in immediate contact with the forms. A careful study of local conditions at certain points on the line, especially in tunnel sections and in deep cuts, may indicate some economy in the use of brick laid in Portland cement mortar. Where this is the case, when contracts are let for this work, brick work may be specified, or perhaps better than that, alternative bids may be asked for brick or for concrete construction.

For a number of reasons that are now recognized as superfluous, it has been common practice to use a lining of brick in large aqueducts. There are therefore but few data at hand to indicate the hydraulic value of interior surfaces such as these proposed. The little information there is indicates a high value, and this is natural to expect from the smoothness of the surfaces that may be obtained. In the design of the various sections the Hazen-Williams formula has been used.

$$v = c r^{0.63} s^{0.54} 0.001^{-0.04}$$

A study of the data at hand indicates that a value for c of 125 will probably be a safe assumption after some deterioration of the surfaces, which is inevitable, shall have taken place.

The slope of the aqueduct can be definitely determined only after the location has been selected and the question of additional storage decided upon. For the purpose of estimating, a slope of 0.176 per 1,000 has been assumed, as determined by the length of the "parallel location" without additional storage. The adoption of the Stubblefield storage project would increase this slope to 0.186 with a slight reduction in the size of the aqueduct section. With this slope of 0.176 per 1,000, and the value c=125, aqueduct and tunnel sections of the general types already described have been designed and are shown on sheets Nos. 14 and 15.

Principal structures on parallel location.—At Great Falls the intake and gatehouse are combined as shown on sheet No. 16. A 48-inch drain leads from the gatehouse to a point below the dam which will give a free fall, thus providing for the drainage of the upper end of the aqueduct. From the gatehouse a tunnel leads to a point near the Anglers' Club, as shown on the general location sheet. At that point the new aqueduct is to be carried under the old one in a short tunnel from which a 24-inch drain will lead to the river. (Sheet No. 17.) The new line then follows the old one on the south side. It is proposed to cross Cabin Johns valley in a section some 70 feet below the hydraulic grade line, and upon a bridge of concrete masonry immediately over the stream. (Sheet No. 19.) The section is to be of steel pipe, entirely surrounded by concrete. A 24-inch blow-off will provide drainage for this portion of the aqueduct.

At the inlet of Dalecarlia reservoir a gatehouse is to be built. The new line will approach this reservoir on the south side and leave it on the north side of the old line. Some means must therefore be provided for crossing the one over the other. This can be done in the gatehouse at the inlet. The old by-conduit can be cut and the new gatehouse constructed as shown on sheets Nos. 20–21, and after the new line has been put in service the old aqueduct and the old by-conduit can be reconstructed for short distances and connected with their respective sets of gates in the gatehouse. From this gatehouse a 48-inch drain is to lead to the old diversion tunnel of Little Falls Branch.

The most direct and economical location for a by-conduit for the new line around Dalecarlia reservoir involves the crossing of the reservoir at the narrow neck near the south end. For this crossing a section of reinforced concrete has been designed, supported upon piers and arches of concrete masonry. (Sheet No. 21.) In order that the waters of the reservoir may at all times have an unobstructed flow over this crossing, the by-conduit has been lowered about 4 feet throughout its length. It may be drained through the drain at the inlet gatehouse.

The outlet gatehouse at Dalecarlia reservoir consists merely of a simple arrangement of gates for controlling the flow either from the reservoir or from the by-conduit into the aqueduct tunnel leading east from this point. (Sheet No. 21.)

This tunnel comes to the surface just west of Rock Creek. The valley of Rock Creek is about 1,400 feet wide at the grade of the aqueduct. The stream itself occupies the bottom of a comparatively narrow gorge which can be crossed by a bridge of moderate proportions, some 35 feet below the hydraulic grade line. The crossing has been designed as a steel pipe section carried upon such a bridge as this. (Sheet No. 22.) The bridge has been designed of a width suitable for a highway. A more economical structure could have been shown, but its location in the very heart of Rock Creek Park and the great value it would have as a much-needed high-level crossing of the valley, seemed to warrant the design. A 48-inch blow-off for drainage is provided at this crossing.

From the last tunnel beginning at about Fourteenth street and Spring road, the water will be discharged through a gatehouse containing a simple arrangement of controlling gates into the north end of McMillan Park reservoir, the most favorable location for deriving the maximum benefit from storage and sedimentation therein. (Sheet No. 22.) There is no point in the vicinity of this gatehouse low enough for its drainage, and the nearest blow-off on the aqueduct, at the Rock Creek crossing, would leave fully 2 feet of water in the gatehouse and lower end of the aqueduct. A small pumping equipment is designed to take care of the last drainage of this section. It consists of an 8-inch centrifugal pump submerged in a pump pit slightly below the level of the gatehouse floor, driven by a motor deriving its power from the dynamos in the filtration plant pumping station.

The description just given applies to the structures that would be needed simply to bring an additional supply of water from Great Falls to McMillan Park reservoir, by the "parallel location," with only the present storage facilities. The proposed project for additional storage of the supply at the Stubblefield site is presented elsewhere in this report. If this should be adopted the above description would not be materially altered. The proposed new reservoir would lie immediately alongside the aqueducts, to both of which it could be easily connected through appropriate gate houses. This would provide for the storage in the proposed reservoir of not only the new but also the old supply.

Principal structures on tunnel location.—For the tunnel location the structures at Great Falls are the same as for the "parallel location." The tunnel from that point takes a more northerly route and leads straight through to Cabin Johns valley near the bridge. Just west of the valley the line drops below the hydraulic gradient to cross on a small bridge passing through under the old Cabin Johns Bridge. This small structure is similar to the one proposed for the same crossing on the "parallel location," being located only a few feet away from the latter. The structures on the remainder of the line to McMillan Park reservoir are the same as already described for the "parallel location."

The tunnel location is far removed from the proposed new reservoir at the Stubblefield site, and there is therefore no simple way that these two projects could be combined. The scheme for storage in Cabin Johns valley could easily be combined with the tunnel location, but its inherent defects, elsewhere described, very properly eliminate that from consideration.

PRELIMINARY TREATMENT OF THE ADDITIONAL SUPPLY.

The imperative necessity for coagulation of the water before filtration with the increased rates at which it is proposed to operate the filters has already been pointed out. The coagulation project now ready to present to Congress for use in connection with the existing aqueduct system will provide for this treatment until the consumption exceeds the capacity of that system; and since it will be necessary to apply coagulant only for short periods, the one coagulating plant between Dalecarlia and Georgetown will probably serve satisfactorily for a capacity greater than that. The construction of a coagulating equipment for the additional supply may therefore be postponed until such time in the future as its need shall be shown.

The location of a future coagulating basin for the new aqueduct depends upon the adoption of the project presented herewith for additional storage. If a new reservoir is to be built at the Stubblefield site, the plant could be located at its outlet, and a favorable site could be found between that point and Dalecarlia reservoir for a sedimentation basin for the removal of the coagulated impurities. If the additional reservoir project is not adopted, the logical location for a coagulating plant would be at the outlet of Dalecarlia reservoir with a coagulating basin on the line of the aqueduct below that point. There is only one possible site east of Dalecarlia on the proposed new line. This is just east of Connecticut avenue in the valley of a small branch leading into Rock Creek. The difficulties of construction in this narrow valley are great, and property is expensive, and a preliminary estimate indicates an extremely high cost. If this site be put aside on the grounds of high cost, as seems advisable, the next location to consider for a coagulating plant for the proposed additional supply from Great Falls is the Stubblefield site. This site has not the natural advantage that the other one has in the preliminary sedimentation of the water before treatment by coagulation; and this deficiency would have to be made up for in construction at the Stubblefield site by building a combined basin for preliminary sedimentation and for coagulation. The total area need be but a small percentage of the area proposed for additional storage alone at that site. An area of 20 acres, properly baffled and paved for drainage and provided with a coagulating equipment and necessary gatehouses, could be constructed for $300,000. This would give a total capacity of about 100,000,000 gallons, and this is believed to be ample for the purpose. In the light of the knowledge that should be gained from the operation of the plant it is proposed to build in connection with the old system at Dalecarlia and Georgetown reservoirs, the equipment for the proposed new system at the Stubblefield site might be built for considerably less than the sum above named.

The coagulation of the old supply below and the proposed new supply above Dalecarlia reservoir would make it necessary to prevent the mixing of the two supplies in Dalecarlia reservoir during coagulating periods. The mixing of an unsedimented water with a water that has been partially or wholly clarified by sedimentation or preliminary treatment is a decided disadvantage. In order to do this, the inlet gate house at Dalecarlia reservoir would have to be redesigned to provide separate channels for the two supplies through it; and when the Stubblefield coagulating plant was in operation, the supply from the proposed new system would be carried through the by-conduit at Dalecarlia and direct to McMillan Park reservoir. The inlet gatehouse at Dalecarlia reservoir, redesigned to meet this requirement, would cost about $72,000.

If the proposed new line from Great Falls were already in operation, the most economical and satisfactory arrangement would be to provide one large combined sedimentation and coagulation basin for both old and new supplies at the Stubblefield site. In view of the fact, however, that coagulation of the old supply is needed now, the project should be carried out as already proposed, between Dalecarlia and Georgetown reservoirs, and the decision in regard to the separate or combined coagulating plant at the Stubblefield site reserved until the time when its construction shall be required.

In the estimate of cost of the Great Falls gravity project, a sum is included sufficient to cover the cost of a coagulating equipment for the proposed new supply at the Stubblefield site, and also a sum sufficient to cover the increased cost of the inlet gatehouse at Dalecarlia reservoir in the event of the adoption of the two separate coagulating equipments instead of the single one for both.

Costs of the Great Falls projects.—Estimates of cost of the two alternative lines from Great Falls to McMillan Park reservoir have been prepared with all possible care. The unit prices assumed are believed to be generous enough so that any modifications that may be made in the estimates will tend to reduce rather than to increase the total costs over those indicated. The estimates are given in detail in Appendix E, and a condensed summary thereof is given below.

The probable prices of land required for the projected work have been obtained by conversation with a number of real estate men and with the county surveyor of Montgomery County. An allowance has been made in the estimate for the cost of tunnel rights, the value of a strip on the surface 25 feet wide and directly over the proposed tunnel lines being given for this purpose.

For the purpose of estimating the quantities of excavation, embankment, masonry, etc., in the masonry aqueduct and tunnels, three types of section were assumed for each, as follows:

Masonry aqueduct: (1) In soft earth; (2) in compact earth; and (3) in earth and rock.

Tunnel: (1) Rock, untimbered; (2) rock, timbered; and (3) earth, timbered.

It is believed that these six sections will constitute a percentage of the total length in actual construction great enough to warrant their use in the estimate of cost for this report. Exact information is not at hand as to the materials that will be penetrated in construction, but much light is shed upon this point by an acquaintance with the old aqueduct. With this knowledge, supplemented by careful surface observations, these six typical sections were apportioned to the total length of the lines to be estimated.

The estimates were made up from the profile of the center line of the proposed structures. Tables were constructed giving the quantities for various depths of center cut, with corrections to be applied for cross slopes. From these tables the quantities were tabulated for each 100-foot station of the line, and from these summaries were made of the total quantities in continuous lengths of sections of a given type.

The following condensed summaries give the costs of the two alternative locations for the Great Falls gravity project:

Condensed summary of estimated cost, parallel location.

Aqueduct, standard section, 44,622 feet	$1,102,562.00
Tunnel, standard section, 30,440 feet	1,389,650.00
Crossing and sections of unusual type, 2,918 feet	310,825.00
Gatehouses, other structures, land, etc	626,346.00
Engineering and contingencies	450,000.00
Total estimated cost	3,879,383.00
Estimated cost of construction per linear foot:	
Aqueduct, standard section	24.71
Tunnel, standard section	45.65
Crossing and sections of unusual type	106.50
Estimated total cost of entire system per linear foot	49.60

Condensed summary of estimated cost, tunnel location.

Aqueduct, standard section, 22,894 feet	$606,061.00
Tunnel, standard section, 50,240 feet	2,280,650.00
Crossing and sections of unusual type, 2,650 feet	287,336.00
Gatehouses, other structures, land, etc	609,639.00
Engineering and contingencies	550,000.00
Total estimated cost	4,333,686.00
Estimated cost of construction per linear foot:	
Aqueduct, standard section	26.46
Tunnel, standard section	45.40
Crossing and sections of unusual type	108.40
Estimated cost of entire system per linear foot	57.20

ADDITIONAL SUPPLY OBTAINED BY PUMPING.

From the Potomac just above the Little Falls.—A supply of water could be obtained from the Potomac just above the Little Falls, and delivered by pumping into Dalecarlia reservoir. Such a project would render unnecessary the construction of a new aqueduct between Great Falls and Little Falls. The first point for consideration in the comparison of this with the Great Falls project is that of cost.

The costs to be compared are the following: The costs of construction and capitalized cost of maintenance and operation—

(1) Of aqueduct from Great Falls down to point of location of pumping station.
(2) Of pumping station at Little Falls.

From the estimates already made, the cost of construction of that portion of the Great Falls gravity project necessary to bring 75,000,000 gallons of water per day to the point of location of the Little Falls pumping station would be about $1,560,000. The cost of maintenance and operation of this portion of the Great Falls project would be about $15,000, which capitalized at 3 per cent amounts to $500,000. This makes a total capitalized cost of the Great Falls gravity project to this point of $2,060,000.

The conditions under which a pumping station would work at Little Falls are as follows: The station would be designed to deliver ultimately 75,000,000 gallons per day, the same as the Great Falls project; this would be lifted against a head of about 110 feet, to the hydraulic grade line in Dalecarlia reservoir.

The cost of complete installation of pumping machinery, station, etc., to lift 75,000,000 gallons per day to a height of 110 feet may be roughly estimated at $400,000. No preliminary designs or refined estimates are presented because the capitalized cost of maintenance and operation alone make careful consideration of this point unnecessary. The pumping expense which will be found considered at some length elsewhere in this report (see Appendix B) is taken at $0.04 per million gallons lifted 1 foot high. On this basis the annual cost of pumping 75,000,000 gallons per day to a height of 110 feet would be about $120,000. This sum capitalized at 3 per cent would amount to $4,000,000, making a total capitalized cost for this pumping project of $4,400,000, or more than twice as much as the Great Falls gravity project from Great Falls to this point.

From the Potomac near the city.—A supply of water could be obtained from the Potomac River at some point near the city which would render unnecessary any of the construction involved in the Great Falls gravity project. Obviously the water taken from the river near the city would have to be both pumped and purified. The purification could be effected either in a new filtration plant near the intake or at the present filtration plant, the capacity of which is discussed more fully elsewhere in this report. (See "Treatment of additional supply.") The hydraulic grade line of the gravity portion of the District distribution system is approximately at elevation 140, or practically the same as the elevation of McMillan Park reservoir, adjoining the filtration plant, the elevation of which may be taken as 143.

All the water would have to be pumped to this height anyway, and therefore the construction of additional filters could be avoided by pumping from the river station to McMillan Park reservoir and filtering the water at the present plant. This fixes the conditions for pumping, which would be as follows: The station would be designed for a nominal capacity of 75,000,000 gallons per day; this would be lifted against a head of about 143 feet plus the friction in the pipe lines.

A favorable site for such a pumping station may be found on the reclaimed land owned by the United States near the new highway bridge. This site would be especially advantageous on account of its proximity to the tidal reservoir, a portion of which would have to be converted into a basin for the preliminary treatment of the muddy Potomac water before pumping it up to mix with the waters of McMillan Park reservoir which have undergone several days of sedimentation.

The cost of pumping 75,000,000 gallons against a head of say 150 feet, at a cost of $0.04 per million gallons 1 foot high (see Appendix B), would be $164,200 per year. This capitalized at 3 per cent would amount to $5,473,000. The cost of pumping equipment, pipe lines, preliminary treatment, sewer diversion, etc., would increase this by more than $2,000,000. The capitalized cost of this project, when the total quantity of 75,000,000 gallons per day had been developed, would be greater than the capitalized cost of the Great Falls gravity project complete, which would be about $5,879,383.

High cost of pumped supply.—The above paragraphs set forth in a general way the two principal possibilities of obtaining an additional supply of water for the District of Columbia by pumping. In both of them, the total cost, based upon a preliminary pumping cost which is representative of the best class of stations in the country, is far and away higher than the cost of bringing the additional supply by gravity from Great Falls. This makes unnecessary any consideration of the unfailing reliability, the much greater permanence, and certain other advantages in favor of the gravity system. The question of pumping the water supply for the District of Columbia from the Potomac River may therefore be finally dismissed.

SUPPLY FROM ROCK CREEK.

In the investigations of half a century ago which led up to the construction of the present aqueduct system, Rock Creek was considered in some detail as a source of supply. The Rock Creek projects were rejected in favor of the Great Falls project because of the practically unlimited supply available at the latter source. The early reports state the limiting quantity available from Rock Creek under dry-weather conditions at about 10,000,000 or 12,000,000 gallons per day. It is readily evident that a quantity considerably greater than that could be developed by impounding, and that source was therefore made the subject of further investigation.

Area of watershed.—The drainage area of Rock Creek is given by the United States Geological Survey as 86 square miles. Only a portion of this could be used for collecting a supply for the District of Columbia. At the site which has so far seemed most favorable for a dam, located in a narrow valley just west of Brightwood and north of the Military road, the drainage area as determined by planimeter from the United States Geological Survey topographical maps is 62.8 square miles. Of this, about 3.5 square miles is or promises to be distinctly suburban and should in the event of the adoption of such a project as this be sewered and diverted from the reservoir. The effective drainage area has therefore been assumed as 59.3 square miles.

Available quantity.—The total discharge of streams of the Rock Creek class commonly lies between 1.0 and 1.5 cubic feet per second per square mile. This would correspond to 40,000,000 to 60,000,000 gallons per day. The dry weather flow, as stated in the old reports, did not exceed 10,000,000 or 12,000,000 gallons per day, and recent observations indicate even smaller discharges. Storage of the flood waters would therefore be essential to the success of this plan.

The only information available as to the discharge of Rock Creek was in the records of the United States Geological Survey. This was very meager and not sufficient to use as reliable basis for computation of the supply that the stream might furnish. The matter was therefore referred to the hydrographic branch of the Geological Survey, and the following memorandum was received in response:

Memorandum on the mean annual flow of Rock Creek, Maryland.

Rock Creek drains a total area of 86 square miles. Records of flow were obtained from August, 1892, to November, 1894, which showed in 1893 the low rate of run-off of 0.703 second-foot per square mile, and even lower rates for the partial years of 1892 and 1894.

There is no apparent reason for discrediting the accuracy of these records, nor can this period be considered abnormally low. A comparison with the annual run-off of the Susquehanna River at Harrisburg, Pa. (see table), tends to show that the rate of flow in the East was generally normal at this time, although, of course, this can not be considered conclusive as regards the rate of flow of Rock Creek.

A comparison of flow of streams in the vicinity of Rock Creek is given in the appended table. With the exception of Antietam Creek, these show a generally high rate of run-off, although Patuxent River, which is nearest to Rock Creek, is somewhat lower than Monocacy and Patapsco rivers. The discharge data in this table are compared on the basis of a seven-year period, 1900 to 1906. This period gives the same values as the longer period of 1897 to 1907, inclusive.

If no information were available other than the flow of neighboring streams, it would be advisable to give Rock Creek a lower value than Patapsco, Deer, and Monocacy rivers, owing to the tendency to a progressive decrease in the rate of run-off of streams from north to south. Furthermore, more weight should be given to the Patuxent River records, because this stream is immediately adjacent to the Rock Creek drainage. On the basis of these neighboring streams alone, it is probable that a run-off per square mile of 1.3 second feet would be a conservative estimate for Rock Creek. Other considerations, however, lead me to believe that this value is much too high.

It is noticeable that the axes of all tributaries of the Potomac River are approximately at right angles to the prevailing direction of storms. A study of the flow of the various tributaries shows that in general the rate of flow of the long narrow basins is less than the flow of wide circular basins. The Monocacy River, which belongs to the latter class, shows a higher rate of run-off than any other stream in the Potomac River drainage with the exception of two tributaries near the source of the Potomac. Antietam Creek and the South Branch of the Potomac River show very low rates of run-off and are long, narrow basins. They average about 1.1 second-feet per square mile. All small tributaries to the Potomac from Cumberland to Point of Rocks average 1 second-foot per square mile. These are all long and narrow and comparable with Rock Creek in shape and size. This general law of shape to run-off seems reasonable. Storms in general tend to a high rate of precipitation on ascending slopes and a low rate on descending slopes, hence in long narrow basins at right angles to the direction of a storm a larger percentage of the total area would receive a relatively lower rate of precipitation than in the case of a circular drainage.

I have been quite intimately acquainted with the general conditions of flow of Rock Creek for the past five years and particularly so for the past year. Rock Creek is noticeable for its generally low flow, averaging not more than 40 second-feet at ordinary stages, and as is the case with other small streams, showing very short flood periods. It seems to have the general characteristics of other small streams in the Potomac River basin and in addition has more than two years records of flow, which there is no good reason to doubt, which show an abnormally low rate of flow. Hence, in my judgment, it would be unsafe to use a higher figure than 1 second-foot per square mile for mean annual flow of Rock Creek, and I believe that 0.9 second-foot would be a more conservative value to use.

R. H. Bolster, *Assistant Engineer.*

Mean annual run-off per square mile.

Year.	Antietam Creek, Md. (Sharpsburg).	Monocacy River, Md. (Frederick).	Rock Creek, Washington, D. C.	Patuxent River, Md. (Laurel).	Patapsco River, Md. (Woodstock).	Susquehanna River, Pa. (Harrisburg).	Deer Creek, Md. (Churchville).	Little Gunpowder Falls, Md. (Belair).	Great Gunpowder Falls, Md. (Glencoe).
Drainage area, sq. miles	295	600	86	137	251	24,000	141	43	160
1892						1.55			
1893			0.703			1.69			
1894						1.66			
1895						1.22			
1896						1.44			
1897	a 1.13	1.49		1.36	1.68	1.34			
1898	1.00	1.59			a 1.26	1.69			
1899	1.18	1.59			a 1.69	1.29			
1900	.65	1.09			a 1.14	1.25			
1901	a 1.00	1.53			a 1.58	1.74			
1902	1.39	2.50			1.92	1.96			
1903	1.71	2.72			2.57	1.98			
1904	a .70	1.06			a .83	1.35			
1905	a .79	1.65			a 1.40	1.45	1.49	1.50	1.60
1906		1.87			1.85	1.28	1.60	1.77	1.48
1907		2.17			1.78		b 1.80	2.12	b 1.67
1900 to 1906 inclusive.	1.09	1.77		c 1.36	1.62	1.59	1.54	1.73	1.51

a Partial year, missing days supplied by a coefficient derived from the ratio of Antietam to Frederick.
b Missing months estimated.
c Based on comparison of 22 months at Laurel with corresponding 22 months at Woodstock.

As a significant addition to this memorandum, the chief of the hydrographic branch of the Geological Survey made the statement that the only Rock Creek gaugings available (those of 1892, 1893, and 1894, of which 1893, the only complete year is noted in the memorandum), were taken at a time when stream measurement was in an experimental stage. On the strength of his knowledge of the conditions and the work done prior to 1895, he was inclined to discredit the Rock Creek gaugings quoted and rely upon the indications given by neighboring streams.

The substance of this is that but little is known of the total discharge of Rock Creek. It may be as low as the conservative estimate of 0.9 cubic foot per second per square mile, or it may be as high as 1.3 cubic feet per second per square mile, as indicated by the neighboring streams. For an area of 59.3 square miles, these two rates of run-off would yield, respectively, about 35,000,000 and 50,000,000 gallons of water per day.

The entire flow of the stream could not be diverted for water-supply purposes. Rock Creek flows through Rock Creek Park and the Zoological Gardens, which are visited daily by thousands of the people of Washington for rest and recreation. The stream is a most important feature of these public parks and any diversion which would mar its beauty would undoubtedly meet with justifiable and strenuous opposition on the part of the park commissioners and the people. The utilization of the waters of Rock Creek by storage, for the additional supply of water for the District, would therefore require a definite reserve secure against encroachment, for maintaining a satisfactory flow in the stream as it passes through Rock Creek Park.

The question of the proper quantity for maintaining the flow of the stream through the park has not been taken up officially with the park commissioners, as such official consideration would not be a controlling factor in determining the value of this project. For the purposes of this investigation it has been assumed that about 18 cubic feet per second, or 12,000,000 gallons per day, should be allowed for this purpose. An examination of the available stream-flow records for the years 1892, 1893, and 1894 shows that the flow in Rock Creek was less than this assumed quantity for 50 per cent of the time during the three dry months, August, September, and October, of those three years. The quantity available for additional supply, with the entire discharge of the stream impounded, would then be, upon the basis already set forth, between 23,000,000 and 38,000,000 gallons per day, or roughly from one-third to one-half the nominal capacity of the existing aqueduct system.

Storage capacity required.—The Geological Survey, recognizing the errors arising from the use of rainfall records in the determination of river discharge, state their figures as given above, in cubic feet per second per square mile, which figures are independent of the rainfall factor. While presumably giving a more accurate total discharge, these figures give no indication of the variations thereof and consequently are useless for the estimation of the amount of storage required. Recourse was therefore had to rainfall records for this purpose. A study was made of the relation between rainfall and run-off, by months, for certain of the neighboring streams for which there were discharge records covering a number of years; and the result of this study was a curve which should afford an approximate indication of the monthly variations in the stream flow of Rock Creek, and of such magnitude that the accumulated discharge for an eighteen-year period should correspond to 1.1 cubic feet per second per square mile, the average of the estimated discharges already referred to. This curve is given in diagram No. 1. It indicates that in order to have conserved the entire flow of the stream during the eighteen-year period represented, an impounding reservoir must have had a capacity above the lowest working level equivalent to 14.6 inches of rainfall over the drainage area of 59.3 square miles; and with this storage the average quantity available would have been about 40,000,000 gallons per day, or about 28,000,000 gallons per day for water supply after providing 12,000,000 gallons for maintaining the flow in the stream through Rock Creek Park. This computation is based upon rather meager data, but the best available. Fourteen and six-tenths inches over the drainage area of 59.3 square miles is equivalent to about 2,000,000,000 cubic feet.

Elevation of storage reservoir.—The elevation of the crest of the dam forming the storage reservoir depends upon two principal factors, the elevation of the minimum flow line or lowest working level and the depth of storage capacity required above that level.

The general elevation of the minimum flow line depends principally upon the service to which the water is to be delivered. The flow lines of the different services in the city are well established. The gravity supply from Great Falls fixes that of the gravity service, and no circumstances surrounding either the present supply or any supply that might be derived in future from Rock Creek seem to suggest any advantage in a change in general flow line elevations. Of the total consumption in the District of Columbia, about two-thirds go to the gravity service, about one-fourth to the first high, and the comparatively small remainder to the higher services. It would be a distinct advantage to be able to deliver a supply derived from Rock Creek at elevation 210, the flow line of the first high service, and do away with a large amount of pumping now required. This could be done. Furthermore, the necessity of having an impounding reservoir of large capacity to make this source feasible, would fix the minimum flow line at a high level anyway. To the extent to which this project has been carried it has, therefore, been assumed that the supply would be developed at such a level that it could be delivered to the city by gravity at elevation 210.

This advantage of greater elevation would necessitate purification works separate from and at a higher elevation than the existing ones. An allowance of 30 feet for the loss of head through the filters and through the pipe line to the city, and for aeration if necessary, fixes the minimum flow line in the reservoir at elevation 240.

The capacity of the valley immediately above elevation 240 is given in diagram No. 1. Two thousand million cubic feet of water, the storage necessary in order to secure the maximum supply from the stream, would fill the valley from elevation 240 to approximately elevation 257.5. For the purpose of a preliminary investigation this evation was assumed for the spillway level and the top of the dam at elevation 260.

General features of the project.—Having approximate figures for the quantity available for water supply from Rock Creek, the location and crest elevation of the dam, etc., a general lay-out was made of the location of structures essential to the full development of this project. This is given in sheet No. 25. The project would require the construction of a dam at the site and with the elevation already mentioned. Just below the dam, filters would be built through which the water would flow by gravity to a filtered water distributing reservoir immediately adjoining. From this reservoir a steel pipe line would lead to a connection with one of the 48-inch mains of the first high service, with a short branch to McMillan Park reservoir through which a large quantity of raw water could be delivered for a limited time from Rock Creek to that reservoir in the event of accident or repairs to the old aqueduct system. The constant diversion at the dam for maintaining the stream flow in Rock Creek would be utilized for the development of power for the operation of the filtration plant. The flooding of the valley above the dam would necessitate the purchase of some 4,000 acres of land and all improvements thereon, the relocation of several miles of county roads, railroads, and electric roads, with the construction of embankments and bridges over the reservoir. A regard for the sanitary quality of the supply would demand also the diversion or the disposal of the sewage from the suburban districts adjoining the reservation site. An electric power station at Chevy Chase Lake would have to be removed and reconstructed.

Cost of the project.—A preliminary estimate of the cost of the various portions of the project is presented in the table below. For a fair comparison with the costs of the other projects, the capitalized value of the annual cost of operation of the entire system is included, thus giving the total capitalized cost of the project. A deduction is necessary for the cost of pumping 28,000,000 gallons of water per day 70 feet high, as the adoption of the Rock Creek project would virtually effect a saving of this amount over the cost of the Great Falls project at the lower level.

Preliminary estimate of cost, Rock Creek project.

Main dam and spillway	$1,250,000
Electric generating station and machinery	10,000
Filtration plant and reservoir	750,000
Pipe line to first high service	450,000
Sanitary drainage of towns	250,000
Land	800,000
Damage to buildings, Forest Glen Seminary, etc	275,000
Reconstruction of Chevy Chase power station	100,000
Relocation of county roads, with embankments and bridges	450,000
Relocation of railroads, with embankments and bridges	730,000
Relocation of electric roads, with embankments and bridges	250,000
Engineering and contingencies	800,000
Estimated total construction cost	6,115,000
Annual operation, filtration plant, $30,000, which capitalized at 3 per cent.	1,000,000
Annual operation, rest of system, $15,000, which capitalized at 3 per cent.	500,000
	7,615,000
Annual cost of pumping 28,000,000 gallons per day 70 feet high, at $0.04 per million gallons 1 foot high, $28,600, which capitalized at 3 per cent.	950,000
Estimated net capitalized cost for comparison with Great Falls project	6,665,000

The enormous cost of this plan, and the limited quantity of water that could be obtained for an additional supply, make any further consideration of this project unnecessary.

Supply from Rock Creek at lower level.—In the estimate just given, the large items of expense are for the high dam required, the filtration plant, and the relocation of roads, railroads, and electric roads. The development of a supply from this source at a lower level, with delivery direct to the existing filtration plant, would eliminate some of this expense and reduce all.

A supply could be developed from Rock Creek with its minimum working level at elevation 185, which would give ample head for its delivery by gravity to the filters at elevation 165. A computation from the available data indicates that a dam with crest at elevation 227 would give adequate storage. This development would require the purchase of only about 1,750 acres of land instead of the 4,000 estimated above. The dam required would be smaller. From the dam a pipe line would lead to a connection with the raw water distribution system to the filters.

A preliminary estimate of the cost of the several portions of this development is as follows:

Main dam and spillway	$500,000
Pipe line to filtration plant	416,000
Sanitary drainage of towns	250,000
Land	355,000
Relocation of roads, railroads, etc	545,000
Engineering and contingencies	300,000
Total	2,366,000

Since writing the above in regard to the available capacity of this source, authoritative statements have been received, based upon wide experience, that indicate the available capacity considerably higher than stated above, namely, about 40,000,000 gallons per day after making allowance for stream flow through Rock Creek Park. On the basis of this increased quantity the development of a supply from Rock Creek at the lower level, with its much lower cost, seems attractive.

The increasing value of real estate, with the rapid suburban growth in the direction of the upper valley of Rock Creek may put a different light upon this point, due to the prohibitively high cost of the large area required, by the time new works will be necessary. At the least, any conclusion upon this point must be left to be determined by future conditions.

PROJECT FOR BRINGING WATER AT HIGH LEVEL FROM SENECA CREEK.

Seneca Creek, which flows into the Potomac about 8.5 miles above Great Falls, has a drainage area of about 127 square miles. The available portion of this area would yield, with storage, 75,000,000 gallons per day or more. This could be impounded at an elevation considerably higher than the Potomac at Great Falls, and could be delivered to the city at least as high as the first high service, elevation 210, thereby effecting a saving in the pumpage of between 25 and 30 per cent of the total supply. This would involve the purification of this portion in new filters located at a high level, and the delivery of the balance of the supply to McMillan Park reservoir for purification in the existing filters. A suitable site could be found for filters and reservoir on the high ground west of Georgetown.

The principal structures required for this development would be a dam across Seneca Creek; an aqueduct to the city; filters and reservoir; connecting pipe lines to the city and to McMillan Park reservoir.

Dam near Seneca.—No topographical maps are available for the Seneca region except those of the United States Geological Survey on the scale of 1:125,000. The much greater distance and the roughness of the topography above Great Falls, indicated without much question that the development could not be as economical as the Great Falls project, and therefore the extensive surveys that would have been required for its full presentation were not undertaken. Without attempting, with the meager data in hand, to obtain an economical balance between slope of aqueduct and height of dam, the slope and section were assumed the same as for the Great Falls aqueduct. This condition would fix the crest of the dam at Seneca at about elevation 270, after making allowances for reservoir fluctuations and losses of head through aqueduct, filters, and pipe lines. The maps of the Geological Survey indicate that a dam just above Seneca with a crest at elevation 270 would have a length of about 1,400 feet and a maximum height of 130 feet. Such a dam would cost in excess of

$2,000,000. Land for reservoir, relocation of roads, clearing, draining, etc., would cost perhaps $500,000 more. As the available data on this point are very meager, a generous assumption is made for the purpose of comparison of this with the Great Falls project, that the dam and reservoir at Seneca would cost no more than in Cabin Johns Valley—that is, about $1,400,000.

Aqueduct from Seneca to Washington.—The lengths of the different types of structures for the aqueduct would be about as follows:

	Feet.
Length in cut-and-cover aqueduct	78,500
Length in tunnel	11,500
Length in inverted siphon, bridge, etc., including all valleys 50 feet deep or more	20,000
Total length	110,000

These would cost, on the basis of the average estimated cost of similar types of sections for the Great Falls project:

78,500×$24.72	$1,940,000
11,500×$31.23	359,000
20,000×$78.50	1,570,000
Total cost of aqueduct	3,869,000

Filters, reservoirs, etc.—Filters for purifying the supply for the first high service would have to have a capacity of about 30 per cent of the total supply. After the increase of the supply this would be about 45,000,000 gallons per day. A filtration plant of 9 acres would properly purify this quantity. This would cost, together with land, gatehouse, sand-washing equipment, etc., about $1,000,000. A distributing reservoir for filtered water would cost $100,000.

Connections with city and McMillan Park reservoir.—Pipe lines to the city would cost about $200,000, and to McMillan Park reservoir about $300,000 more.

Cost.—A summary of the approximate cost of bringing a supply of water from Seneca Creek is given below. In order to make it comparable with the estimated cost of the Great Falls gravity project, the maintenance and operation charges are included, giving the total capitalized cost; and a deduction is made for the cost of pumping which would be saved in the event of the adoption of a high level project, such as this.

Summary of estimated cost of Seneca project.

Dam, reservoir, lands, etc., near Seneca, at least		$1,400,000
Aqueduct		3,869,000
Filters, reservoirs, etc		1,100,000
Connections with city and with McMillan Park reservoir		500,000
Engineering and contingencies		820,000
Total construction		7,689,000
Maintenance and operation per year:		
Aqueduct system	$30,000	
Filtration plant	30,000	
Total maintenance and operation	60,000	
Which capitalized at 3 per cent		2,000,000
Total capitalized cost of Seneca project		9,689,000
Credit for cost of pumping saved: 45,000,000 gallons per day, 70 feet high, at $0.04 per million gallons 1 foot high, $46,000 per year, which capitalized at 3 per cent		1,533,000
Estimated net capitalized cost of Seneca project, for comparison with Great Falls project		8,156,000

The estimated cost of the Great Falls gravity project, complete, is $3,879,383. If the maintenance of this system be estimated at $30,000 per year, and the additional cost of maintenance and operation at the filtration plant be $30,000 more, the total capitalized cost of this project in its final development would be about $5,879,383. The estimated capitalized cost of the Seneca project is so greatly in excess of this that it may be dismissed from any further consideration in this report.

GROUND-WATER SUPPLY.

As a source of a large supply of water for the District of Columbia the ground water can not be seriously considered. A ground-water supply for this city would mean one drawn from wells driven into the water-bearing gravel deposits underlying the District. Very few large cities have supplies of this kind, and it may be stated that only under most exceptional conditions would a city of the size of Washington depend upon such a supply if a supply of surface water were available.

The city of Brooklyn, N. Y., draws half or more of its supply from the sands of Long Island. The geological formation of Long Island is unusually favorable for a large storage of ground water in readily available form for a well supply.

The experience with so-called "deep wells" in the District of Columbia has demonstrated the presence of water-bearing strata quite widely distributed, but the conditions are far less favorable than on Long Island. The average yield from 21 of the deep wells of the District is about 40 gallons per minute. It would require 1,350 wells of this capacity to supply 75,000,000 gallons per day.

Flowing wells can not be obtained in this locality. Such a supply as this would involve continuous pumping, and in general the projects we have outlined involving continuous pumping cost more than the gravity projects. The pumping, moreover, would have to be at a number of isolated stations, as the wells obviously could not all be grouped together, and this would tend to make the cost of pumping still higher.

It may be suggested as an advantage in favor of a ground-water supply that no filtration would be required. The data at hand do indicate, it is true, that a deep-well supply, locally so-called, would be of excellent sanitary quality without filtration; but the quantity of iron in this water would make its general use prohibitive without subjecting it to some process for the removal of the iron. Presumably aeration and filtration would be necessary and sufficient and therefore the high sanitary quality of such a supply would not be an economical advantage.

From the known facts regarding the mutual interference of wells placed in groups, and the uncertainty of any predetermination of the quantity of water that might be drawn from the water-bearing strata underlying the District of Columbia, such a plan could not be entered upon with any assurance of success as to quantity developed nor as to relative economy. A single well or a small group of wells may make an ideal supply for private consumers or for industries of some magnitude, but it does not afford a generally satisfactory solution of the problem of securing a sufficient and unfailing supply for a large community.

ADDITIONAL SUPPLY FROM THE UPPER BRANCHES OF THE POTOMAC RIVER.

The idea of bringing a supply from the upper branches of the Potomac River has been suggested. It would be possible, of course, and the idea appeals to the layman who thinks only of the purity of a stream near its source.

The confluence of the two forks of the south branch of the Potomac which lies just above the town of Petersburg, W. Va., is about 115 miles from Washington in a direct line. Assuming that construction over this line were a possibility, the cost of bringing water from that source, at the same total cost per linear foot as the Great Falls gravity project, would be about $24,000,000. The advantage argued for such a distant source is the pristine purity of the water, but that term is only relative. The possibilities of the pollution of supply from even the most remote source are so great, and the protection afforded by filtration has been so thoroughly demonstrated, that there is a strong tendency toward the filtration of all surface supplies. The purification of the water from the Potomac at Great Falls has been so eminently satisfactory as to bring forth favorable comment from every authority. Cities that are going great distances for supplies from mountain sources are commonly doing so not because of a fear of the efficiency of purification processes but because of the insufficiency of nearer sources. The expenditure of this great amount of money for an additional supply would be entirely unwarranted under existing conditions.

RAISING THE DAM AT GREAT FALLS.

The quantity of water flowing through the present aqueduct system could be increased by raising the dam at Great Falls, which would increase the slope of the hydraulic gradient. Such a plan is limited by two considerations:

(1) Interior pressure on aqueduct.

(2) Damages due to raising the water level above the dam.

The old aqueduct, where not in tunnel, is of brick masonry and was not designed for nor expected to resist any interior pressure. In some places it is actually under a pressure of as much as 3 or 4 feet but the strength to resist this pressure lies in the earth embankment over it. From this consideration it would therefore not be safe to make much of a raise in the hydraulic gradient at Great Falls.

The principal parties that might be damaged by raising the water level above the dam at Great Falls are the Great Falls Power Company and the Chesapeake and Ohio Canal Company. The Great Falls Power Company owns Conns Island, which would be partially or entirely submerged. This island has very little intrinsic value, but its submergence might be made the pretext for another expensive damage suit by that company against the United States. The Chesapeake and Ohio Canal Company holds property along the Maryland side of the stream above Great Falls. Any considerable damage done them would be at times of freshet in the river. The question of the limiting height of the dam from this point of view has been considered before. Mr. Josiah Pierce, jr., chief engineer of the Great Falls Power Company, in 1902 or earlier, conferred with Mr. Nicolson, chief engineer of the Chesapeake and Ohio Canal Company, with reference to the safe elevation for the crest of a dam at this point, and they reached the conclusion that elevation 153, or 2.5 feet above the present crest, was as high as it would be safe to build it.

If the dam were to be raised 2.5 feet, the capacity of the aqueduct system would be increased by less than 10,000,000 gallons per day. The dam has already been raised once, and to raise it again simply by placing more material on top would lower its factor of safety to a dangerous point. It would be necessary, therefore, to increase the mass of the dam throughout its height, and the cost would probably be about $500,000.

In view of the limitations to such a plan as this, together with its cost and the small increase it would make in the capacity of the system, its consideration seems of small importance.

WASTE OF WATER IN WINTER OF 1904-5.

During the winter of 1904-5 there occurred the greatest draft that the aqueduct system has ever been subjected to. The maximum daily consumption rose almost to 100,000,000 gallons, corresponding to a quantity in excess of 300 gallons per capita per day. This abnormal draft lasted the greater part of January and February, and made the mean consumption for the year 70,600,000 gallons per day, whereas the mean for nine months of the year, excluding the winter months, was only 67,100,000 gallons per day.

The days of abnormal draft occurred invariably when the temperature was low. It has been the common experience of a great many cities to have the consumption jump up to a considerable percentage over the normal upon the occurrence of freezing weather. There is no mystery as to where the water goes. Fixtures are opened freely in all parts of the city to create a current in the house service pipes sufficient to prevent the freezing thereof. The high consumption here referred to was without doubt caused by just such waste as this. There is nothing inherent in freezing weather that would tend to increase the legitimate use of water. The tendency would, if anything, be in the other direction. There is nothing, either, which would tend to increase the waste from fixed leaks in mains or service pipes. The greater part of the excess of the abnormal draft over the normal consumption may therefore, without much chance of error, be charged to the waste of water from open fixtures to prevent freezing.

The effect of the increase in the consumption of water in the city is to draw down the levels of the reservoirs. In an aqueduct system a certain slope of the water surface is required to produce the flow of a certain quantity, and the greater this quantity the greater must be the slope. If the quantity taken from the lower end of the system be increased, the greater quantity flowing through the aqueduct system to replace it adjusts itself to the steeper slope required. Since the water level at the upper end of the system is not susceptible of control, it therefore follows that this adjustment to the steeper slope involves the lowering of the water levels in the lower end of the system, including the reservoirs. This may be seen from the "Discharge diagram of the Washington Aqueduct," Appendix D, whereon are platted lines indicating the slopes the water takes for various volumes of discharge.

The greatest disadvantage resulting from this abnormal draft upon the system arises from the conditions fixing the safe annual average consumption that the system is good for. As has been stated, the maximum capacity of the system is 90,000,000 gallons per day, and under existing conditions an occasional abnormal draft may be expected 45 per cent in excess of the mean daily consumption for the year. Nearly a third of the ultimate capacity of the system must therefore be held in reserve to meet these periods of abnormal waste. Remedying the condition by cutting down the percentage excess will obviously have the effect of increasing the safe working capacity of the entire system.

Another disadvantage resulting from the drawing down of the reservoirs of the aqueduct system is that it results in a reduction of the available reserve that would constitute the only source of water supply for the city in the event of the interruption of flow in the aqueduct. It reduces also the reserve available for maintaining the supply to the city when the consumption exceeds the maximum quantity which can flow through the aqueduct. The reduction of the quantity of water in the reservoirs, ogether with the increase in quantity flowing, combine to make a great reduction in the time it takes for water to pass through the reservoirs, and consequently in the degree of purification effected thereby.

The high consumption of January and February, 1905, drew down the levels of the reservoirs to an alarming extent. It reduced the total quantity of water that could possibly be drawn from the three reservoirs in the event of an interruption of flow above Dalecarlia reservoir from 400,000,000 to about 275,000,000 gallons, or from six days' supply at the normal rate of consumption to less than three days' supply at the rate existing at the time of the depletion. This total quantity, practically speaking, would not have been available, as the rate at which it could be drawn would have dropped off rapidly. Under these conditions water could have been supplied to the city in quantity sufficient for ordinary uses and for effective fire protection for only thirty to forty hours.

The high consumption also reduced the quantity that could be drawn at or in excess of the limiting capacity of the system from 156,000,000 to 32,000,000 gallons. In other words, if the cold weather and the maximum rate of consumption had persisted five days longer, this small reserve would have been used up; and thereafter until the reservoirs were again filled, any demand in excess of the limiting capacity could not have been supplied. The relations between the abnormal consumption, the temperature, and the depleted storage are shown graphically in Diagram No. 2.

Such a condition as this might arise, in greater or less degree, any winter. There has been nothing approaching the consumption of February, 1905, during the winters since then, as they have been, by comparison, very open and free from severe and long continued cold weather. An examination of the temperature records kept in this office for about forty years indicates that a winter no less severe than that of 1904–5 has occurred in about one year out of five.

Remedies for this condition.—The problem of predicting a recurrence of such a condition as this with possible disastrous results is entirely indeterminate in view of the highly indeterminate character of the two factors controlling it, namely, the severity of the winters and the amount of the flagrant waste that goes on at such times. An interruption of the flow in the aqueduct when conditions such as these might prevail is equally indeterminate, but the possibility thereof is set forth elsewhere in this report, and in that possibility lies the contingent one of a disastrous water famine.

There are two remedies that might be applied, both of which aim at holding the reservoirs as full as possible. This could be done either by lifting the entire supply by means of pumps located at the inlet of the first, or Dalecarlia, reservoir; or by taking proper measures to prevent the extreme waste in freezing weather, thus holding the total quantity of water demanded down within a reasonable percentage of the normal and maintaining naturally the normal conditions of a storage.

Pumping station at inlet of Dalecarlia reservoir.—All the functions desired of a pumping station at this point would be fulfilled by an equipment having a capacity of 90,000,000 gallons per day against a head not exceeding 6 feet. The quantity of water pumped can not exceed the limiting capacity of the aqueduct above that point; and the head need not exceed that necessary to lift it up to the elevation of the spillway of Dalecarlia reservoir, which is 146.5.

Preliminary designs have been prepared for a pumping station of this capacity, and are shown on sheet No. 24. The station would consist essentially of three 36-inch vertical shaft centrifugal pumps, each directly connected to a horizontal shaft engine. These would be placed in a bay along the east side of the station and would discharge directly into the reservoir. From the corner of the building a dam would extend south across the inlet channel, and in this dam would be placed gates which would ordinarily be wide open, but would be closed when it was desired to raise the reservoir level by putting the pumps in operation. The engines would be driven by steam generated in a boiler plant in the west half of the building.

In the construction of this plant the dam, with its gates, could be built complete in a cofferdam, after which the gates could be left wide open and the pumping station completed ready for operation without interrupting the flow through the conduit; or the reservoir might be by-passed and drained and the construction carried on with the reservoir out of service throughout the construction period.

The cost of such a pumping equipment is estimated approximately as follows:

Pumping station building, coal storage, sluice gates, etc	$20,000
Three pumps and engines complete	18,000
Two 100-horsepower steam boilers, with automatic stokers	6,000
Stack, piping, valves, crane, etc	12,000
Engineering and contingencies	9,000
Total construction	65,000

Measures for preventing cold-weather waste.—The cold-weather waste that causes the condition now under discussion is a result, as has been stated, purely of wanton waste from house fixtures. This is entirely under the control of the individual water taker, who, in the absence of a meter on the house service, can carry on this practice undetected. If his service is metered, he will not, as a rule, let the water run to prevent freezing of pipes; if he does prefer this method, at his own expense, he will at least waste it judiciously and pay for what he wastes. In the waste problem in the District of Columbia, if there were no meters on any of the services, but the pitometer investigations were pushed until the entire city had been covered, the most aggravated form of waste then remaining would be this cold-weather waste from house fixtures, which puts such a drain upon the limiting daily capacity of the system. Using this as the basis for argument, and assuming no other means for protecting the city against possible water famine some winter, the remedy clearly would be a meter on every service in the city.

Relative costs and advantages.—The complete pumping equipment at Dalecarlia reservoir for lifting the water high enough to keep the reservoir system filled up, would cost $65,000. The annual operating charges it is believed would not exceed $3,000, which, capitalized at 3 per cent, would be $100,000, making a total capitalized cost of protecting the city by this means of about $165,000.

The cost of applying meters to every service in the District is estimated elsewhere at about $775,000.

A comparison of these two costs should not be construed as indicating an advantage in favor of the pumping station for the purpose of remedying this cold-weather condition. If this were the one and only benefit to be derived from the universal use of meters, the pumping station would be the more economical remedy, but the other benefits of metering are many, as may be seen by referring to that subject. The pumping station project has no advantages over the other, but from its very nature is designed to encourage the waste of water by furnishing a supply by means of which householders could protect themselves as they do now against the annoyance of frozen pipes. The United States and District governments are not benevolent institutions, and should not in justice be expected to afford protection against structural defects in the houses of water takers, each one of whom could protect his own plumbing at small expense.

There are, moreover, certain disadvantages of the pumping-station project in comparison with the policy of universal metering:

(1) The possibility of an excess draft of 40 to 50 per cent over the normal would reduce to a large extent the opportunity for excluding muddy water from the reservoir system in time of freshet.

(2) It would cause an increased cost of pumping at the filtration plant.

(3) It would cause an increased cost of filter operation at the filtration plant.

(4) It would bring an increased burden on the filters at a time when all natural conditions are least favorable for a high degree of purification.

(5) It would cause an increase in the cost of pumping that portion of the water going to the high services of the District.

(6) It would cause diminished pressures in the city mains.

(7) It would not effect the remedy that would be to a large degree effected by the universal metering of services, in reducing the maximum percentage excess over the normal consumption and thereby increasing the safe working capacity of the system and postponing the time when new works would be required.

These are all disadvantages caused by abnormal fluctuations in the daily demand. The greatest economy in many respects and the greatest efficiency of the filters may be obtained by uniformity in the daily consumption, and this can be obtained in no way so well as by the universal use of meters. Although it would involve a greater cost, the universal application of meters to house services would produce benefits which are indispensable to the District, none of which would be brought about by the pumping-station project. And these facts, together with the arguments already presented in favor of the universal metering of services for other reasons than the abnormal winter consumption, point emphatically to this as the most advantageous policy to be followed for the avoidance of risk of shortage of water during severe and long-continued freezing weather.

PROJECT FOR ADDITIONAL STORAGE OF WATER SUPPLY.

The existing aqueduct system includes three reservoirs through which under ordinary conditions the water passes successively before going to the filters. The total storage area is about 125 acres. The period of effective storage therein for a flow of 65,000,000 gallons per day is about four days. The natural purification effected in the three reservoirs is shown in the following table:

	Percentage of turbidity remaining after passing reservoirs.		Percentage of bacteria remaining after passing reservoirs.		Percentage of 0.10 c. c. samples containing B. coli after passing reservoirs.	
	1907.	1908.	1907.	1908.	1907.	1908.
Dalecarlia inlet	100	100	100	100	61	45
Dalecarlia outlet	40	45	40	43	58	32
Georgetown outlet	32	38	35	47	51	34
McMillan Park reservoir outlet	25	27	13	20	33	22

It is evident at a glance that there is great value in the storage to which the present supply is subjected. The percentage removal of turbidity and of bacteria is large. With no storage whatever, the operation of the filters would be impracticable during certain periods and the excellent sanitary quality now obtained in the filtered water would be impossible.

The degree of natural purification thus effected depends upon the length of the period of effective storage. The future increase in the rate of flow through the reservoirs with increasing consumption will cause a reduction in the storage period and a consequent reduction in the efficiency of removal of turbidity and bacteria. When the draft on the system shall have increased to twice the present consumption, the results of all parts of the purification process, both in the reservoirs and in the filters, will have become decidedly poorer than those now obtained. Besides the purification due to storage, a large influencing factor in this is the length of the period during which freshet water of high turbidity and high bacteria can be excluded from the system. This becomes shorter and shorter as the draft increases, thus requiring the introduction from year to year of increasing quantities of water of this kind, and it is this water which yields the poorest quality of filtered water. It is possible under present conditions to exclude freshet water for about three days, after which the gates must be opened to avoid a dangerous depletion of the reserve supply. This is sufficient in many cases to avoid the worst of the turbid conditions. It is rarely enough to avoid all, and frequently fails to exclude the worst of it. Before the consumption reaches the limit of the capacity of the two systems it may be possible to exclude the turbid water for but little more than one day, which will greatly aggravate the above conditions.

In order to maintain the high standard of quality of the water supply of the District which has been set during the three years of operation of the filtration plant these conditions will demand some remedy, the necessity for which will increase as the years go by.

The advocates of additional storage have in mind not so much the mere maintaining of present high standards under conditions of increasing complexity, but rather the actual improvement of the quality of the raw water. Much has been said and written upon the relations between typhoid fever and polluted water in Washington. While it is generally accepted that the Potomac water before filtration was not as large a factor in the causation of typhoid fever in the District as was formerly believed, the probability of the occasional infection of the supply and the consequent appearance of the disease under the old conditions is denied by no one. And while from the standpoint of the best bacteriologic knowledge the effluent of the filters has in general been excellent and, as far as could be ascertained by an able commission, not responsible for the spread of the infection, still it is recognized that the process of filtration does not produce a sterile water, and that at certain times of the year large numbers of bacteria are found in the effluent of the filters. The storage of a water supply containing the specific germs of typhoid fever causes a progressive reduction in its numbers. Additional storage is therefore advocated as an added safeguard against the possibility of the introduction of disease-producing organisms into the water supply.

Storage possibilities investigated.—There are two sites, either of which could be adapted to use as a reservoir of large capacity. One of these, Cabin Johns valley, could be used with either the parallel or the tunnel location. The other, the so-called "Stubblefield site," could be used only with the parallel location.

The Stubblefield site is a comparatively flat area of some 180 acres lying between the old aqueduct and the Chesapeake and Ohio Canal about 4 miles below Great Falls. A reservoir could be built upon this site by the construction of earth embankments around three sides, somewhat similar to the present Georgetown reservoir. These long embankments or dikes would be the principal item of expense of this project. There would also have to be two gatehouses and a drain. The details of this project are shown on sheet No. 23.

The designs for this project show a by-conduit extending from inlet to outlet gatehouses, a distance of 4,100 feet. Experience in the operation of the old aqueduct system has shown the necessity for by-conduits around the reservoirs, and most particularly around the one nearest the intake; and their capacity should be great enough to offer little or no more restriction to the flow than would be met in an equal length of main aqueduct under conditions of maximum discharge. This condition would necessitate the construction of the by-conduit, as shown, some time before the consumption should have reached the limiting working capacity of the old and new systems combined. Its construction at present would be unnecessary, however, and this would effect a saving of $100,000 or more in the first cost of construction. Gate openings should be left in the gatehouses and stubs built to facilitate the future construction of the by-conduit. The cost of the by-conduit is not deducted from the estimate, as it would some day be required to complete the system.

A detailed estimate of the cost of this project is given in Appendix E, a summary of which follows:

Summary of estimated cost of reservoir at Stubblefield site.

Land	$36,200
Clearing and grubbing	5,790
Embankment, paving, etc	1,028,396
Inlet gatehouse	50,025
Outlet gatehouse	50,025
Sluice tower, etc	30,152
Engineering and contingencies	180,000
Estimated total cost of construction	1,380,588

The valley of Cabin Johns Creek could be turned into a reservoir by the construction of a dam above Cabin Johns Bridge. This possibility seemed seductive at first. The area of the valley at high-water level of the reservoir is about 230 acres. The dam to form this reservoir could be built for less than $650,000. The important difficulty in the problem lies in the disposition of the freshet flow of the stream. This project does not purposely contemplate the use of the water at Cabin Johns Creek for the supply. The flow of the stream is probably often less than 5,000,000 gallons per day. It would either flow into the proposed reservoir, however, or else expensive diversion works would be required to prevent this. Any objection to its discharge into the reservoir would be on account either of physical or bacteriological impurities.

The bacteriological condition of the water of this stream is shown by the following data obtained from the examination of weekly samples covering a period of some seven months; and for the sake of comparison, similar figures for the Potomac River water for approximately the same period:

	Cabin Johns Creek.	Potomac River.
Average number of bacteria per cubic centimeter	1,350	3,230
Percentage of samples of 10 cubic centimeters or less which contained Bacillus coli	23	24

This indicates the water of Cabin Johns Creek to be at least as good and probably somewhat better in sanitary quality than that of the Potomac River. This consideration does not make it either necessary or desirable at the present time to exclude the water of this stream from the reservoir. The increase in population in the future might make it desirable to do so.

In physical condition the water of Cabin Johns Creek is similar to that of the Potomac. At ordinary stages it carries but little turbidity, but in freshet it carries a great deal. In a general way, maximum turbidity and maximum volume of discharge are coincident; and the flood flow of this stream would at times be sufficient to displace all the clear water in the reservoir with very turbid water in a short time, thus defeating one of the main objects of additional storage. The ordinary flow of the stream could be easily diverted, but the diversion under the difficult conditions of topography there found of a possible freshet flow approaching 4,000 cubic feet per second would involve an expense that would be absolutely prohibitive. The project has been thoroughly studied and a scheme for the storage and gradual diversion of ordinary freshets worked out in detail. This scheme would not be effective in the total exclusion of the waters of the stream during high or prolonged floods. The excess over the combined capacity of the diversion channel and the flood storage basins would overflow into the reservoir, thus completely defeating at such times, as stated before, one of the important objects sought in additional storage.

Designs have been made for all the works necessary to carry out the Cabin Johns Valley storage project along the above lines. Because of the defects in the project, these are not presented with this report, but are filed in the office of the Washington Aqueduct. An estimate shows that its cost, if used in connection with the parallel location, would be $1,610,102, or about 17 per cent more than the project for storage at the Stubblefield site with the same aqueduct location.

Storage in Cabin Johns Valley without complete diversion of the waters of that stream would not accomplish the objects desired. A scheme for its partial diversion only would make the cost of the project considerably higher than that for storage at the Stubblefield site. The latter has none of the complicating disadvantages of the former, but would make an excellent reservoir in every respect. For the additional storage of Potomac water for the supply of the District of Columbia the Stubblefield site therefore offers the best advantages to be found. The reservoir outlined for this site on sheet No. 23 has an area of about 140 acres, which is somewhat larger than the combined area of the three existing reservoirs of the aqueduct system.

Opinions of authorities upon the question of additional storage.—The value of this portion of the report dealing with the additional storage of the water supply should be increased by the comment of authorities upon this point. During the summers of 1906 and 1907 a board of officers of the United States Public Health and Marine-Hospital Service was engaged in an exhaustive study of the typhoid fever situation in the District of Columbia. Through this study they became thoroughly familiar with the question of the storage of the Washington water supply and the benefits resulting therefrom. A request was therefore made of the Surgeon-General of that service for an expression from that board or some member thereof upon the sanitary advantages to be derived from additional storage of the supply.

In response to this request, the following communication was received:

SURGEON-GENERAL, PUBLIC HEALTH AND MARINE-HOSPITAL SERVICE,
TREASURY DEPARTMENT,
Washington, D. C., April 17, 1909.

SIR: I beg leave to acknowledge the receipt of your letter of the 23d ultimo, relative to plans for increasing the water supply of the District of Columbia, and requesting the opinion of the board of officers engaged in the investigations of typhoid fever in the District of Columbia as to the advantages of providing additional storage for the water supply of Washington.

In reply, there is forwarded herewith a copy of a letter from Passed Asst. Surg. L. L. Lumsden, acting chairman of the above-mentioned board, containing the opinion as requested.

Respectfully,

WALTER WYMAN,
Surgeon-General, Public Health and Marine-Hospital Service.

Maj. JAY J. MORROW,
United States Engineer Office, Washington, D. C.

PUBLIC HEALTH AND MARINE-HOSPITAL SERVICE,
HYGIENIC LABORATORY,
Washington, D. C., April 14, 1909.

SIR: Referring to a letter of March 23 from Major Morrow, Corps of Engineers, in regard to the advisability of additional storage to meet the increasing water supply of the District of Columbia, and referred on March 29 by the bureau to the chairman of the typhoid fever board for an expression of an opinion, we have the honor to submit the following:

The results of our bacteriologic studies have shown that from 55 to 86 per cent of the total bacteria in the Potomac River are removed by storage in the three sedimentation reservoirs before the water is applied to the filter beds.

Besides the removal of the bacteria, the storage clears the water of much sediment which would clog the sand filters, making necessary more frequent cleaning of the beds and so causing greater difficulty in the operation of the filters to accomplish the desired purification of the water. Believing the storage to be an important part of the system for the purification of the water, we recommended in our report on typhoid fever in the District of Columbia for 1907 (Hygienic Laboratory Bull. No. 44, p. 60) "that in order to furnish a water supply of a satisfactory grade of purity throughout the year, additional storage reservoirs shall be constructed, or a coagulant (alum) shall be used during periods of high turbidity."

We believe that, with an increase in the water supply, it would be highly advisable to have storage reservoirs of increased capacity, and we would recommend that such increased storage capacity of the reservoirs be made sufficient to give the water a considerably longer period of storage than is done with the present supply.

Respectfully,

L. L. LUMSDEN,
Passed Assistant Surgeon, Acting Chairman Typhoid Fever Board.

The SURGEON-GENERAL, PUBLIC HEALTH AND
MARINE-HOSPITAL SERVICE.

The health officer of the District of Columbia was also asked to express his views on the subject of additional storage, and he submitted the following letter:

HEALTH DEPARTMENT,
Washington, D. C., April 3, 1909.

DEAR SIR: In reply to your letter of the 22d ultimo, I beg to say that I am heartily in favor of action looking toward an increase in the storage capacity of the water supply system of this District. The terrors of a water famine in a community of this size are so apparent as to render an effort to describe them unnecessary; and the fact that an increase in the storage facilities would, in proportion to the extent of such increase, diminish the danger of a water famine in event of an accident to the conduit or conduits above the storage reservoirs would alone justify a very considerable expenditure for the purpose of providing such an increase. The occasions, however, upon which the storage facilities of our water supply system will be called into use for the purpose of averting a water famine will presumably, in the future as in the past, be few and far between. It is important, then, to realize that the advantages to be derived from an increase in such facilities would not be limited to such rare occasions.

The figures already published by your office show beyond question the extent to which storage alone will remove bacteria and other suspended matter from the water, and demonstrate that an increase in the storage facilities would be of permanent and continuous sanitary benefit to the community. Even though the sources of our water supply may not be at all times polluted with infective organisms, and even though our water supply as it comes into the city may not be responsible for the undue prevalence of typhoid fever in this community, nevertheless we know that the sources of our water supply are exposed to infection and that after infection occurs it is too late to begin to adopt preventive measures. Increased storage facilities should, therefore, be provided without waiting for the occurrence either of a water famine or of a water-borne outbreak of disease.

The fact that we have an efficient filtration plant standing between the city and the danger of a water-borne outbreak of disease does not do away with the desirability for an increase in our storage facilities. The more extensive storage facilities the less will be the work thrown upon the filter beds and the more efficiently and economically can they be operated; and this will be true not only during periods of excessive turbidity of the Potomac River, when a large storage capacity would permit the river water to be shut off until the excessive turbidity had subsided, but it will be true also at other periods. The fact that increased storage will diminish the work to be performed by the filtration plant will, moreover, postpone the time when it will be necessary to enlarge our filtration facilities, which in any event, with the growth of the community, must sooner or later be done. The increased purification of the water, resulting from the extension of storage facilities, would moreover, in event of the occurrence at any time of any accident that would prevent the use of our filtration plant, render it possible to deliver with greater safety unfiltered water to the community.

As a protection against water famine, as a measure that will tend to assure at all times a pure, safe water to the community, and as a measure that will render it possible more economically to operate our filtration plant and that will postpone the time when an extension of that plant will be necessary, the establishment of additional storage facilities seems to me to be highly desirable.

Very respectfully,

WM. C. WOODWARD, M. D., *Health Officer.*

Maj. JAY J. MORROW,
United States Engineer Office, Washington, D. C.

COAGULATION AS A SUBSTITUTE FOR ADDITIONAL STORAGE.

The objects of additional storage capacity may be briefly summed up as follows:

(1) To compensate for the detrimental effect upon the physical and bacteriological condition of the water due to the shortening of the period of storage with increasing draft on the system, by providing for a longer period of exclusion of undesirable water and a longer period of sedimentation and storage for all water.

(2) To effect an actual additional improvement, aside from the compensating effect just referred to, in the physical and especially in the bacteriological condition of the water, by the same means above mentioned.

(3) To increase the reserve available for the supply of the city in the event of an interruption of the flow in the aqueduct above the point of storage.

The necessity for attaining at least the first of these objects has been elsewhere discussed, and here need only be emphasized again. It is pertinent to consider, however, whether an additional reservoir is the only means or the best means to this end; and also whether any other means suggested would give the improvement mentioned in the second object.

In the discussion of the increase in the capacity of the existing filtration plant by a simple increase in the rate of filtration, strong emphasis was laid upon the necessity for the coagulation of the water during occasional turbid periods. The whole subject of the preliminary treatment of the water was investigated and reported upon at length by this office in February, 1908, and coagulation was found to be unquestionably the only feasible method. The conclusions of that report have been properly approved. The Medical Society of the District of Columbia has publicly given its indorsement to that method of treatment. A project and estimates for the coagulating treatment are ready to be submitted to Congress. In view, therefore, of the necessity for this treatment in connection with increasing the capacity of the filters, its great importance in the improvement in quality of the water during periods of high turbidity, and its unqualified approval by the proper engineering officials and by the medical society, coagulation may be considered an assured adjunct to the aqueduct system and filtration plant in the future.

Coagulation can be made to give exactly the objects desired in (1) above by effecting the sudden precipitation and removal of a large percentage of both turbidity and bacteria in any quantity in which they are likely to enter the system. In fact, coagulation is more flexible and its efficiency could be more constantly depended upon than could that of any system of reservoirs feasible to construct as a part of the Washington Aqueduct system. This fact is generally recognized, and data are given in detail in support of the case in hand, in the report of February, 1908, on the "Preliminary treatment of the Potomac water." Under present conditions it is proposed to coagulate the water only during periods of high turbidity. Under conditions of greatly increased consumption the same specification would hold, only the periods would be longer and more severe.

These arguments apply with equal force to the attainment of the second object (2). The investigations and report of February, 1908, were carried out with that specific object in view and the conclusions of that study remain unchanged. The only point in which coagulation, as proposed, could not effect an improvement equal or better than could be brought about by additional storage is in the bacteriological condition of the water accompanying low turbidity. It is not proposed to use any coagulant at such times. Admitting the efficiency of the coagulation treatment at times of high turbidity, the advisability of additional storage for the purpose of improving the bacteriological condition of the water depends upon the strength of the arguments in favor of this particular point.

The conditions that exist in the aqueduct system during these favorable periods are characteristically as follows: The water is relatively clear. The bacteria in the river water commonly number only a few hundred, and *B. coli* is not detected in samples as large as 10 c. c. for periods of two or three weeks at a time. In the water that has passed through the three existing reservoirs there are periods as long as four months during which the bacterial counts do not exceed 100 c. c., and frequent periods of a month or longer during which *B. coli* is not detected in 10 c. c. or less. This is certainly proof positive that there is no large and constant sewage pollution in the unfiltered water. This water, fair in quality, as it is, is then filtered through filters of the most modern type. More than three years of experience has demonstrated the efficiency and reliability of these filters. There is no reason to believe that they would not give results beyond criticism in the filtration of Potomac water direct from the river under the favorable condition just assumed.

In view of the excellent purification that can be and is now effected in the passage of the water through the three reservoirs and then through the filtration plant, it would be a nice question, involving deeper knowledge than we now have of the laws governing the persistence of disease-producing organisms in natural and artificial processes of water purification, to be able to state definitely that the danger of infection of the filtered supply was real and great enough to warrant any such expenditure as would here be required to provide another reservoir in this already efficient system.

The excellent results of filtration, as judged from the highest bacteriological standards, lead strongly to the belief that this would not be warranted for the sole purpose of improving the bacterial quality of the water in the absence of any considerable turbidity. And since coagulation is proposed only for turbid water, and is all sufficient for that condition, an additional reservoir is not necessary for the attainment of the objects (1) or (2) set forth above.

The argument of relative cost is strongly in favor of coagulation. The first cost of the completion, construction, and equipment for this process for the old aqueduct system has been generously estimated at $130,000. The maintenance and operating cost, likewise estimated high in order to cover the worst conditions that might occur the first year, is $14,120. This capitalized at 3 per cent is $470,000, making the total capitalized cost not in excess of $600,000. The first cost of the storage project is estimated at considerably more than twice that amount.

The proposed new reservoir, if constructed, would be 17,700 feet from the intake at Great Falls. This new reservoir, to fulfill the object defined in (3) would, in other words, afford some measure of protection against water famine, due to an accident in less than 25 per cent of the length of the aqueduct system. Considered as insurance, the cost of this would be enormous, amounting to about $78 per linear foot for the 17,700 feet above the reservoir; and, furthermore, it would be but imperfect insurance, because it would be limited by the available capacity of the reservoir. If the argument of insurance were of great enough importance, perfect insurance could be provided by other means at much lower cost than that.

From a consideration of the foregoing facts there appears to be no argument that imperatively demands the construction of an additional reservoir in connection with the present or the proposed new aqueduct system.

LANDS REQUIRED FOR THE PROJECTED WORK.

The lands required for the construction of the proposed aqueduct system are generally shown on the location plans. For the parallel location but little additional land will have to be taken west of Dalecarlia reservoir, because the new line will be located for much of the distance within the present limits of the aqueduct right of way. In order, however, to guard against the possibility of damage suits due to construction operations requiring more room than lies within these limits, the estimate for land includes a sum large enough to purchase a strip averaging 25 feet wide from the Anglers' Club to Dalecarlia reservoir. There are five small areas, aggregating 2.7 acres, that are clearly necessary for the construction, and these are indicated on the location plans.

East of Dalecarlia reservoir the aqueduct goes directly into tunnel until Rock Creek Valley is reached. It is not proposed to purchase land over the tunnel line, but an amount is included in the estimate as compensation for tunnel rights.

Across Rock Creek Valley the location plans and estimates indicate a 100-foot right of way for the aqueduct in cut and cover. This amounts to 6.8 acres.

In the event of the adoption of the project for additional storage at the Stubblefield site, an area of about 181 acres will have to be taken. This is indicated on the Stubblefield location plan.

The fact that it is considered unnecessary to recommend the immediate construction of the proposed works for increasing the water supply should not deter the United States from acquiring the lands necessary for these works. Certain of the lands, especially those lying within the District of Columbia, are constantly increasing in value and should be purchased at an early date.

SUMMARY AND CONCLUSIONS.

This investigation of the problem of increasing the water supply of the District of Columbia was undertaken in the belief that the increasing consumption was dangerously near to and would soon exceed the safe limit of the capacity of the existing aqueduct system. Up to a year or so ago this belief was entirely justified, as the published figures on the consumption of water clearly show. In the reports of the officers in charge of the Washington Aqueduct in the past several years, recommendations have been made for various measures designed to meet this condition. Among others were recommendations that steps be taken to suppress the large waste of water. The water department of the District began active prosecution of this work about two or three years ago. Because of the uncertain efficiency of measures for the suppression of waste, dependence was not placed, however, upon this alone, but the preliminary work for the increase of the supply herein reported upon was undertaken.

The efforts of more than two years in the elimination of waste have produced results. From these results, which are set forth in some detail in Appendix A, the following facts may be stated. A large part of the water supplied to the city is wasted. A great reduction has been effected in this waste. A still further reduction can unquestionably be effected by the means now in the hands of the water department. With this large amount of waste once suppressed, the maintenance of a moderate force for the specific purpose of the examination of the distribution system by the means now in use will insure the city against any considerable increase in the underground waste in the future. It is shown, also, that while there exists a tendency for the per capita daily consumption to increase from year to year in most cities, this tendency does not seem to exist in cities that have become thoroughly awakened to the possibilities of waste prevention. These facts warrant the conclusion—

(1) That the per capita daily consumption and waste of water in the District of Columbia in the next few decades will be somewhat lower than it has been during the last few years.

The figures given in Appendix A, showing the actual results that have been accomplished; the high degree of efficiency of the corps engaged in the work of waste elimination, as shown by the current weekly reports of the results of their work; the large area of the city so far untouched by the waste surveys; the consistent reduction from month to month throughout the past year in the quantity supplied to the city from the filtration plant; and the consideration of the question of future population of the District; these facts give safe grounds for the conclusion—

(2) That the total consumption and waste of water in the District in the next few years will be far enough below the safe working capacity of the existing aqueduct system to make it entirely safe to postpone the construction of new works until fuller and more definite results are available of the measures for the prevention of waste, which will afford a more reliable figure for the future per capita consumption than we are now justified in assuming.

The consideration by the officer and the assistants in charge of the Washington Aqueduct, and by the writer of this report, of the stability of the structures of the old aqueduct system has led to the conclusion—

(3) That there is no weakness in the existing aqueduct system sufficiently serious or threatening to justify at the present time a recommendation for the construction of the proposed new works for the purpose of insurance alone.

Obviously the increase of the supply, though not now necessary, is only a matter of time. One most important measure may be taken in this direction before the construction of a new aqueduct is actually undertaken. The application of meters to all services in the District would check a large part of the sudden and abnormal increase in waste that occurs from time to time, especially in extreme cold weather. This would have the effect of reducing the percentage of excess capacity that must be maintained, which would virtually increase the working capacity of the system. Universal metering is advocated not alone on the grounds just stated. Other well recognized reasons are given at length in Appendix A. In addition to these reasons and their valid bearing upon the reduction of waste and the ideal apportionment of charges against water takers, the importance of the fact above stated justifies the conclusion—

(4) That the first and most important step that could be taken at the present time for the purpose of increasing the available capacity of the aqueduct system would be the application of meters to all services in the District.

There is a wide variation in the relative costs of construction and of maintenance and operation of the several projects touched upon in this report for increasing the water supply of the District of Columbia. In the case of the gravity projects the construction cost constitutes the larger part. Information is not at hand for the accurate estimation of the cost of maintenance and operation, but the wide difference in the costs of the several projects makes the consideration of this point unnecessary. In the case of the projects involving pumping, the capitalized operating costs alone are in excess of the construction costs of the gravity projects, and the construction costs of the former would increase this difference in favor of the gravity supply.

The following table gives the estimated total construction costs of the gravity projects, and the estimated operating costs of the pumping projects, capitalized at 3 per cent:

Source.	Assumed normal capacity per day.	Estimated cost of project construction.
Potomac at Great Falls:	*Gallons.*	
Parallel location	75,000,000	$3,879,383
Tunnel location	75,000,000	4,333,686
Seneca Creek	75,000,000	7,689,000
Rock Creek:		
High level	40,000,000	6,115,000
Low level	40,000,000	2,366,000
Potomac by pumping from—		
Little Falls	75,000,000	[a] 4,000,000
Tidal basin	75,000,000	[a] 5,473,000

[a] Operating charges capitalized.

The choice between the two lines from Great Falls, namely the parallel and the tunnel locations, admits of no clearly drawn conclusion. It is purely a matter of judgment in determining the policy to be pursued on the part of the appropriating committees in Congress. The most that can be given here is an expression of personal opinion as to the insurance value there might be in the fact that the two aqueducts, new and old, were separated by a considerable distance. The alternative line designated as the tunnel location is presented in accordance with the argument previously stated—"to reduce to a minimum the chance of a single cause disabling both." The adoption of the tunnel location would afford all the benefits implied in this argument, short of the calamity that might result from earthquake disturbances. The separation of the two lines might or might not give protection against that.

On the other hand, the construction upon the parallel location would add materially to the strength of the old system, stable as that now is. Each embankment, underrun by a culvert that is now looked upon as a point of weakness, would be increased in width and consequently in stability. The construction of a massive concrete masonry aqueduct on the south or lower side of the existing aqueduct would effectually protect the less stable brick ring against the dangers arising from the remote possibility of flood waters overtopping and washing away the aqueduct embankment; and the repairs which it is proposed to make in the old aqueduct as soon as a new one is built will eliminate the possibility of leaks or collapsing sections over embankments.

It is pertinent to refer, too, to a point which can hardly be reckoned in an estimate, and yet which is of much financial weight. Compared with work in the open, tunnel construction affords large opportunities for inferior workmanship on the part of unscrupulous contractors. The experiences with the Croton Aqueduct, and with the Lydecker Tunnel here in Washington, are sufficiently illustrative of this possibility. Between Great Falls and Cabin Johns Bridge there are on the tunnel location 29,000 linear feet of tunnel, while on the parallel location there are only 9,200 linear feet, or less than one-third as much. In view of these facts the writer of this report feels justified in expressing the opinion that the separation of the two lines by the adoption of the tunnel location at an increased expense of nearly $450,000 would not be advisable.

From the point of view of cost, the choice among the above, if works were soon to be constructed, would lie between the Great Falls gravity project, parallel location, and the low level development from Rock Creek. Since the actual construction of new works is a problem for the future rather than for the present, a consideration of the relative economical advantages of the two under present conditions would not be applicable at that time, due to the changing conditions in the valley of Rock Creek. The residence district of Washington is unquestionably growing in that direction, and a few years may find the necessary land too valuable for this use.

Mention has been made of the periodic occurrence under existing conditions of high bacterial counts and visible turbidity in the filtered water. The increased draft upon the system will shorten the period during which the objectionable water can be excluded from the aqueduct; it will shorten the time for sedimentation and natural purification in the reservoirs; and in general it will greatly aggravate the conditions as they now exist and make the necessity for some remedy still more imperative. There are two remedies for this, namely, additional reservoir capacity and preliminary treatment by coagulation. Of these two an additional reservoir of the capacity it is feasible to build will not afford a complete remedy for these conditions. It has been clearly demonstrated, both upon other waters and upon the Potomac water, that preliminary treatment by coagulation can be made to give a complete remedy and at a much lower cost.

In connection with the increase of the supply it has been proven entirely feasible and safe to operate the filters at rates considerably higher than those for which they were designed. An imperative requirement of this adaptation of the existing plant to higher rates is an adequate form of preliminary treatment. The storage that could be obtained in connection with the old and the proposed new aqueduct system could not be depended upon at all times to give the desired results. Coagulation would unquestionably give a satisfactory preparation. In a question upon which depends the maintaining of the supply at critical times, there is only one choice, and that the one that will give perfect results. The conclusion is therefore justified—

(5) That preliminary treatment by coagulation must be considered an essential part of the purification process in the future as applied to the water supply drawn from the Potomac River for the District of Columbia; and since coagulation is more flexible, more certain in its action, and cheaper than additional storage, that the construction of a new reservoir for that purpose is unnecessary.

RECOMMENDATIONS.

It is therefore recommended:

(1) That provision be made for the installation of meters on all the services in the District of Columbia.

(2) That provision be made for the preliminary treatment of the existing supply by coagulation in accordance with the project already prepared for that purpose.

(3) That in view of the fact that changing conditions may change the relative economical advantages of the projects, the choice of a source and route for an additional supply be deferred until such time as its actual construction shall be required.

Respectfully submitted.

FRANCIS F. LONGLEY,
Assistant Superintendent.

Maj. JAY J. MORROW,
Corps of Engineers, U. S. Army.

APPENDIX A.

THE USE AND WASTE, AND THE FUTURE CONSUMPTION OF WATER IN THE DISTRICT OF COLUMBIA.

The subjects of this study are taken up in the following order:

(1) Use and waste of water in the District of Columbia: Legitimate domestic uses; commercial uses; public uses; waste; sufficient quantity for the per capita daily consumption from the above considerations.

(2) Prevention of water waste in the District of Columbia: The use of meters; waste survey of the distribution system; causes affecting the variations in per capita daily consumption in the District of Columbia in recent years.

(3) Increase in per capita daily consumption.

(4) Future per capita daily consumption in the District of Columbia.

(5) Summary of discussion relating to use and waste and per capita consumption of water.

(6) The future population of the District of Columbia.

(7) The future consumption of water in the District of Columbia.

USE AND WASTE OF WATER IN THE DISTRICT OF COLUMBIA.

A large part of the total quantity of water supplied to the District of Columbia is wasted. It was the intention of the designers of the existing aqueduct system in 1853, that the cities of Washington and Georgetown, as they then were, should be furnished with "an unfailing and abundant supply of pure and wholesome water." Their estimate of per capita consumption, in a day when 20 to 35 gallons per day was commonly considered ample for this purpose, was set at the extravagant figure of 90 gallons per capita per day. This quantity included provision for domestic and public uses, washing of streets, etc., and upon this figure they predicted the total quantity needed by the cities for the forty years from that date. At the end of that forty years the per capita daily consumption was practically twice as great, and in 1905 it had reached a maximum of 218 gallons or nearly 2.5 times as great as their almost unprecedented assumption of 90 gallons in 1853.

Water supplied to a city is disposed of in one of the following ways: (1) Legitimate domestic uses; (2) commercial uses; (3) public uses; (4) loss or waste.

(1) *Legitimate domestic uses.*—The quantity of water chargeable to legitimate domestic uses has been investigated, directly or indirectly, in a number of cities. It is dependent apparently upon such factors as the class of dwellings, the general character of the city, and the character of the population; and dependent, too, most logically, upon the proper care and restrictions placed upon the distribution of the water, in which respect the use of meters on service pipes is an important measure. The best analysis available of the quantities of water going to these different uses is probably that of Dexter Brackett for the city of Boston in 1895. His studies, together with the other information at hand, indicate a wide range of quantities for domestic use, varying from less than 10 gallons to nearly 50 gallons per capita per day under fair and reasonable conditions of restriction.

The investigations of the water department of the District during the last three years afford interesting information about the per capita consumption. These studies have now covered about one-half the services in the District. In each section studied data are recorded from which the per capita consumption can be determined. A summary of these data is given in the following table:

Separated.			Accumulated.		
City blocks.	Per cent of total so far investigated.	Per capita daily consumption.	City blocks.	Per cent of total so far investigated.	Per capital daily consumption.
		Gallons.			*Gallons.*
99	24	30	99	24	30
65	16	47	164	40	37
60	14	65	224	54	44
55	13	91	279	67	54
70	17	132	349	84	69
24	6	155	373	90	75
43	10	304	416	100	99
416	100				

This table shows clearly that the total per capita daily consumption in a large section of the city is low; in 24 per cent of the city blocks so far investigated it averages 30 and does not exceed 40 gallons; in 40 per cent it averages 37 and does not exceed 60 gallons. These comparatively low figures for total per capita consumption probably represent domestic use in large part; certainly domestic use does not exceed these amounts. They may not be representative of the entire District because the areas first covered by the investigations were the high service areas which are comparatively new and largely residential. A per capita quantity sufficient for the domestic uses of so large a part of the population, however, should in all reason be sufficient for the entire population, and therefore the table should afford a good criterion of the actual quantity chargeable to this use for the entire District. It seems probable that 40 gallons per capita per day is sufficient for this purpose.

(2) *Commercial uses.*—The per capita quantity of water used for commercial purposes depends upon the commercial and manufacturing development of the city and upon the relative extent to which the public supply and other sources are used for this purpose. The few statistics available on this point indicate the prevalence of figures for a number of cities varying from 20 to 35 gallons per capita. The figure for Boston in 1892 was about 30 gallons; Syracuse, N. Y., 1889, about 30 gallons; Yonkers, N. Y., 1897, about 27 gallons; New York, N. Y., about 24 gallons.

Special circumstances often make this lower. Fall River, a manufacturing city, in 1892 had a commercial consumption estimated at only about 2 gallons per capita per day, owing to the fact that most of the factories took their own water directly from the river.

The development of manufacturing in the District of Columbia is relatively small. During the fiscal year 1908 the total daily quantity of water used by all consumers taking about 100,000 gallons per day or more was 2,800,000 gallons, which is equivalent to about 8 gallons per capita per day. This does not include the great many stores and office buildings which would come in this class using less than that quantity. It would seem as though 20 gallons per capita per day would be sufficient for commercial uses in this city.

(3) *Public uses.*—Investigations by the District water department in 1905 indicated a quantity of water supplied to the United States Government buildings amounting in round numbers to about 8,500,000 gallons a day, which was equivalent to a per capita daily amount of about 27 gallons. In addition to this there are large quantities chargeable to the various buildings coming under the District government. It has recently been shown that the schools, police stations, engine houses, etc., take large amounts, and much water is of course used for street sprinkling, fountains, sewer flushing, etc.

The quantities of water that have been used for fire purposes in the last few years have been: 1904, 26,800,000 gallons; 1905, 23,300,000 gallons; 1906, 22,700,000 gallons; 1907, 28,600,000 gallons; the maximum of which is equivalent to less than 0.25 gallons per capita per day.

The large item of this use is the quantity taken by the public buildings of the Government and of the District. In the past this has been excessive, much of it having been unwarranted waste, as the records of the water department clearly show.

Public uses in other cities are extremely low compared to that in Washington. In Boston in 1892 it was estimated at less than 4 gallons and in Fall River in 1899 at less than 6 gallons per capita per day.

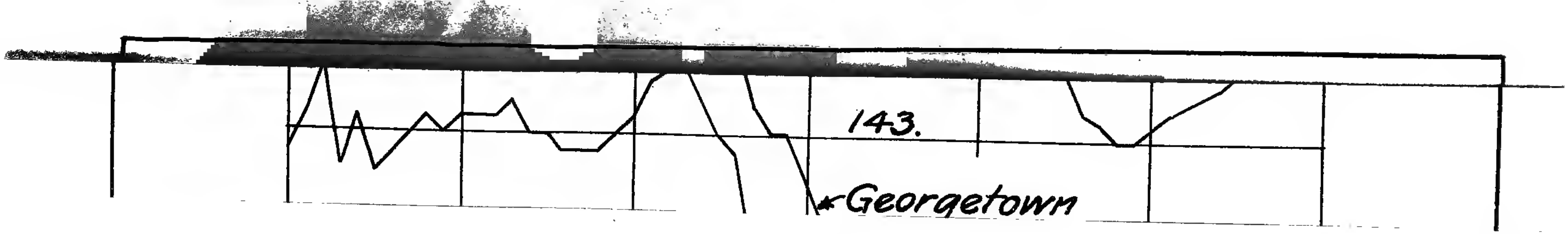
In all reason the quantity of water for public uses in the District of Columbia should be greatly diminished by reasonable measures for the suppression of useless waste. Considering this fact, and not losing sight of the legitimate demands of the District and the United States Government in the matter, it seems that 30 gallons per capita per day should be an ample allowance for this purpose, erring on the side of extravagance rather than of parsimony.

(4) *Waste.*—From the preceding considerations it would seem that an allowance of about 90 gallons per capita per day was ample for the legitimate domestic, commercial, and public uses of this city; that is, if all unnecessary waste of water were suppressed and only that quantity demanded which would serve some useful purpose, even though this actual use be lavish, the total quantity of water required should not exceed, but should probably be somewhat less than 90 gallons per capita per day. This, it will be remembered, was the assumption, then considered highly extravagant, made by the designers of the existing aqueduct system half a century ago.

The excess of the enormous per capita consumption over this amount in recent years has been waste; has performed no useful services. What this has amounted to may be seen from the following table:

Fiscal year.	Total consumption per day.	Population.	Actual per capita daily consumption.	Quantity required, per day at rate of 90 gallons per capita per day.	Quantity wasted on these assumptions per day.
	Gallons.		*Gallons.*	*Gallons.*	*Gallons.*
1900	48,500,000	295,000	164	26,600,000	21,900,000
1901	50,700,000	300,600	169	27,000,000	23,700,000
1902	56,000,000	306,200	183	27,600,000	28,400,000
1903	58,300,000	311,800	187	28,100,000	30,200,000
1904	63,000,000	317,400	199	28,500,000	34,500,000
1905	70,600,000	323,100	218	29,100,000	41,500,000
1906	67,700,000	326,400	207	29,400,000	38,300,000
1907	66,900,000	329,600	203	29,700,000	37,200,000
1908	64,900,000	339,400	191	30,600,000	34,300,000

This table is based upon the estimated populations for the District given elsewhere in this appendix, which are believed to be more consistent than those assumed for this purpose in the annual report of the Washington Aqueduct for 1906. The fifth column indicates that if waste had been effectively suppressed and the per capita consumption kept within the 90-gallon limit, the aqueduct system as it now stands would have a capacity more than double the demand.


143.
Georgetown

Waste, even of this magnitude, is not of any great importance while the capacity of the aqueduct system is greatly enough in excess of the proper demands to keep up the supply at practically no increase in cost. But when an enormous waste like this makes necessary the expenditure of large sums of money for improvements and extensions which would be absolutely unnecessary in the absence of such waste, then it assumes an importance which can not be too greatly emphasized.

Washington does not stand alone in this useless and excessive waste of water. A considerable percentage of the total supply is wasted in practically every city, and the waste in such cities as Pittsburg, Philadelphia, Buffalo, Chicago, and Denver, is probably equal to or greater than it is here, as may be seen from the following table (see also Diagram No. 3):

City.	Population.	Total consumption.	Per capita consumption per day, 1907.	Percentage of meters.
		Gallons.	*Gallons.*	
Buffalo, N. Y	410,000	132,000,000	322.0	3.4
Salt Lake City, Utah	70,900	17,000,000	240.0	3.0
Pittsburg, Pa	294,000	68,491,000	232.7	15.4
Denver, Col	191,000	40,655,700	214.0	1.0
Albany, N. Y	100,000	21,377,000	214.0	18.0
Chicago, Ill	2,232,000	455,000,000	204.3	4.2
Washington, D. C	330,000	66,900,000	203.0	14.3
Philadelphia, Pa	1,522,000	320,000,000	201.7	5.0
Erie, Pa	67,800	11,860,000	175.6	2.3
Detroit, Mich	412,000	68,817,000	166.7	30.5
Jersey City, N. J	236,000	37,500,000	159.0	9.0
Boston, Mass	614,000	96,423,000	157.0	5.5
Grand Rapids, Mich	106,600	14,772,000	138.5	30.2
Baltimore, Md	556,000	71,726,000	129.0	25.0
Reading, Pa	93,600	11,915,000	127.3	9.2
Springfield, Mass	83,100	9,960,000	120.0	50.8
Cleveland, Ohio	501,000	58,880,000	117.5	88.6
Richmond, Va	112,000	12,480,000	113.0	53.0
Cambridge, Mass	100,000	11,065,000	110.0	22.0
Wilmington, Del	87,500	8,353,000	95.4	25.5
St. Louis, Mo	728,000	69,200,000	95.0	6.5
Milwaukee, Wis	363,000	33,730,000	93.0	95.0
Rochester, N. Y	191,700	16,616,000	86.6	69.7
New Bedford, Conn	88,400	7,430,000	84.0	29.0
Taunton, Mass	28,500	2,129,000	74.7	47.0
St. Joseph, Mo	100,000	7,200,000	72.0	50.0
Providence, R. I	225,800	16,227,000	72.0	88.0
Lynn, Mass	85,500	6,015,000	70.5	35.0
Worcester, Mass	140,800	9,434,000	66.8	98.2
Newton, Mass	38,500	2,316,000	60.3	88.1
Hartford, Conn	113,000	6,682,000	59.1	98.2
Minneapolis, Minn	300,000	17,591,000	58.6	71.8
Lowell, Mass	95,500	5,526,000	58.0	73.5
Madison, Wis	27,500	1,457,000	53.0	98.2
Manchester, N. H	65,900	3,400,000	51.6	75.0
Fall River, Mass	112,400	4,950,000	43.9	97.9
Quincy, Mass	39,300	1,414,000	36.0	54.0
Brockton, Mass	52,000	2,020,000	35.0	91.5

This table shows, too, in a general way, the beneficial effect of a reasonable measure for the restriction of waste. The larger the percentage which the metered services are of the total, the smaller in general is the per capita daily consumption. This tendency is unmistakable. The question of meters will be dealt with at a greater length under "Waste prevention."

Waste falls naturally under two heads—that which can be prevented and that which can not. The line of demarkation between these two clases is, from the nature of the problem, indistinct. Owing to the intricacies of a system for the distribution of water to a large community, the enormous length of pipe with joints every few feet, and the whole system subjected to heavy internal pressure; the fact that the entire system is liable to corrosion from natural causes, and that it is entirely hidden from sight under the ground, which does not in any way resist, but does most effectively conceal any tendency to leakage, it is no surprise that some water should be actually lost. The distribution system of the District of Columbia includes nearly 100 miles of water mains from 10 to 75 inches in diameter, about 350 miles of smaller sizes, and some hundreds of miles of house-service pipes.

The statistics of certain cities in which more than usual care is taken to account for all the water supplied show a considerable percentage still unaccounted for. The following figures represent this portion for the cities named for the year 1908:

City.	Percentage of total services metered.	Percentage of total consumption that passes through meters.	Percentage of total which is not accounted for.
Milwaukee, Wis	96.0	58.5	39
Yonkers, N. Y	100.0	62.8	37
Brockton, Mass	94.0	72.4	23
Worcester, Mass	98.2	79.2	19
Hartford, Conn	98.2	80.4	18
Woonsocket, R. I	86.5	74.6	14
Fall River, Mass	98.2	85.4	13
Newton, Mass	88.6	79.0	11

The figures in the last column are obtained by subtracting from 100 per cent those in the second column, after correction, on the assumption that the quantity passing through the small remaining portion of unmetered services is proportional to that through the metered services. There are many reasons given for the inability to account for the entire supply. Among these are certain public uses, such as for parks, fountains, watering troughs, street cleaning, sewer flushing, fire protection, etc., and also certain other undesirable and uncontrollable losses, such as leakage from street mains, etc., leakage from reservoirs, and stealing.

In those cities having the larger percentages unaccounted for, the explanations offered for this fact indicate that a considerable portion should, if measured, be included in "public uses." Beyond this, these figures afford a measure of the unavoidable waste that has taken place in these cities. After making some allowance for "public uses," etc., these figures indicate that a city should by proper measures be able to restrict its unavoidable waste to less than 25 per cent of the total supply, and 33 per cent for this purpose would seem a most generous assumption.

(5) *Sufficient quantity for the per capita consumption from the preceding considerations.*—On the basis of 90 gallons per capita per day for the legitimate domestic, public, and commercial uses of the community, and of one-third of the total supply for waste under reasonable conditions of restriction, the total for consumption and waste in the District of Columbia should not exceed 135 gallons per capita per day.

PREVENTION OF WATER WASTE IN THE DISTRICT OF COLUMBIA.

Actual loss of water may take place due to any one of the following conditions:

(1) Flagrant waste from faucets, hose, etc.

(2) Defective plumbing in houses.

(3) Leaks in mains or service pipes.

In addition to these there may be an apparent loss of water due to slippage in the pumps where stated quantities are determined from plunger displacement. This is sometimes a serious matter, but affects the economical operation of the pumping stations more directly than it does the matter of capacity of the supply. Water may also be stolen by large consumers, by by-passing meters, unauthorized use of fire mains, etc. This water, though surreptitiously taken and not paid for, may serve some useful purpose, and hence may not be actually lost; but it is an abuse that merits the attention of the water registrar if detected.

(1) *Use of meters.*—The use of meters on house services puts an effective control on the first two items of loss noted above. With a meter on the service pipe, substantially all the water going into a house is measured, to be paid for by the taker, whether it be used for proper domestic purposes, whether it wastes from leaky fixtures, or whether it be willfully wasted as is so frequently done by allowing it to run all night in winter weather to prevent freezing, and in summer by considerable waste in the effort to obtain cooler water by "letting it run." Metering a house does not imply any desire upon the part of a water department to restrict the use, even the lavish use of the water, but merely to let each taker assume the burden of any extravagant waste that may exist upon his premises. A taker who uses only reasonable care in this respect need not suffer by paying for his water by measure. In view of the mil-

lions of dollars invested in the system of water supply of a large city that is, in fact, the only logical basis upon which he should pay for it.

The use of meters has an unmistakable tendency to reduce the per capita consumption of water. This is shown by the table of consumption in various cities for the year 1907 (p. 55), which indicates clearly that the cities in which a large percentage of the services are metered have generally the lowest per capita consumption. It is shown more specifically in the following table, which gives the reductions in per capita consumption effected in a number of cities by the use of meters:

City.	Year.	Per cent of meters.	Per capita daily consumption.	Reduction per capita per day.
			Gallons.	*Gallons.*
Cleveland, Ohio	1900	6	169	70
	1908	92	99	
Grand Rapids, Mich	1899	6	174	39
	1908	34	135	
Richmond, Va	1890	1	168	55
	1907	53	113	
Milwaukee, Wis	1891	40	112	32
	1903	90	80	
New Bedford, Mass	1899	12	107	23
	1908	32	84	
Hartford, Conn	1900	6	85	26
	1907	98	59	
Minneapolis, Minn	1899	22	94	36
	1908	75	58	
Lowell, Mass	1893	28	83	25
	1907	73	58	

Opinions vary as to the distinct advantage to be gained by the universal use of meters on the service pipes of a city. One argument frequently used follows from an examination of curves showing the general relation existing between the per capita consumption and the percentage of services metered, such as the one given under "Use and waste of water," for thirty-eight cities for the year 1907. It is in substance, that the use of a small percentage of meters, judiciously placed, will effect a very marked reduction in the per capita consumption; and beyond that the reduction becomes less and less for a given additional percentage of meters. The curves might logically lead to the question as to whether there were in the general case enough advantage to be derived from the extension of meters beyond 40 to 50 per cent of all services to warrant the expense of that extension and in fact, an adverse view is not uncommonly taken upon this point. It is pertinent to repeat here that such curves as these do not indicate a definite relationship that, because of any existing conditions, should exist between per capita consumption and the percentage of metered services; but rather the average relationship that actually happens to exist under the varying conditions in different cities. They do not indicate the actual reduction in per capita consumption that would follow upon the progressive installation of meters, nor the actual numerical values we should expect in any case. Generally speaking, it would seem that the quantity of waste suppressed should be approximately proportioned to the number of meters installed. The suppression of waste on the services of manufacturers and other large takers would undoubtedly be relatively large, but beyond that it would be most difficult to discriminate between the 50 per cent of takers whose waste was serious and the 50 per cent whose waste was not worth suppressing. This view of the case has been taken, too, by investigators of the water-waste problem in Pittsburg, who have predicted a reduction diminishing slightly for successive increases in the percentage of metered services, but not departing very much from the proportional relation referred to above. There should be perhaps an even greater tendency for this to hold true in Washington, where there are but few manufacturers and other large takers compared to most cities of its class.

The most important argument in favor of universal metering of services in the District is touched upon elsewhere. Under existing conditions of waste, the maximum daily consumption may at times be 40 to 50 per cent in excess of the mean daily consumption for the year. During the fiscal year 1905 there occurred an excess draft of about 45 per cent. This means that a large percentage of the capacity of the system must lie entirely useless except when drawn upon to supply this enormous and unwarranted waste; yet, useless as it is, the excess capacity must be maintained under these extravagant conditions, else when the abnormal draft does occur the supply will not equal the demand. Plainly, in order to secure the benefits of as large a percentage as possible of the capacity of the aqueduct system, the essential thing to obtain is uniformity of demand for the water in the city. This will be accomplished better than in any other way by the application of a meter to every service in the District. In fact, that is the only way.

To illustrate the benefit of this, let it be assumed that the universal use of meters would reduce the maximum variation above referred to from 45 per cent to 15 per cent. With the limiting capacity of the aqueduct system, 90,000,000 gallons per day, that would be equivalent to raising the safe annual average that could be depended upon from 62,000,000 to 78,000,000 gallons per day. And this would virtually have the effect of increasing the working capacity of the system by 25 per cent. The effect of this argument upon the necessity for the construction of new works needs no comment.

The important advantages of the universal use of meters, then, would be as follows:

(1) It would suppress the waste from house fixtures, which in the absence of the meters would be entirely undetected.

(2) It would give the water department of the District the only reasonable and logical basis upon which to determine proper charges against all water takers.

(3) It would afford the greatest attainable degree of uniformity in the daily consumption which would virtually have the effect of increasing the working capacity of the aqueduct system by a substantial percentage.

The record of the number of meters in the District in the last few years has been as follows:

Year.	Service connections.	Water meters in service.	Percentage which metered services are of total.
1905	54,035	2,104	3.9
1906	55,721	2,401	4.3
1907	57,672	8,267	14.3
1908	59,532	12,611	21.2

In 1905 and 1906 there were comparatively few metered services in the District. Following upon the abnormal consumption of those years the water department began to install meters at the rate of about 5,000 a year, but since 1908 there have been no funds provided specifically for that purpose. They now have authority to use for installing meters only the surplus from the regular maintenance appropriations. This is being used to install meters on all new houses, as far as possible, especially in the high-service districts. The funds are not more than sufficient to keep up with the new services, however, and there will therefore continue to be some 47,000 unmetered services in the District unless money is provided for their installation.

The cost of purchasing and installing meters in the District for the last year or two has been about $16.50 each. At this price it would cost about $775,000 to equip every service in the city with a meter. Estimates for the installation of meters are submitted for the next fiscal year by the District water department, and they merit the unqualified approval and support of Congress.

(2) *Waste survey of distribution system.*—The detection of leakage in the mains and service pipes involves either the examination of the outside of the pipes for visible evidence or its indirect determination by the measurement of the flow at a great many points on the system. The examination of the outside of hundreds of miles of pipe buried in the ground is obviously out of the question. To accomplish this purpose, then, we are limited to the second means, which also is a difficult proposition.

This is effected in practice by the isolation of a convenient district, shutting all valves and cross connections except one, through which all the water supplying that district must pass. The flow through this is then determined. If there is waste as indicated by a large flow during the night, this is localized by shutting off successively different portions of the district and observing the effect on the rate of flow through the main inlet. If a portion in which there is much waste be shut off, there will be a corresponding reduction at the principal point of measurement. The waste may be still further localized to the individual house services, which are, of course, the limit of such an investigation.

The flow into the isolated district may be determined by either of two devices, the Deacon waste meter and the Cole-Flad pitometer. Both of these record, automatically and continuously, the rate of flow through the pipe to which they are attached.

The Deacon device is of thirty-five years' standing, but it is very expensive and not largely used in this country. The pitometer is a development of recent years, and is coming into common use with its efficiency well demonstrated. The pitometer has been used in the recent Washington investigations.

The work of the pitometer division of the District water department commenced in July, 1906. It has been pursued continuously since that time, and has produced excellent results. Between July 1, 1908, and January 16, 1909, the following leaks were detected and repaired:

	Number of leaks.	Total quantity per day.	Average quantity per leak per day.
		Gallons.	*Gallons.*
In broken services, hydrant connections, etc.:			
Less than 1,000 gallons per day	99	43,800	440
1,000 to 2,000 gallons per day	54	67,000	1,240
2,000 to 3,000 gallons per day	67	143,700	2,140
3,000 to 5,000 gallons per day	105	348,600	3,320
5,000 to 10,000 gallons per day	86	526,000	6,120
10,000 to 20,000 gallons per day	114	1,489,[illegible]00	13,070
More than 20,000 gallons per day	40	1,044,000	26,100
	565	3,663,200	6,490
In broken and leaking mains, fire hydrant valves, etc	44	613,700	13,940
Total	609	4,276,900	7,020

A summary of the results since the investigations began in 1906 is as follows:

Year.	Class 1.			Class 2.			Class 3.		
	Number of leaks.	Quantity per day.	Average quantity per leak per day.	Number of leaks.	Quantity per day.	Average quantity per leak per day.	Number of leaks.	Quantity per day.	Average quantity per leak per day.
		Gallons.	*Gallons.*		*Gallons.*	*Gallons.*		*Gallons.*	*Gallons.*
1906-7	20	343,000	....	3	149,000	....	6	422,000	....
1907-8	205	3,0[illegible]6,000	....	55	1,188,000	....	7	2,338,000	....
1908-9 (partial)	565	3,670,000	....	44	614,000	....	......	....	....
Total	790	7,069,000	8,950	102	1,951,000	19,100	13	2,760,000	212,000

RECAPITULATION.

Number of leaks		905
Quantity per day	gallons	11,780,000
Average quantity per leak per day	do	13,000

Class 1 includes all broken or leaking service pipes, defective wiped joints on service pipe connections, defective goosenecks on corporation cocks, hydrant connections, etc., and, in general, all points between the mains and the buildings served.

Class 2 includes all breaks or leaks in mains and fire hydrants, fire-hydrant valves, etc.

Class 3 includes all other sources of waste detected, such as extraordinary flow to government buildings, schools, police stations, parks, and other District property; improper use by large consumers, etc. In other words, in the two and one-half years that these investigations have been under way there has been a suppression, according to the records of this division of the water department, of nearly 12,000,000 gallons per day of useless waste.

This estimated saving is quite consistent with the actual reduction in the total consumption. The year 1904–5 was abnormally high, due to the extreme cold-weather consumption in January and February. Aside from that year the average yearly increase in the total consumption for six years had been at the rate of 3,200,000 gallons per day. At this rate, figuring from July, 1906, when the pitometer investigations began, the present total consumption would have been about 77,000,000 gallons per day. The mean consumption for this fiscal year will not exceed 65,000,000 gallons per day, and will probably be slightly less, and this difference is approximately equal to the reduction in waste as estimated by the water department.

The records of the pitometer division do not show directly just what percentage of the total area of the distribution system has been covered by their investigations. An examination of their maps seems to indicate that they have covered about two-thirds of the area. An indirect computation from their population statistics would seem to indicate that their work so far had included about one-half of the total number of house services. These two estimates may be consistent and approximately true, as the area so far covered has included most of the newer outlying districts where the area for a given number of house services is relatively larger than in the older parts of the city still to be covered.

It is the intention of the water department of the District to continue these most profitable investigations as long as they show any efficiency in the suppression of waste.

(3) *Causes affecting the variations in per capita daily consumption in the District of Columbia in recent years.*—The increase in per capita consumption in Washington up to the year 1903–4, as shown in the table under "Waste of water," seems explainable by the arguments elsewhere set forth regarding the general tendency in all cities toward this increase. The per capita consumption reached its highest mark in the year 1904–5. The high average for that year was due to the abnormal cold weather in February, 1905, which made the maximum draft on the system nearly 100,000,000 gallons per day, corresponding to a per capita for consumption and waste in excess of 300,000,000 gallons. The effect of this cold-weather draft upon the total daily consumption in comparison with the total for the following year is evident from the fact that while the total for 1904–5 was 70,600,000 gallons and that for 1905–6 was only 67,700,000 gallons per day, the average for the nine months, exclusive of the winter months, for 1904–5 was 67,100,000 gallons and for 1905–6 was 68,300,000 gallons. Therefore since the installation of meters and the waste investigations did not commence during the latter year, the decrease in per capita consumption for that year can be ascribed only to the natural cause of a less severe winter. The winters since then have all been more open. In 1904–5 there were 18 consecutive days on which the temperature at 8 a. m. was not above freezing. In 1905–6 the longest consecutive freezing period was 8 days; in 1906–7, 6 days; and in 1907–8, 5 days. We may further conclude then that the decrease in consumption effected by measures for the suppression of waste have not been complicated by any extreme cold weather consumption.

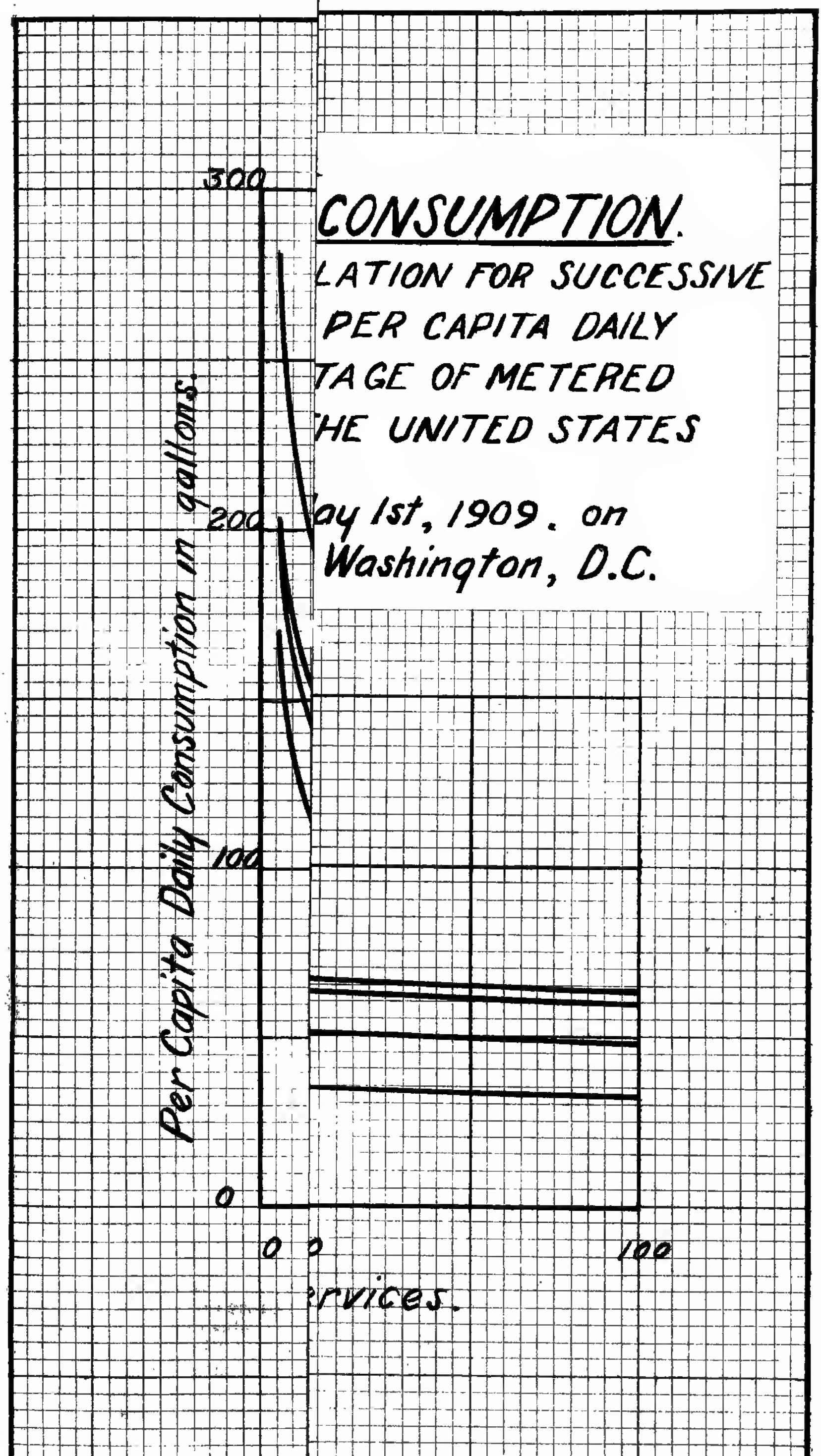
Both the measures intended to reduce the waste, namely, the installation of meters and the pitometer investigations, were begun early in the fiscal year 1906–7. From the effectiveness of these measures, and in the absence of any other known contributing causes, it is reasonable to conclude that the decrease in per capita daily consumption since 1905–6 has been the direct result thereof.

INCREASE IN PER CAPITA CONSUMPTION.

The statistics of water consumption in practically every city in the United States show an unmistakable tendency to increase from year to year. This is due to the increased numbers of faucets, bathtubs, water-closets, etc., in modern houses; to the tendency toward better service pressures; to the advances in sanitary science, etc. The increased number of house fixtures and the greater pressures tend to increase both the legitimate consumption and the useless waste. A measure of this increase is complicated by the question of meters, as the percentage of metered surfaces is growing larger in most cities. In order to eliminate this factor, the increase has been demonstrated by the following procedure.

Figures giving the per capita daily consumption and the percentage which the metered services are of the total number of services have been obtained from some thirty-five to forty cities of the United States for the period 1890 to date. These have been divided into periods of five years each. All the figures for each of these periods have been plotted with the percentages of meters as abscissæ and the per capita daily consumptions as ordinates. The general distribution of these points may be seen from the diagram already given showing per capita consumptions, etc., for thirty-eight cities for the year 1907. By an application of the principles of the method of least squares, the most probable line passing through each of these series of points has been constructed. Each one of these lines therefore shows for that period the average relation between the per capita consumption and the percentage of metered services. They do not indicate a definite relationship that, because of any existing conditions, should exist between per capita consumption and the percentage of metered services, as the deviations from the curves are for some cities very wide; but they do indicate the average relationship which actually does exist under the widely varying conditions in different cities.

In Diagram No. 4 the average lines thus determined for the four periods have been plotted, omitting, to avoid confusion, the several hundred points from which they were determined. They indicate that for any given condition as regards the use of meters there has been a large increase in per capita consumption from each five-year



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for the per capita daily consumption in this city under reasonable conditions for the prevention of waste. The diagram given under "Increase of per capita consumption" indicates that there is little, if any, tendency toward this increase in cities that make determined efforts for the suppression of waste; and the experience of many cities in the past decade bears out this belief. A per capita daily quantity of 135 gallons therefore seems to be clearly indicated as sufficient for the needs of the District for some time to come, on condition that the measures for the prevention of waste be vigorously prosecuted.

SUMMARY OF DISCUSSION RELATING TO USE AND WASTE AND PER CAPITA CONSUMPTION OF WATER.

The present consumption of water in the District of Columbia is extravagantly high, amounting to nearly 200 gallons per capita per day. It has been clearly demonstrated that a large part of this is useless waste. A generous consideration of the actual needs of the community, based upon existing facts and conditions, leads to the conclusion that 90 gallons per capita per day should be ample for all the legitimate uses of the District. Besides legitimate use there is in every city a variable amount of waste. Some of this can be prevented by proper measures, but not all of it. On the condition that these measures are vigorously carried out, the unsuppressed waste in the District of Columbia should certainly be limited to one-third of the total consumption, which would make the total reasonable requirements of the District amount to 135 gallons per capita per day.

The measures which should be taken for the suppression of waste are the metering of services and the surveys for the detection and suppression of waste on the distribution system. About one-fifth of the services in the District are now equipped with meters. This is not enough to bring about the benefits that should be derived from the meter system. The pitometer surveys for the detection of waste have covered about half the city and are being carried on under the ordinary appropriations of the water department of the District. In order to positively reduce the present enormous waste and to maintain it within the reasonable limit stated above, that department should be given unstinted help in this work. The good showing they have made so far with the limited funds at their disposal has been a positive demonstration of the results that may finally be accomplished under favorable conditions.

The work of waste prevention has so far resulted in a saving of about 12,000,000 gallons of water per day, with about one-half of the distribution system still to be covered. There should in the end be a total suppression of at least 24,000,000 gallons per day, which would reduce the per capita consumption to about 135 gallons per day, the same figure reached above from a consideration of the reasonable requirements of the community.

THE FUTURE POPULATION OF THE DISTRICT OF COLUMBIA.

It is difficult to make a reliable estimate of the future population of any city, because it is influenced so greatly by local conditions. The two factors that frequently cause irregular or abnormal increases in population are (1) acquisition of new territory, by annexation or otherwise; (2) extraordinary commercial or manufacturing activity. In the case of the District of Columbia the territorial limits of the population are definitely fixed by the boundaries of the District, and the nature of a city given over so largely to governmental functions is such as to preclude the likelihood of commercial or manufacturing activities that will greatly alter the natural increase in population.

A statement from the Director of the Census gives the following populations for the area included within the territorial limits of the District as they now exist:

Census year.	Population.	Increase during decade.	Percentage of increase.	Census year.	Population.	Increase during decade.	Percentage of increase.
1800	8,144			1860	75,080	23,393	45
1810	15,471	7,327	90	1870	131,700	56,620	75
1820	23,336	7,865	51	1880	177,624	45,924	35
1830	30,261	6,925	30	1890	230,392	52,768	30
1840	33,745	3,483	12	1900	278,718	48,326	21
1850	51,687	17,942	53				

The estimates of population made by the police department in recent years are given below:

Year.	Population.	Estimated from the United States census.	Year.	Population.	Estimated from the United States. census.
1885	203,459	204,000	1905	323,123	304,000
1888	218,157	220,000	1906	326,435	309,000
1892	258,431	240,000	1907	329,591	314,000
1895	270,519	255,000	1908	339,400	320,000
1897	277,782	264,000			

The population for corresponding years, estimated approximately from the United States census figures, is also given in this table. The populations indicated by the police censuses since 1892 are several thousands greater than indicated by the estimate made from the United States census of 1900. Plainly, they can not both be right. To judge of the relative accuracy of the two sets of figures, we have from 1885 to the present year two figures from the United States census and nine figures from the police census. These nine figures are quite consistent among themselves. The enumerators employed to obtain them have been, in general, the policemen on their own beats, whose acquaintance with the houses and inhabitants of their several localities might probably be much better than of census enumerators, who were comparative strangers to the localities.

It is believed, therefore, that the figures of the police census more nearly represent the true population of the District than do the others for the period covered. Interpolation between the figures given by the police census gives populations of about 238,000 for 1890 and 295,000 for 1900, which are, respectively, about 8,000 and 16,000 greater than indicated for those years by the United States census.

A population table can therefore be constructed, using the United States census figures up to include 1880 and the two figures given above for 1890 and 1900.

Census year.	Population.	Increase.	Percentage of increase.	Census year.	Population.	Increase.	Percentage of increase.
1860	75,080			1890	238,000	60,000	34
1870	131,700	57,000	75	1900	295,000	57,000	24
1880	177,624	46,000	35				

The increase during the four decades, 1860 to 1900, has been fairly uniform. The maximum increase during any decade was 60,000, the minimum 46,000, and the average 55,000. The future population of cities is sometimes estimated by assuming a fixed percentage increase which has been found to be true in those particular cases for several successive decades. But a glance at the column above, showing percentage increases in the population of the District of Columbia through successive decades, shows plainly that there would be no justification for such a method of estimating in the case under consideration.

In the absence of any constancy in the percentage rate of increase in the District of Columbia, a logical procedure would seem to be to construct a table of estimated future populations based upon the comparatively uniform numerical increase that has taken place during the last four decades, maximum, minimum, and average.

Estimated future population of the District of Columbia upon above assumptions.

Year.	Maximum.	Minimum.	Average.	Year.	Maximum.	Minimum.	Average.
1900	295,000	295,000	295,000	1940	535,000	479,000	515,000
1910	355,000	341,000	350,000	1950	595,000	525,000	570,000
1920	415,000	387,000	405,000	1960	655,000	571,000	625,000
1930	475,000	483,000	460,000				

The increase in population of large cities from one decade to the next is often an increasing quantity. This is true of New York, Chicago, Philadelphia, and other cities, especially where their importance as great commercial centers has given impetus to their growth. It is not generally true, however. The probable population of the District in 1910, as estimated from the police census from 1900 to 1908, will correspond closely to the population estimated in the last table for that year based upon the average increase. This fact, together with the conditions stated at the beginning of this discussion which seem to mark a tendency to uniformity of growth of population in the District of Columbia, make it seem advisable to use for our estimates of future population the figures given in the last column of the table above, based upon the assumption of an approximately uniform numerical increase during each decade equal to the average increase during the past four decades. It is believed that these figures will represent the population of the District reasonably well for the immediate future periods which we must consider.

THE FUTURE CONSUMPTION OF WATER IN THE DISTRICT OF COLUMBIA.

From the estimates of future population and of future per capita daily consumption in the District of Columbia, the following table may be constructed showing the probable quantities of water that will have to be provided for:

Year.	Population.	Mean annual consumption per day.	Maximum capacity to provide for per day.	Year.	Population.	Mean annual consumption per day.	Maximum capacity to provide for per day.
		Gallons.	*Gallons.*			*Gallons.*	*Gallons.*
1920	405,000	55,000,000	80,000,000	1950	570,000	77,000,000	112,000,000
1930	460,000	62,000,000	90,000,000	1960	625,000	84,000,000	122,000,000
1940	515,000	70,000,000	101,000,000				

The actual capacity to be provided for in any system is not the mean annual consumption. It has been pointed out that a maximum draft of 45 per cent in excess of the mean annual average has occurred and may be expected to occur again in this city. For the mean annual consumption given in the third column this would indicate the need of the maximum capacities stated in the last column. The limiting capacity of the old aqueduct system has been found to be practically 90,000,000 gallons per day. It must be borne in mind that the probability of having to provide only the quantities stated in this table is contingent upon the reduction of waste, as has already been emphasized. With this practically assured by the experience of the last two years, however, the limit of the capacity of the old aqueduct system should not be reached until about 1930.

Assuming the approximate correctness of the prediction as to the future per capita daily consumption in the District of Columbia, there still remains a factor of safety in favor of the above statement. The means advocated for the highest degree of restriction of waste should have the effect of reducing the 45 per cent assumed in the above table for the excess of the maximum required capacity over the mean annual consumption. This would reduce the figures in the last column, or, in other words, should still further postpone the date when the maximum demand will equal or exceed the maximum capacity of the system.

APPENDIX B.

THE COST OF PUMPING WATER.

The scope of this investigation does not confine us to the consideration of gravity supplies. With the Potomac flowing right past the city, the possibility of drawing the supply from the river at some nearer point than Great Falls and lifting it by means of pumps to the height required for distribution seemed a possibility not to be ignored. The pumping of the large quantity of water, against the considerable heads necessary, would constitute so large a portion of the annual charges against such a project that the cost of pumping water became a matter of importance.

The cost of pumping water, as herein considered, is made up of the following parts:

Cost of materials, including coal, oils, grease, waste, etc.

Cost of labor, including engineers, firemen, oilers, and other pumping station employees.

Cost of ordinary maintenance repairs, etc.

It does not include interest on investment, depreciation, extraordinary repairs, etc., at station, nor any portion of maintenance of distribution system nor general administration.

Of the first part, the item of coal constitutes the larger part; in the general case it may be from 85 to 90 per cent of the total cost of materials. This total for materials is commonly 40 to 50 per cent of the total pumping expenses. The item of coal alone is therefore important. With the advances that have been made in recent years in the design of pumping machinery and the greater economy resulting therefrom, the item of coal has decreased. It is not possible, however, to predict, even from the guaranteed duty of a pumping equipment, what its actual station duty in service will be. As has been aptly stated in the pumping investigations for the commission on additional water supply for New York City, "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." So much depends upon the intelligence and watchfulness of the employees intrusted with the immediate care of the station that the prediction of the amount of coal used per unit of water pumped is not attended by any certainty.

Statistics of the cost of pumping water at stations in large cities afford a good means of arriving at the probable cost in actual operation. A study has been made of the cost records of a number of cities, supplemented by information from the engineers in charge. The costs as given in reports are generally not comparable with the costs in the District of Columbia for a number of reasons, among which are the following:

(1) Different heads pumped against.
(2) Different types of machinery used.
(3) Different kinds of ccal used.
(4) Different freight rates on coal.

The differences in (1) are equalized as far as possible by computing the pumpage of each station compared to an equivalent quantity pumped 1 foot high. The equalizing of the differences in (3) and (4) offeis the greatest difficulties. The cost of coal used at any point depends upon its quality and upon the distance of the point of consumption from the coal fields. The first step in this equalization process seemed to be to eliminate the variable factor of freight rates. This could not be done with precision, except at an unwarranted expense of time, but an approximate correction, which is believed to be generally accurate, was applied after a study of the freight tariffs in the files of the Interstate Commerce Commission.

Following upon this, the assumption was made that in a general way the values of the different coals for pumping were proportional to these equalized coal prices. The coal cost for each station was thus changed in the ratio of the cost of good steaming coal in the District of Columbia to the cost at that station, and upon this and the other proper pumping-station expenses the cost was computed of pumping 1,000,000 gallons of water I foot high. Without going into any greater refinement, which, with the meagre data would have been difficult and perhaps no more accurate, these resulting costs were assumed to be approximately what the costs would have been at the various stations if they had been operated with coal of the quality and cost used here in the District.

Average costs of pumping water at various stations for entire periods considered (5 to 10 years), after freight corrections, etc., per 1,000,000 gallons 1 foot high, coal at current Washington prices ($3.50 per ton).

Philadelphia, Pa.:	
Spring Garden	$0.049
Belmont	.047
Queens lane	.033
Roxborough	.059
Frankford (new)	.030
Boston, Mass.:	
Chestnut Hill, low service	.040
Chestnut Hill, high service	.036
Spot pond	.044
Cleveland, Ohio:	
Kirtland street	.040
Fairmont street	.094
Division street	.093
Chicago, Ill.:	
Fourteenth street	.035
Chicago, Ill.—Continued.	
Sixty-eighth street	$0.049
Twenty-second street	.052
Chicago avenue	.054
Springfield avenue	.043
Central Park avenue	.043
Harrison street	.049
Lake View	.054
Detroit, Mich	.032
Milwaukee, Wis	.043
Providence, R. I	.039
Fall River, Mass	.070
Minneapolis, Minn	.030
Washington, D. C.:	
Trumbull street station	.048
Filtration plant station	.056

The table indicates costs ranging from $0.03 to nearly $0.10 per 1,000,000 gallons lifted 1 foot high under Washington conditions. The average cost is about $0.049 and there are but few below $0.040. The cost of pumping at the Trumbull street station here in the District for the fiscal years 1907 and 1908 was $0.048, or practically the same as the average given above. The cost at the pumping station at the filtration plant was slightly higher than the average, or $0.056 for the fiscal years 1907 and 1908.

The assumption of the cost, for purposes of estimating, as $0.040 per 1,000,000 gallons 1 foot high, would seem to be as low as was advisable, and would put any stations built on that assumption in the class with the best stations in the country. This figure therefore has been assumed.

Appendix C.

SEPARATE SUPPLY OF UNFILTERED WATER FOR PUBLIC BUILDINGS, LARGE CONSUMERS, FIRE SERVICE, ETC.

The quantity of water used by the Government, for all of which the water department receives nothing, is very great. At the navy-yard and in many of the public buildings enormous streams are flowing continuously, without restriction, for purposes such as condensing water, etc., for which filtered water is unnecessary. It seemed desirable, therefore, to inquire into the propriety of a separate supply of unfiltered water for these and for certain large private consumers, and for fire service.

Inquiry of persons in charge of the various public buildings, etc., and of private consumers, brought out the fact that in a general way one-half of the water supplied to those consumers might be unfiltered water. There were general expressions of protest against the idea, however, and especially against the expense it would involve in every case of separating the filtered and unfiltered supplies within the building.

The government buildings and the large private consumers use a total of about 12,000,000 gallons per day. Of this, the indications are that about 6,000,000 gallons per day might be unfiltered water. The points at which this quantity would be used are widely scattered and the plan would necessitate an extensive and entirely separate set of mains.

This supply might be obtained by pumping from a small plant at the river, or by gravity from McMillan Park reservoir, without filtration. Of these the latter would obviously be simpler and cheaper.

The saving that would be effected by this plan would be the reduction in total expenses at the filtration plant due to not having to filter this quantity of water. The cost of filtration is about $3.10 per 1,000,000 gallons, but the saving in total expenses would be much less than this for a reduction of 6,000,000 gallons in the quantity filtered. This reduction would make no change in office and laboratory expense, which constitutes 22 per cent of the total. The change in pumping expense would be practically confined to the fuel item, which is about 20 per cent of the total. This would be reduced in proportion to reduction in quantity pumped, or, say, six sixty-fifths of 20 per cent, or 2 per cent of totals. The change in filter operation expense may be assumed to be reduced in proportion to the reduction in quantity pumped, or, say, six sixty-fifths of 32 per cent, or 3 per cent of total. The reduction would therefore be about 5 per cent of the total expense. For the year 1908, 5 per cent of $82,400 would be $4,120, which is equivalent to $1.88 per 1,000,000 gallons as the actual saving effected by reducing the quantity filtered by 6,000,000 gallons.

The capitalized value of $4,120 at 3 per cent is $137,000. In order for the plan to be financially attractive, therefore, $137,000 should cover all expenses incident to laying the complete new set of mains for this separate supply, and all changes in the various public buildings and private properties necessitated by the separation of the two supplies. It is believed that this sum would be insufficient for the purpose.

This plan is not carried out in any more detail, because it is plain that it has no direct bearing upon the principal point of this investigation, which is for an additional supply for the entire city. The quantity of unfiltered water that might be used in the city without inconvenience is obviously too small to warrant the construction of a separate system of mains and the maintenance of a special pumping station at the river, and the plan for a separate system from McMillan Park reservoir, as described above, is simply a part of the larger problem of procuring an additional supply for the entire city.

Fire service.—The reports of the fire department of the District give the total quantity of water used for fire service in recent years as between 25,000,000 and 30,000,000 gallons per year, or about one-tenth of 1 per cent of the total consumption. As far as the actual value of the water is concerned, this quantity is relatively insignificant, and the saving effected by use of unfiltered water may be ignored.

The two things above all others that are essential for efficient fire protection are ample capacity and sufficient pressure. The problem resolves itself into one of obtaining a large quantity of water under high pressure at any place and at any time required, regardless of the actual value of the water used.

In the District of Columbia this might be effected in either of two ways:

(1) High-service fire mains laid from Fort Reno reservoir (flow line elevation 423, or practically 175 pounds pressure in business district).

(2) Fire-pumping station at river front, and fire-service mains to business district.

The first involves (*a*) the laying of mains of proper size from Fort Reno reservoir to the city and to the District of Columbia pumping station; (*b*) pumping with present equipment into Fort Reno reservoir, entirely as at present; (*c*) the only maintenance charges, aside from the pumping above specified, would be those incident to the inspection and repair of the fixed high-service system.

The second involves (*a*) the laying of mains of proper size from a fire pumping station near river into the city; (*b*) construction of pumping station having capacity of 18,000,000 to 25,000,000 gallons of water per day against a pressure of 184 pounds (equivalent to the elevation of the flow line, Fort Reno reservoir); (*c*) maintenance and operation charges, including inspection and repair of high-service system; the maintenance of complete pumping station force all the time, keeping boiler pressure up at all times, ready for use.

Of these two ways, the former would probably be the simpler and more economical, and has been studied and reported upon by the superintendent of the water department. Like the last plan, as far as we are concerned in the present investigation, this is therefore a part of the larger problem of procuring an additional supply for the entire city. A high pressure supply designed purely for fire service in the business portions of the city can not be too emphatically recommended; but if a consideration of the subject fails to show any relief in the general problem of increasing the supply of water for the city, it is clearly not within the scope of this investigation, but lies rather with the District water department who already have a project for this purpose before Congress.

Appendix D.

CAPACITY OF THE EXISTING AQUEDUCT SYSTEM.

With the mean daily quantity of water demanded by the city for consumption and waste not far from the safe limit, and the maximum daily quantity so great as to cause a most serious depletion of the reservoirs, it becomes important to know the limiting capacity of the present aqueduct system.

Only one careful study of the flow in the aqueduct has previously been made. This was in 1896–97, by Capt. (now Lieut. Col.) D. D. Gaillard, Corps of Engineers, U. S. Army, and the details thereof are reported in full in the annual report of the Chief of Engineers for 1897, pages 4004–4009. No significent changes have been made since then in the structures of the system. The result of his studies, stated briefly, was that the ultimate capacity of the system with the Potomac at its lowest stage and the water in the Georgetown reservoir at elevation 144, was about 76,500,000 gallons per day. Georgetown reservoir was at that time the distributing point to the city mains, and McMillan Park reservoir was not yet in service.

Those studies did not include any consideration of the maximum quantity the aqueduct would deliver if the water in Georgetown reservoir were drawn still lower. The assumed elevation of 144 left more than 2 feet of water above the crown of the conduit at that point, and obviously the discharge could be increased by drawing it lower. The problem now consists in the determination of the ultimate capacity of the system at the lowest attainable levels, from the intake at Great Falls to the outlet of McMillan Park reservoir, or, in other words, to the filtration plant pumping station.

Since the studies of 1896–7, estimates have been made of this limiting quantity. Curves have also been constructed to show the discharge corresponding to a given loss of head through a certain section of the conduit. These have all been based upon the coefficients derived in the studies of twelve years ago. Until October, 1905, there had never been a direct and continuous measurement of the discharge. Since that date all the water flowing into the distribution system of the District has passed through the Venturi meters at the filtration plant. The accuracy of these meters has been tested over and over, and they are safely within a limit of error of 2 per cent. For some time before October, 1905, the total recorded consumption was determined from the loss of head through a certain section of the conduit, as referred to above. Shortly after that date it was observed that this method of determining the discharge did not check with the records obtained from the Venturi meters. This indicated a change in the discharge for a given loss of head, resulting probably from a change in the hydraulic quality of the interior surfaces of the conduit since the determinations of 1896–7. The recent study was taken up with a view to the determination of the coefficients under present conditions, and for a knowledge of the ultimate limiting capacity of the entire system.

The earlier studies were carried out by current meter measurements, from which the mean velocities, the values of the coefficients, etc., were determined. The formula used was $v=c\sqrt{rs}$. The continuous records of discharge through the Venturi meters over a period of more than three years afford accurate data as to quantity for the present study.

The data and procedure followed, together with a résumé of the old experimental data, are given below. The formula used, and to which the old figures have been adapted to make them comparable with the present ones, is the exponential formula devised by Messrs. Hazen and Williams, now widely used for this work:

$$v=cr^{0.63}\,s^{0.54}\,0.001^{-0.04}$$

Experiments in 1896–7.—From Colonel Gaillard's report (Report of Chief of Engineers, U. S. Army, 1897, Part 6, pp. 4004–4009), we have—

Section A—Dalecarlia to Georgetown reservoir, 10,150 feet.
Section B—Gauging station No. 2 to Dalecarlia reservoir, 22,719 feet.
Section C—Bridge No. 2 to gauging station No. 2. 17,526 feet.
Section D—Manhole No. 1 to bridge No. 2, 7,201 feet.
Gauging station No. 1, probably at ventilators just south of south connection, Dalecarlia reservoir.
Gauging station No. 2, between tunnels just west of bridge No. 3.

Slopes and velocities determined by Colonel Gaillard August and September, 1896, and June and July, 1897.

	Length.	Mean velocity.	Fall in length stated.	Slope per 1,000.	C, H. & W.
	Feet.				
Section A	10,150	1.169	0.569	0.056	105
		1.267	.649	.064	106
		1.279	.639	.063	107
		1.334	.739	.073	103
					105
Section B	22,719	1.055	.717	.032	127
		1.063	.717	.032	128
		1.379	1.207	.053	127
		1.382	1.217	.054	126
		1.534	1.527	.067	124
		1.545	1.527	.067	125
		1.765	2.145	.094	119
		1.800	2.162	.095	121
		1.826	2.217	.097	121
		1.898	2.217	.098	125
					124
Section C	17,526	1.765	1.54	.0884	123
		1.800	1.54	.0884	126
		1.826	1.64	.0935	123
		1.898	1.64	.0935	128
					125
Section D	7,201	1.765	....	.150	93
		1.800	....	.150	95
		1.826	....	.143	99
		1.898	....	.143	103
					97

SUMMARY.

Section A to C	105
Section B to C	124
Section C to C	125
Section D to C	97

B and C may be taken together as 125. D is evidently a decidedly restricted section. B, C, and D combined, give C equal 119, which may be used as long as the aqueduct is flowing full.

Flow under present conditions through aqueduct.

[Section, Great Falls (M. H. No. 1) to Dalecarlia, 47,446 feet.]

Period.	Quantity (mil. gals. per day).	L. H.	Slope per 1,000.	C
September 12 to October 15, 1906	70.9	6.35	0.134	97
November 11 to December 19, 1906	64.6	4.79	.099	103
January 1 to March 3, 1907	70.9	5.19	.109	108
May 29 to June 30, 1907	63.4	4.91	.103	99
March 16 to March 28, 1906	64.6	4.84	.102	102
Mean value of C				102

The above periods were chosen for their uniformity of conditions. The quantities were obtained from Venturi records, corrected for changes in level of reservoirs during the periods. The losses of head were obtained from aqueduct records. The values of C were derived from the H. & W. formula.

The values of C are very low in comparison with Colonel Gaillard's value, about 119 for this section.

Possible errors in recent data: Leakage from reservoirs, conduits, or tunnels; evaporation; water for sand washing.

Leakage from reservoirs, etc., if any, would be practically constant and might account for an apparent reduction in capacity, as recent measurements of Q are obtained after passing through entire reservoir system, while Colonel Gaillard's were obtained by measuring the capacity at a point in this section. This does not seem likely, however, as we have no evidence of any loss of water from this cause.

There might have been some evaporation during the first and the fourth periods; enough possibly to have increased C for those periods by 1 point each.

A large quantity of water for sand washing was used during the first period; enough to have increased C for that period by 2 points. The amounts during the other periods were small.

Applying these corrections, the average value for C equals 103 with variations not greater than 5 per cent each way.

Colonel Gaillard's observations were made shortly after a most thorough cleaning of the conduit. Some 750 cubic yards per mile of deposits were removed, and "men provided with hoes and stiff brooms scraped and swept the conduit and by-conduits for their entire length." (Report for 1896, p. 3910.)

As far as the records show, this is the only comprehensive and thorough cleaning the conduit has ever had. It has been cleaned at frequent intervals since then by removing any large masses of solid matter, fallen rock, roots, logs, etc., and simply stirring up the soft deposits and attempting to flush them out upon first turning in the water. Some sweeping of the walls is done, but evidently much less thoroughly than Colonel Gaillard's cleaning, for which $14,000 was specially appropriated. The insufficiency of flushing for removing deposits is set forth in Report of the Chief of Engineers, U. S. Army, 1896, page 3910.

The deposits now are very small, and would not diminish the cross-section area by any significant amount; but this, together with the deterioration of the condition of the wall surface which has taken place in the absence of scraping and systematic treatment, probably makes the present value of C lower than Colonel Gaillard's figures would indicate.

Section D has about 25 per cent unlined tunnel.
Section C has about 7 per cent unlined tunnel.
Section B has about 6 per cent unlined tunnel.

The five periods above worked out seem to indicate a value C equal 103 for the entire Great Falls-Dalecarlia section flowing full. The low coefficient in the D section is due plainly to the 25 per cent of rough unlined tunnel. This value of C for this will diminish but little, if at all, because it is already so rough. Assume that it remains 97 and compute the coefficient C for B and C sections. The coefficient for B and C sections seems to be at present from this computation about 105, which would be a reduction of 13.5 per cent in the carrying capacity of the B and C sections since Colonel Gaillard's observations.

[Section, Dalecarlia to Georgetown, 10,150 feet.]

Period.	Quantity (mil. gals. per day).	L. H.	Slope per 1,000.	C
September 12 to October 15, 1906	70.8	1.60	0.157	89
November 11 to December 19, 1906	64.5	1.18	.116	95
January 1 to March 3, 1907	70.9	1.44	.142	93
May 29 to June 30, 1907	63.4	1.28	.126	89
March 16 to 28, 1906	64.5	1.24	.122	92
Mean value of C				92

The data were obtained as heretofore explained. A correction of +0.09 foot has been applied to the recorded loss of head based upon level determinations made upon the aqueduct system in the spring of 1908, in which the gauge at Dalecarlia outlet was found to be 0.09 foot too high. This change accounts for about 3 per cent of the total 13 per cent of apparent reduction in capacity since Colonel Gaillard's observations, which gave C equal 105. The remaining 10 per cent can be accounted for only by deterioration of the interior surfaces.

[Section, Georgetown to McMillan Park reservoir, 20,700 feet.]

Standard section:
Area =76.34 square feet.
Perim.=31.72 feet.
r =2.40.

There are three abrupt changes in direction, at the points where the east and west shafts join the tunnel. For average conditions of flow, allow a total of 0.2 foot for the loss of head at these points, etc.

A correction of +0.57 foot has been applied to the recorded loss of head based upon recent level determinations on the aqueduct system, in which the gauge at the east shaft house was found to be 0.57 foot too low.

Period.	Quantity (mil. gals. per day).	Velocity.	L. H. corrected.	Slope per 1,000.	C
September 12 to October 15, 1906	70.8	1.44	1.63	0.079	100
November 11 to December 19, 1906	64.3	1.31	1.51	.073	95
January 1 to March 3, 1907	70.9	1.44	1.81	.089	95
May 29 to June 30, 1907	63.4	1.28	1.56	.075	92
March 16 to 28, 1906	64.1	1.31	1.64	.079	91
June 4 to 7, 1908	67.9	1.38	1.37	.066	106
June 21 to 24, 1908	68.0	1.38	1.37	.066	106
June 30 to July 4, 1908	72.2	1.47	1.91	.092	94
July 14 to 18, 1908	74.0	1.50	1.74	.084	108
August 1 to 6, 1908	71.4	1.45	1.67	.081	100
September 9 to 13, 1908	64.7	1.31	1.76	.085	88
October 10 to 16, 1908	65.1	1.32	1.18	.057	110
Mean value of C					98

These observations indicate a value for C equal to about 98 for the Lydecker tunnel; and to the loss of head resulting therefrom must be added 0.2 foot for loss of head at the shafts. It is believed that the wide variations from the mean value for C are due to the fluctuations in the level of water in McMillan Park reservoir. The draft at the pumps is so irregular that conditions of uniform flow through the tunnel for several consecutive days practically never occur.

Actual test of limiting capacity of the Washington Aqueduct.—During the week of November 23 to 28, 1908, the following procedure was carried out to determine by actual trial the limiting capacity of the system. Computations from the coefficients derived above indicated that this would be about 90,000,000 gallons per day. The requirements for the test then were—

(1) Adjustment of the reservoir levels to those indicated by the preliminary computations for a discharge of 90,000,000 gallons per day.

(2) Draft of 90,000,000 gallons per day at filtration plant pumping station, where the quantity was recorded by the Venturi meters.

(3) Observations of levels and other conditions throughout aqueduct system after steady flow at this computed limiting rate had been established.

The reservoir levels were adjusted by closing the gates at Great Falls at 6 p. m. November 23, which caused the levels in all the reservoirs to drop. On Tuesday, November 24, an inspection trip was made through the conduit from Great Falls to Dalecarlia. When Dalecarlia reservoir had reached elevation approximately 142.6 the stop planks were put in at both ends. When Georgetown reservoir had reached elevation 140.25 it was shut off to prevent further drop. Meanwhile, after the conduit had been inspected and repaired, it was slowly filled with water. When McMillan Park reservoir had nearly reached elevation 137.5 the three pumps were started at approximately a combined rate of 90,000,000 gallons per day, the gates at Great Falls were opened wide, and Dalecarlia and Georgetown reservoirs put in service again.

Unforeseen condition in Georgetown reservoir.—When Georgetown reservoir was drawn down to this level a condition was noted which had not previously been taken into account. In the middle of the division embankment in the reservoir there is an opening 15 feet wide, the sill of which is approximately at elevation 140.1. For the level desired in this reservoir this opening would carry but a small quantity. The by-conduit was therefore left open, and because of this restriction the greater portion of the 90,000,000 gallons (roughly estimated at 75,000,000 gallons) passed through the by-conduit and the remainder through the reservoir. This accounts for the large difference in elevations at the two ends of Georgetown reservoir and for the elevation being several tenths lower than we expected at McMillan Park reservoir.

Procedure during test.—Pumping at the high rate specified was kept up for a period of more than forty-eight hours, during which time observations were taken at various points at intervals of two hours. Between the hours of 10 a. m., November 27, and 10 a. m., November 28, there was practically no change in the established conditions throughout the system. The elevations, meter readings, etc., at these times are given below:

ELEVATIONS.

	10 a. m.—		Raised.
	Nov. 27.	Nov. 28.	
Great Falls, M. H. No. 1	150.5	150.5	0
Dalecarlia reservoir	142.6	142.7	0.1
Georgetown:			
Inlet	140.8	140.9	....
Outlet	140.1	140.2	0.1
McMillan Park:			
Inlet	137.4	137.4	0
Outlet	137.0	137.0	0

METER READINGS.

[In millions of gallons.]

	10 a. m.—		Difference.
	Nov. 27.	Nov. 28.	
72-inch meter	52,073.9	52,132.7	58.80
54-inch meter	6,041.5	6,070.34	28.84
Total passing meter during 24 hours	....	....	87.64

The differences in elevation at Georgetown inlet and outlet were explained above. Those at McMillan Park inlet and outlet were due to loss of head through the circulating conduit and through the pumping station intake.

Capacity of aqueduct for established conditions.—For the levels established the aqueduct system carried about 87,500,000 gallons per day. There was a tendency for the upper sections to carry slightly more than this, as is indicated by the rise of 0.1 foot in Dalecarlia and Georgetown reservoirs. This depth corresponds to between 2,000,000 and 3,000,000 gallons and it is probably reasonable to assume that the entire system would have gradually adjusted itself to a rate of about 90,000,000 gallons.

Results of increasing quantity pumped.—At the end of the period described above, the pumps were speeded up so that the quantity discharged between 10 a. m. and

8 p. m., March 28, was 40,580,000 gallons, or at the rate of 97,500,000 gallons per day. The effect of this increase in rate was to draw down McMillan Park reservoir to elevation 136.6, while the elevation at Georgetown outlet remained unchanged at elevation 140.2, and of course Dalecarlia did not change.

Apparently this increase over a rate of 90,000,000 gallons per day was drawn entirely from the storage in McMillan Park reservoir, and did not tend to steepen the slope of the hydraulic gradient above the outlet of Georgetown reservoir. Conditions above that point remained just as they had been during the preceding period of twenty-four hours during which the measured flow had been 88,000,000 to 90,000,000 gallons.

Conclusion.—It seems entirely reasonable, therefore, to conclude that the aqueduct system as it now stands will discharge approximately 90,000,000 gallons per day, but can not discharge much, if any, more than that.

Additional loss of head data.—As a result of the test just described, the following revisions apply to the figures given above. The data from which were derived the values for the coefficient C for the Dalecarlia-Georgetown section, include an error due to the restriction in the middle of Georgetown reservoir. The elevations at Georgetown used for determining the loss of head through that section were the elevations at the outlet, as no regular record is kept of the elevation at Georgetown inlet. In the absence of data it was assumed that the elevations at inlet and outlet would not differ materially. They do differ, however, on account of the restricted area at the opening in the division embankment, which is 15 feet wide and the sill at elevation 140.1 approximately. From computation, the loss of head through this opening would seem to be as follows:

Elevation.	48 million gallons.	60 million gallons.	75 million gallons.
142.1	0.52	0.96	....
143.1	.20	.32	0.54
144.1	.11	.18	.28

Correcting for this loss of head will increase the value of C in the Dalecarlia-Georgetown section. This corrected value of C is given in the table below, and seems more consistent than the lower value, $c=92$, previously deduced.

[Section, Dalecarlia to Georgetown, 10,150 feet.]

Period.	Quantity.	Observed L. H.	Average elevation Georgetown outlet.	Corrected L. H.	Slope per 1,000.	C
September 12 to October 15, 1906	70.8	1.60	143.2	1.14	0.112	106
November 11 to December 19, 1906	64.5	1.18	145.4	1.08	.106	100
January 1 to March 3, 1907	70.9	1.44	145.0	1.30	.128	99
May 29 to June 30, 1907	63.4	1.28	145.4	1.18	.116	93
March 16 to 28, 1906	64.5	1.24	145.6	1.14	.112	97
Mean value of C						99

This value of C indicates a reduction of capacity of about 6 per cent, 3 per cent of which is an apparent reduction only, and due to the correction in the gauges.

The loss of head through the Georgetown reservoir by-conduit and through the circulating conduit in McMillan Park reservoir are as follows:

Million gallons per day.	Georgetown by-conduit.	Circulating conduit.
60	0.32	0.13
65	.38	.15
70	.44	.18
75	.50	.20
80	.57	.22
85	.64	.25
90	.72	.28

Summary of loss of head figures.—From the foregoing data the following summary is made up, giving the losses of head through the several principal sections of the aqueduct system for the conditions stated:

	Quantities (million gallons per day).								
	60.	65.	70.	75.	80.	85.	90.	95.	100.
Section D, 7,201 feet, C=97:									
Full, s<.150	0.7	0.8	0.9	1.07	......	......	......	......	......
Maximum section, L. H.=1.08 for Q=82, s>.150	......	......	......	......	......	......	1.33	1.47	1.63
Sections B and C, 40,245 feet, C=105:									
Full, s<.150	3.4	3.9	4.5	5.1	5.8	......	......	......	......
Maximum section, L. H.=6.05 for Q=88, s>.150	......	......	......	......	......	......	6.55	......	......
Sections B, C and D combined, 47,446 feet, C=103:									
Full, s<.150	4.1	4.8	5.5	6.3	7.1	......	......	......	......
Maximum section, L. H.=7.12 for Q=86, s>.150	......	......	......	......	......	......	7.9	......	......
Section A, 10,150 feet, C=99:									
Full, s<.150	0.9	1.1	1.3	1.4	1.6	1.8	......	......	......
Maximum section, 1.52 for Q=87.5, s>.150	......	......	......	......	......	......	1.95	......	......
Lydecker tunnel, 20,700 feet, C=98:									
Full	1.2	1.4	1.7	1.9	2.1	2.4	2.6	2.9	3.2
Add 0.2 foot	1.4	1.6	1.9	2.1	2.3	2.6	2.8	3.1	3.4

Discharge diagram.—From the loss of head figures so far given, a discharge diagram has been constructed. In plotting a discharge diagram, the water level at Great Falls (M. H. No. 1) may be taken for average conditions as elevation 151.0. This elevation will not be proper to use in computing and plotting the limiting flow, however, for there are numerous periods of many consecutive days when the elevation of water at M. H. No. 1 does not rise above 150.5. Some of these periods are more than thirty days long. The elevation at this point never falls much below 150.5. Moreover, the same conditions that tend to produce the limiting flow in the aqueduct, that is, long continued cold weather, tend also to keep the river at a low stage. In plotting the diagram, therefore, elevation 151.0 has been assumed for average conditions and 150.5 for the limiting conditions of flow.

The data from which are plotted the normal discharge curves are given above. The curves for limiting conditions of flow were determined by assuming the conduit to be divided up into short sections and computing the slopes required in the successive sections to discharge the stated quantity.

Effect of lowering the sill in the opening in the embankment in Georgetown reservoir.—The removal of this sill would enable us to maintain a draft of 90,000,000 gallons per day at McMillan Park reservoir without a loss of head of 0.7 foot at Georgetown reservoir; that is, with additional available storage equal to 0.7 foot in McMillan Park reservoir and the east half of Georgetown reservoir, and with 0.7 foot less lift at the pumping station.

The removal of this sill would not give any material increase in the ultimate capacity of the aqueduct. The lowering of the hydraulic gradient 0.7 foot at this point it is est mated would increase the discharge about 1 per cent.

Summary of study on aqueduct discharge.—The values of the coefficient C in the Hazen-Williams formula, as derived from the old and new series of observations are as follows:

Section.	1896–7.	1908.
Great Falls to Dalecarlia, entire	119	103
Dalecarlia to Georgetown	105	99
Georgetown to McMillan Park	....	98

The report setting forth the results of the earlier observations shows them to have been conducted with great care. Admitting the approximate accuracy of both of these studies there is indicated a reduction in capacity in the Great Falls-Dalecarlia section since 1896–7 of about 13.5 per cent and in the Dalecarlia-Georgetown section of about 6 per cent. After an inspection of the structures themselves, and examination into all the factors involved, this reduction seems explainable only by the deterioration of the wetted surfaces. As already stated, the earlier measurements were made designedly just after the only thorough cleaning the conduit has ever had. Large areas of the interior surfaces especially on the bottom and sides, are now covered with a soft but rough layer of clay averaging perhaps one-fourth inch in thickness. The presence of this rough deposit seems to be the explanation for the reduction in capacity in the last twelve years. Reductions in the capacities of other aqueducts are on record. The capacity of a portion of the Croton Aqueduct is reported to have diminished about 4 per cent; of other portions, larger but unstated percentages; of the Wachusett Aqueduct, Boston, 10 or 11 per cent; of the Cochituate and Sudbury aqueducts, Boston, respectively, 11.75 per cent and 13.5 per cent.

The coefficients determined as a result of the recent studies are low in comparison with those of the aqueducts just referred to. They correspond more nearly to the coefficients for good brick sewer work than for first-class aqueduct construction.

The analysis of the aqueduct records of discharge, loss of head, etc., covering a three-year period indicates that the maximum quantity of water that can be drawn through the system at the present time, from Great Falls to McMillan Park reservoir, is 90,000,000 gallons per day. This conclusion from the computations was confirmed by the actual test in November, 1908.

Appendix E.

ITEMIZED ESTIMATES OF COST.

Itemized estimate of cost of Great Falls gravity project, parallel location.

Land, 24.2 acres, at $150	$3, 630. 00
Land, 6.8 acres, at $17,500	119, 000. 00
Clearing and grubbing, 15 acres, at $160	2, 400. 00
Great Falls gatehouse:	
Excavation, earth, 1,003 cubic yards, at 60 cents	602. 00
Excavation, rock, 2,840 cubic yards, at $2.50	7, 100. 00
Concrete, 2,047 cubic yards, at $8	16, 376. 00
Riprap, 140 cubic yards, at $2.25	315. 00
House, 996 square feet, at $4	3, 984. 00
Structural steel, 5,520 pounds, at 8 cents	442. 00
Iron, guides, ladders, 6,950 pounds, at 10 cents	695. 00
Gates, 3½ by 9 feet, 2, at $900	1, 800. 00
Gate, 4-foot, circular	550. 00
Cast-iron pipe, 48-inch, 675 feet, at $14	9, 450. 00
Stop planks, 2,000 feet b. m., at $60	120. 00
Reinforcing steel, 2,220 pounds, at 4 cents	89. 00
Present aqueduct crossing	1, 000. 00
Railing, 24 linear feet, at $1.50	36. 00
Add for contingencies	6, 000. 00
	48, 559. 00
Tunnel, station 0 to station 92 (10 per cent timbered):	
9,200 feet, at $45 per foot	414, 000. 00
Crossing near Anglers' Club (estimate covers 150 feet):	
Excavation, earth, 4,160 cubic yards, at 50 cents	2, 080. 00
Embankment, ordinary, 3,918 cubic yards, at 40 cents	1, 567. 00
Top soil, 80 cubic yards, at $1.30	104. 00
Concrete, 390 cubic yards, at $8	3, 120. 00
Steel reenforcing, 6,820 pounds, at 4 cents	273. 00
Cast-iron pipe, 12-inch, 60 feet, at $2	120. 00
Gate valve, 12-inch	75. 00
Manhole top	15. 00
Steel, structural, 17,280 pounds, at 8 cents	1, 382. 00
Hardware, 1,360 pounds, at 5 cents	68. 00
Lumber, 30,000 feet b. m., at $60	1, 800. 00
Add for contingencies	2, 500. 00
Total cost of crossing	13, 104. 00
Cost per foot	87. 40

Masonry aqueduct, station 92 to station 235 (excluding cross-over) (full masonry section):	
Excavation, earth, 85,480 cubic yards, at 50 cents	$42, 740. 00
Embankment, ordinary, 95,276 cubic yards, at 40 cents	38, 110. 00
Embankment, rolled, 2,054 cubic yards, at 55 cents	1, 130. 00
Top soil, 22,093 cubic yards, at $1.30	28, 721. 00
Concrete, 25,797 cubic yards, at $8	206, 376. 00
Length, 14,150 feet	317, 077. 00
Cost per foot	22. 40
Blow-off, station 172:	
Excavation, earth, 134 cubic yards, at 50 cents	67. 00
Embankment, ordinary, 106 cubic yards, at 40 cents	43. 00
Concrete, 17 cubic yards, at $8	136. 00
Steel reenforcing, 140 pounds, at 4 cents	6. 00
Sluice gate, 48-inch	550. 00
Cast-iron pipe, 48-inch, 60 feet, at $14	840. 00
	1, 642. 00
Masonry aqueduct, station 235 to station 267, except 200 feet at bridge, No. 3 siphon (reduced masonry section):	
Excavation, earth, 10,135 cubic yards, at 50 cents	5, 068. 00
Excavation, rock, 8,901 cubic yards, at $2.50	22, 253. 00
Embankment, ordinary, 15,976 cubic yards, at 40 cents	6, 391. 00
Embankment, rolled, 1,655 cubic yards, at 55 cents	911. 00
Top soil, 3,928 cubic yards, at $1.30	5, 107. 00
Concrete, 4,620 cubic yards, at $8	36, 960. 00
Length, 3,000 feet	76, 690. 00
Cost per foot	25. 56
Siphon and bridge, station 257 to station 259:	
Excavation, earth, 2,698 cubic yards, at 60 cents	1, 619. 00
Embankment, ordinary, 854 cubic yards, at 40 cents	338. 00
Top soil, 330 cubic yards, at $1.30	429. 00
Concrete, plain, 686 cubic yards, at $8	5, 488. 00
Steel reenforcing, 624 pounds, at 4 cents	25. 00
Cast-iron pipe, 12-inch, 70 feet, at $2	140. 00
Gate valves, 12-inch, 2, at $40	80. 00
Iron doors, 2, at $50	100. 00
Steel pipe, 7 feet diameter, 372 feet, at $18.25	6, 790. 00
Stop plank, 4,320 feet b. m., at $60	260. 00
Stop plank grooves, 3,152 pounds, at 10 cents	315. 00
Checker plate, steel, 140 square feet, at 75 cents	105. 00
Length, 200 feet	15, 689. 00
Cost per foot	78. 45
Masonry aqueduct, station 267 to station 321+42 (full masonry section):	
Excavation, earth, 43,874 cubic yards, at 50 cents	21, 937. 00
Embankment, ordinary, 37,299 cubic yards, at 40 cents	14, 920. 00
Embankment, rolled, 26 cubic yards, at 55 cents	15. 00
Top soil, 8,638 cubic yards, at $1.30	11, 230. 00
Concrete, 9,600 cubic yards, at $8	76, 800. 00
Length, 5,442 feet	124, 902. 00
Cost per foot	22. 93

Siphon and bridge, Cabin John Creek, station 321+42 to station 327:	
Bridge—	
Excavation, earth, 1,230 cubic yards, at 60 cents	$738.00
Concrete, plain, 1,710 cubic yards, at $8	13,680.00
Concrete, face stones, 290 cubic yards, at $10	2,900.00
Blow-off—	
Cast-iron pipe, 24-inch, 50 feet, at $6	300.00
Gate valves, 24-inch, 2, at $175	350.00
Bridge and blow-off	17,968.00
Siphon—	
Excavation, earth, 6,766 cubic yards, at 50 cents	3,383.00
Embankment, ordinary, 4,300 cubic yards, at 40 cents	1,720.00
Top soil, 150 cubic yards, at $1.30	195.00
Concrete, 1,096 cubic yards, at $8	8,768.00
Steel pipe, 1,180 feet, at $18.25	21,525.00
Steel reenforcing, 624 pounds, at 4 cents	25.00
Stop plank, 4,320 feet b. m., at $60	260.00
Checker plate, steel, 140 square feet, at 75 cents	105.00
Stop plank grooves, 3,152 pounds, at 10 cents	315.00
Cost of siphon, length 558 feet	36,296.00
Cost per foot, siphon alone	65.00
Total cost with bridge	54,264.00
Cost per foot, including bridge	97.25
Masonry aqueduct, station 327 to station 416 (full masonry section):	
Excavation, earth, 71,670 cubic yards, at 50 cents	35,835.00
Embankment, ordinary, 65,369 cubic yards, at 40 cents	26,148.00
Embankment, rolled, 2,902 cubic yards, at 55 cents	1,596.00
Top soil, 13,700 cubic yards, at $1.30	17,810.00
Concrete, 16,266 cubic yards, at $8	130,128.00
Length, 8,900 feet	211,517.00
Cost per foot	23.76
Masonry aqueduct, station 416 to station 451 (reduced masonry section):	
Excavation, earth, 10,367 cubic yards, at 50 cents	5,184.00
Excavation, rock, 4,388 cubic yards, at $2.50	10,970.00
Embankment, ordinary, 23,926 cubic yards, at 40 cents	9,571.00
Embankment, rolled, 1,239 cubic yards, at 55 cents	682.00
Top soil, 5,898 cubic yards, at $1.30	7,668.00
Concrete, 5,439 cubic yards, at $8	43,512.00
Length, 3,500 feet	77,587.00
Cost per foot	22.17
Masonry aqueduct, station 451 to station 465 (full masonry section):	
Excavation, earth, 15,386 cubic yards, at 50 cents	7,693.00
Embankment, ordinary, 9,332 cubic yards, at 40 cents	3,733.00
Top soil, 1,851 cubic yards, at $1.30	2,407.00
Concrete, 2,408 cubic yards, at $8	19,264.00
Length, 1,400 feet	33,097.00
Cost per foot	23.64
Tunnel, station 465 to station 473+70, 870 feet (25 per cent timbered):	
870 feet, at $45	39,150.00

Intake gatehouse, Dalecarlia reservoir:	
Excavation, earth, 3,450 cubic yards, at 60 cents	$2,070.00
Concrete, 2,173 cubic yards, at $8	17,384.00
House, 3,550 square feet, at $4	14,200.00
Iron, guides, ladders, 19,100 pounds, at 10 cents	1,910.00
Cast-iron pipe, 36-inch, 300 feet, at $9	2,700.00
Gates, 3½ by 9-foot sluice, 12 at $900	10,800.00
Gate, 3 by 3-foot sluice	350.00
Stop planks, 6,000 feet b. m., at $60	360.00
Reenforcing steel, 14,230 pounds, at 4 cents	570.00
Railing, 160 linear feet, at $1.50	240.00
Checker plate, steel, 150 square feet, at 75 cents	113.00
	50,697.00
Same gatehouse, redesigned for requirements of coagulation at Stubblefield site	72,000.00
Masonry aqueduct, station 474+20 to station 508+50, except 1,450 feet in tunnel, under-water section, and gatehouse (reduced masonry section):	
Excavation, earth, 9,439 cubic yards, at 50 cents	4,720.00
Excavation, rock, 18,458 cubic yards, at $2.50	46,145.00
Embankment, ordinary, 21,949 cubic yards, at 40 cents	8,780.00
Top soil, 2,370 cubic yards, at $1.30	3,080.00
Concrete, 2,333 cubic yards, at $8	18,664.00
Steel reenforcing, 70,775 pounds, at 4 cents	2,832.00
Length, 1,980 feet net	84,221.00
Cost per foot	42.50
Tunnel, station 481 to station 490, 900 feet (50 per cent timbered):	
900 feet, at $45	40,500.00
By-conduit, Dalecarlia reservoir, under-water section:	
Excavation, earth, 2,610 cubic yards, at 60 cents	1,566.00
Masonry, reenforced concrete, 916 cubic yards, at $12	10,992.00
Reenforcing steel, 39,390 pounds, at 4 cents	1,576.00
Add for contingencies	5,000.00
Length, 460 feet	19,134.00
Cost per foot	41.60
Gatehouse, south connection, Dalecarlia reservoir:	
Excavation, earth, 748 cubic yards, at 60 cents	449.00
Excavation, rock, 900 cubic yards, at $2.50	2,250.00
Masonry, concrete, 1,107 cubic yards, at $8	8,856.00
House, 1,540 square feet, at $4	6,160.00
Iron, guides, ladders, 9,650 pounds, at 10 cents	965.00
Gates, 3½ by 9 feet, 6 at $900	5,400.00
Stop planks, 3,000 feet b. m., at $60	180.00
Reenforcing steel, 4,590 pounds, at 4 cents	184.00
Railing, 84 linear feet, at $1.50	126.00
Checker plate, steel, 100 square feet, at 75 cents	75.00
	24,645.00
Tunnel, station 508+50 to station 642+50, 13,400 feet (75 per cent timbered):	
13,400 feet, at $45	602,800.00

Masonry aqueduct, station 642+50 to station 723+50, except 1,850 feet in siphon at Rock Creek and tunnel at Sixteenth street (reduced masonry section):	
Excavation, earth, 21,665 cubic yards, at 50 cents	$10,833.00
Excavation, rock, 23,743 cubic yards, at $2.50	59,358.00
Embankment, ordinary, 35,550 cubic yards, at 40 cents	14,220.00
Embankment, rolled, 4,709 cubic yards, at 55 cents	2,590.00
Top soil, 9,155 cubic yards, at $1.30	11,902.00
Concrete, 9,821 cubic yards, at $8	78,568.00
Length, 6,250 feet	177,471.00
Cost per foot	28.39
Rock Creek siphon, including bridge, station 670+50 to station 686:	
Rock Creek siphon bridge—	
Excavation, earth, 5,100 cubic yards, at 60 cents	3,060.00
Excavation, rock, 3,890 cubic yards, at $2.50	9,725.00
Masonry, 10,620 cubic yards, at $8	84,960.00
Reenforcing steel, 45,000 pounds, at 4 cents	1,800.00
Blow-off house—	
Excavation, 408 cubic yards, at 50 cents	204.00
Concrete, 90 cubic yards, at $8	720.00
Reenforcing steel, 1,160 pounds, at 4 cents	47.00
Steel ladder, 200 pounds, at 10 cents	20.00
Manhole	25.00
Cast-iron pipe, 24-inch, 144 feet, at $6	864.00
Cast-iron pipe, 12-inch, 164 feet, at $2	328.00
Gate valve, 24-inch	175.00
Gate valve, 12-inch	40.00
Bridge and blow-off (not including roadway)	101,968.00
Rock Creek siphon; total length, 1,550 feet—	
Excavation, earth, 5,616 cubic yards, at 60 cents	3,370.00
Excavation, rock, 8,750 cubic yards, at $2.50	21,875.00
Embankment, ordinary, 12,105 cubic yards, at 40 cents	4,842.00
Top soil, 1,400 cubic yards, at $1.30	1,820.00
Concrete, 2,163 cubic yards, at $8	17,304.00
Steel pipe, 7 feet diameter, 3,108 feet, at $18.25	56,750.00
Steel reenforcing, 624 pounds, at 4 cents	25.00
Stop plank, 4,320 feet b. m., at $60 per M	260.00
Stop-plank grooves, 3,152 pounds, at 10 cents	315.00
Steel checker plate, 140 square feet, at 75 cents	105.00
Total for siphon alone	106,666.00
Cost per foot for siphon alone	68.85
Total, including bridge, etc	208,634.00
Total cost per foot	134.60
Tunnel, station 705+50 to station 708+50, 300 feet (all earth):	
300 feet, at $45	13,500.00
Tunnels, station 723+50 to station 781+20, 5,770 feet (all earth):	
5,770 feet, at $45	259,700.00
Add for contingencies, street repairs, etc	20,000.00
	279,700.00
Intake gatehouse, McMillan Park reservoir:	
Excavation, earth, 2,180 cubic yards, at 60 cents	1,308.00
Masonry, concrete, 1,166 cubic yards, at $8	9,328.00
House, 966 square feet, at $4	3,864.00
Centrifugal pump and motor	833.00
Iron, guides, ladders, 3,350 pounds, at 10 cents	335.00
Gates, 3½ by 9 feet, 2 at $900	1,800.00
Stop planks, 1,000 feet b. m., at $60	60.00
Reenforcing steel, 3,170 pounds, at 4 cents	127.00
Railing, 20 linear feet, at $1.50	30.00
Checker plate, steel, 70 square feet, at 75 cents	52.00
	17,737.00

Conduit from gatehouse to reservoir:	
Excavation, earth, 2,410 cubic yards, at 60 cents	$1,446.00
Concrete, 137 cubic yards, at $8	1,096.00
Embankment, earth, 1,912 cubic yards, at 40 cents	765.00
Loam, 118 cubic yards, at $1.30	154.00
	3,461.00
Miscellaneous items:	
Repairing present by-conduit at Dalecarlia reservoir	4,000.00
Repairing damages to Conduit road	24,500.00
Tunnel rights	3,570.00
Manholes, 48, at $25	1,200.00
	33,270.00
Summary:	
Land	122,630.00
Clearing and grubbing	2,400.00
Intake and gate house at Great Falls	48,559.00
Tunnel, station 0 to 92	414,000.00
Crossing, station 94+78 to station 96+28	13,104.00
Masonry aqueduct, station 92 to station 235	317,077.00
Blow-off station 172	1,642.00
Masonry aqueduct, station 235 to station 267 [a]	76,690.00
Siphon, station 257 to station 259	15,689.00
Masonry aqueduct, station 267 to station 321+42	124,902.00
Siphon, station 321+42 to station 327	54,264.00
Masonry aqueduct, station 327 to station 416	211,517.00
Masonry aqueduct, station 416 to station 451	77,587.00
Masonry aqueduct, station 451 to station 465	33,097.00
Tunnel, station 465 to station 473+70	39,150.00
Intake gatehouse, Dalecarlia reservoir	72,000.00
Masonry aqueduct, station 474+20 to station 508+50 [a]	84,221.00
Tunnel, station 481 to station 490	40,500.00
Under-water section, by-conduit, Dalecarlia	19,134.00
Outlet gatehouse, Dalecarlia	24,645.00
Tunnel, station 508+50 to station 642+50	602,800.00
Masonry aqueduct, station 642+50 to station 723+50 [a]	177,471.00
Siphon and bridge, Rock Creek	208,634.00
Tunnel, station 705+50 to station 708+50 (Sixteenth street)	13,500.00
Tunnel, station 723+50 to station 781+20	279,700.00
Intake gatehouses, McMillan Park reservoir	17,739.00
Connection McMillan Park gatehouse to reservoir	3,461.00
Coagulating equipment for future installation	300,000.00
Miscellaneous	33,270.00
Engineering and contingencies	450,000.00
Total estimated cost	3,879,383.00
Condensed summary:	
Aqueduct, standard section, 44,622 feet	1,102,562.00
Tunnel, standard section, 30,440 feet	1,389,650.00
Crossings and sections of unusual type, 2,918 feet	310,825.00
Gatehouses, other structures, land, etc	626,346.00
Engineering and contingencies	450,000.00
Total estimated cost	3,879,383.00
Estimated cost of construction per linear foot:	
Aqueduct, standard section	24.71
Tunnel, standard section	45.65
Crossings and sections of unusual type	106.50
Estimated total cost of entire system per linear foot	49.60

[a] Excepting certain portions in siphons, tunnels, etc., which are estimated separately.

Itemized estimate of cost of Great Falls gravity project, tunnel location.

Land, 21.5 acres, at $150	$3,225.00
Land, 6.8 acres, at $17,500	119,000.00
Clearing and grubbing, 21 acres, at $160	3,360.00
Great Falls gatehouse (identical with that given in estimate for parallel location)	48,559.00
Tunnel, station 0 to station 290, rock (25 per cent timbered):	
29,000 feet, at $45	1,305,000.00
Masonry aqueduct, station 290 to station 298+84 (reduced masonry section):	
Excavation, earth, 3,210 cubic yards, at 50 cents	1,605.00
Excavation, rock, 2,799 cubic yards, at $2.50	6,997.00
Embankment, ordinary, 3,426 cubic yards, at 40 cents	1,371.00
Top soil, 888 cubic yards, at $1.30	1,155.00
Concrete, 1,380 cubic yards, at $8	11,040.00
Length, 864 feet	22,168.00
Cost per foot	25.65
Cabin John Bridge and siphon, station 298+64 to station 305+04:[a]	
Bridge (complete as in parallel location)	17,968.00
Siphon, 640 feet, at $65[b]	41,600.00
	59,568.00
Masonry aqueduct and all other structures from station 305+04 on tunnel location (station 327 parallel location) to McMillan Park reservoir, identical with those given in the estimate for parallel location	2,205,156.00
Miscellaneous:	
Repairing present by-conduit at Dalecarlia reservoir	4,000.00
Repairing damages to Conduit road	10,500.00
Tunnel rights	2,550.00
Manholes, 24 at $25	600.00
	17,650.00
Summary of cost of proposed aqueduct, tunnel location:	
Land	122,225.00
Clearing and grubbing	3,360.00
Intake and gatehouse, Great Falls	48,559.00
Tunnel, station 0 to station 290	1,305,000.00
Masonry aqueduct, station 290 to station 298+64	22,168.00
Siphon and bridge, station 298+64 to station 305+04	59,568.00
Aqueduct, tunnel and other structures, from this point to McMillan Park reservoir	2,205,156.00
Miscellaneous	17,650.00
Engineering and contingencies	550,000.00
	4,333,686.00
Condensed summary:	
Aqueduct, standard section, 22,894 feet	606,061.00
Tunnel, standard section, 50,240 feet	2,280,650.00
Crossings and sections of unusual type, 2,650 feet	287,336.00
Gatehouses, other structures, land, etc	609,639.00
Engineering and contingencies	550,000.00
Total estimated cost	4,333,686.00
Estimated cost of construction per linear foot:	
Aqueduct, standard section	26.46
Tunnel, standard section	45.40
Crossings and section of unusual type	108.40
Estimated cost of entire system per linear foot	57.20

[a] Station 305+04 of tunnel location is station 327 of parallel location.
[b] This is cost per foot of siphon alone for parallel location.

Itemized estimate of cost of project for additional storage at the Stubblefield site (adaptable only to the parallel location).

Land, 181 acres, at $200	$36, 200. 00
Clearing and grubbing, 36.2 acres, at $160	5, 790. 00
Stubblefield reservoir, embankment, etc.:	
Excavation, earth, 164,724 cubic yards, at 50 cents	82, 362. 00
Embankment, rolled, 823,988 cubic yards, at 55 cents	453, 194. 00
Concrete, core wall, 51,780 cubic yards, at $8	414, 240. 00
Slope paving, 43,640 square yards, at $1.80	78, 600. 00
	1, 028, 396. 00
Gatehouses and sluice tower:	
Inlet and outlet gatehouses, just alike and exact duplicates of Dalecarlia inlet gatehouse, cost of 2 gatehouses	100, 050. 00
Blow-off tower—	
Excavation, earth, 356 cubic yards, at 60 cents	214. 00
Concrete, 2,611 cubic yards, at $8	20, 888. 00
Cast-iron pipe, 48-inch, 600 feet, at $14	8, 400. 00
Sluice gate, 4-foot	550. 00
Iron, ladders, etc., 1,000 pounds, at 10 cents	100. 00
	30, 152. 00
Summary:	
Land	36, 200. 00
Clearing and grubbing	5, 790. 00
Embankment, paving, etc	1, 028, 396. 00
Inlet gatehouse	50, 025. 00
Outlet gatehouse	50, 025. 00
Sluice tower, etc	30, 152. 00
Engineering and contingencies	180, 000. 00
Estimated total cost of construction	1, 380, 588. 00

MR. ALLEN HAZEN'S REVIEW OF MR. LONGLEY'S REPORT.

June 28, 1909.

Major: In accordance with your instructions I have examined Mr. Longley's work and report in reference to securing an additional supply of water for Washington; and I beg to report as follows:

Mr. Longley's conclusions in general are well founded, and I agree with him entirely in regard to all his main positions. There are some matters, however, that should be investigated further before the question is finally settled; and this must therefore be considered as a progress report and not as a final one.

It may be as well that the matter must be left in this way, because it now appears that the present works will be sufficient to serve the city for some years, and it is not necessary to immediately build additional works; and it will be better to defer decision as to many matters concerning these new works until it becomes necessary to build them.

Capacity of present works.—Before the construction of the filtration plant the present works, according to the best information available, had a capacity of delivering water at the rate of about 76,000,000 gallons per day in the city. The tests upon which this rating was made were carried out after the most thorough cleaning that the aqueduct has ever had, and they therefore represented conditions considerably more favorable than average conditions.

The construction of the filtration plant increased the capacity of the aqueduct to a notable extent. This was brought about by the pumping plant installed in connection with the filters. The use of this pumping plant allowed more head to be used up in friction in the aqueduct than had previously been available, and therefore allowed more water to be brought through it. On the basis of the old gaugings the calculated increase in capacity was about 20,000,000 gallons per day, or in round figures the total capacity was raised to 95,000,000 gallons per day. An actual test, arranged and carried out by Mr. Longley, under existing conditions, demonstrates that the capacity of the structures as they actually stand is about 90,000,000 gallons per day.

The falling off from the 95,000,000 gallons computed from the earlier gaugings to the 90,000,000 gallons actually found is clearly due to the fact that the structures at the present time are not as clean and otherwise in good condition as they were when the previous gaugings were made.

The accumulation of sediment in the aqueduct and the growth of sponges and other organisms and the deterioration of the inner surface of the aqueduct may be expected to continue, and if not adequately cleaned the discharging capacity of the aqueduct may be expected to be further decreased during a term of years. The difficulty of cleaning the aqueduct thoroughly, so as to keep the sides entirely smooth, will become more difficult as the consumption approaches the carrying capacity of the aqueduct. It will therefore be prudent, in considering the time during which the present works will serve, to rate them at something less than 90,000,000 gallons, their present capacity; and without attempting further calculation I shall take this limiting capacity for the purpose of estimate at 85,000,000 gallons per day.

Mr. Longley has investigated the question of peak load, or the excess in the rate of consumption at times over the annual average consumption. He has found that under present conditions the winter consumption in periods of extreme cold weather may rise to 45 per cent above the annual average rate. He is right in assuming that this excess winter consumption will largely be cut off with the gradual installation of meters on the services; but when this is done there will be left a summer peak load, representing the extra use of water in watering streets and lawns, and for other uses in continued hot and dry weather.

There is no evidence to determine just how great this summer peak will be. I have examined the record of the daily use of water since the filter plant was started, and also general experience in other cities; and I do not think it safe to count on this summer peak being less than 30 per cent above the annual average rate.

On this basis the extreme capacity of the aqueduct will be required at time of maximum consumption in summer, when the average annual consumption is about 65,000,000 gallons per day. In other words, when the average annual consumption reaches 65,000,000 gallons per day; the use during hot, dry weather may be reasonably expected at times to reach 30 per cent more than this, or 85,000,000 gallons per day, the capacity which I take as a safe one for the present works through a reasonable period of the future.

During the last five years the consumption has reached and exceeded at times these figures. If no new conditions had been introduced, there would seem to be urgent need for an additional supply. This was the condition when Mr. Longley's studies were undertaken.

Use and waste of water.—During the past year there has been a great decrease in the consumption of water. This has been brought about largely by the efforts of Mr. W. A. McFarland, superintendent of the distribution system, which is managed by the District of Columbia. Mr. McFarland's work in finding and stopping leakage can not be too highly commended. The reduction in consumption has been brought about in part by the partial metering of the services and in part by a study of the flow of water in the pipes in the streets and a detection and stoppage of leakages in the mains and in service pipes.

The results already accomplished have so far reduced the consumption that it is clear that no additional works for the supply of water will be required for several years. The continuation of the work of stopping leaks by Mr. McFarland is certain to result in further saving of water and it will still further extend the period during which the present works will suffice.

The postponement of new works is not to be regarded as indefinite. Washington is growing rapidly and there is every indication that the growth will continue. A liberal use of water is desirable and necessary. Mr. McFarland's effort is to cut off needless waste but not to restrict any legitimate use. With the waste cut off there will still remain a large use of water and a larger supply than the present one will be required at a period that is not very remote.

It may be that cutting off the waste will extend the period during which the present works will suffice, by as much as from ten to twenty years. The exact period can not be determined, as it depends upon the rate of growth of the city, the effectiveness of the measures taken for suppressing waste, and upon the actual use of water that will remain; and none of these matters can be determined with certainty. Whether the period proves to be longer or shorter, the works for additional supply have ceased to be necessary at the present time, and deliberate attention can be given to selecting the best means of getting more water when the time for it arrives.

Metering government buildings.—I recommend most strongly the installation of meters on all services for public buildings. Even though the water is not paid for by meter measurement, the meters on the services will allow accurate knowledge to be had of what water is drawn and at what times, and comparison can be made between the actual drafts and the actual needs and uses of water. Carrying out this policy is certain to disclose leaks in services and fittings in government buildings now taking place, the stoppage of which will represent a saving in water equal to an added capacity of the present works reaching in value many times beyond the cost of the meters required to demonstrate the conditions and allow the leaks and wastes to be stopped.

Flashboards on Great Falls dam.—The capacity of the conduit is figured for extreme low water conditions in the Potomac River. Under all other conditions more water will flow through it. The difference is not very great, perhaps only a matter of 3,000,000 to 5,000,000 gallons a day. I have not been through the calculation needed to determine the amount exactly, so the figure mentioned must be taken as only a rough approximation. Mr. Longley believes that it would be unsafe and unwise to raise the Great Falls dam on its present base, and I fully agree with this conclusion; but iron pins can be put in holes drilled in the top of the stone dam and flashboards placed against them, raising the water by from 1 to 2 feet without very great expense. The pins should be calculated so that they will bend over and allow the boards to escape before the flood flow reaches such a height that there would be any increased strain on the dam beyond that represented by ordinary floods without flashboards. With this done it is perfectly safe to use flashboards in this way. I regard this simply as a temporary measure that can be taken in the years when the consumption approaches dangerously near the capacity of the conduit.

Auxiliary pump at Dalecarlia.—Mr. Longley mentions in his report the installation of a pumping station at Dalecarlia to lift the water as it comes from the aqueduct to the reservoir and thereby allow the hydraulic slope of both ends of the aqueduct to be increased. This would increase slightly the carrying capacity of the aqueduct. I am disposed to think that a very much simpler and cheaper pumping station than that proposed by Mr. Longley can be used for this service. I would suggest a single large screw pump driven by an inexpensive steam engine, supplied by common fire tube boilers, without any of the appliances for securing economy which were included in Mr. Longley's estimate. The building to contain the pumping machinery also might be temporary and of an inexpensive character. This pumping station should be regarded as only for temporary use when the consumption approaches near the carrying capacity of the aqueduct, and regarded in this way the few million gallons additional daily capacity would be very cheaply obtained. All needed apparatus can be installed without interfering with the normal operation of the aqueduct, and whenever a new aqueduct is built the pumps may be removed, as it would not be worth while to keep them with a wide margin of capacity otherwise available.

Stability of present aqueduct.—The question has been raised as to the stability of some of the structures in the present aqueduct, and it has been suggested that as a matter of insurance a second aqueduct ought to be provided so that in case of failure of any of the structures the supply to the city would be maintained.

This is certainly an important matter. Mr. Longley has investigated the condition of the structures of the aqueduct. I have not investigated them personally, but I have talked over with him his investigations and have questioned him concerning many matters.

In general, the structures of the present aqueduct are of a stable character, and there does not seem to be much reason to apprehend accidents which will shut off the supply of water. Even in case of the actual collapse of a section of the aqueduct there are several days' supply of water always held in the reservoirs; and with the facilities of the Engineer Corps for putting men promptly on the ground for repairs in an emergency it would seem possible to construct timber trestles and flumes to bridge over in a temporary way any section of aqueduct that might be so destroyed, before the water in the reservoirs was exhausted, and so maintain the supply.

Every reasonable effort should be made to ascertain the condition of all the structures of the aqueduct, and to strengthen any points that may be found weak; and with this done there does not seem to be any risk in the use of the present structures which justifies at this time the construction of a new aqueduct not otherwise required.

Best arrangement for additional supply.—I have examined Mr. Longley's survey for an additional aqueduct from Great Falls to McMillan Park reservoir, and it seems to me that the route selected by him is well chosen and the structures proposed by him are in general suitable and adequate.

A number of thoughts concerning possible improvements in details and matters of secondary importance have occurred to me, and these I have suggested to Mr. Longley. It seems to me unnecessary to take up a discussion of these points in detail, as under present conditions the immediate construction of an additional aqueduct is not necessary; and it will be time enough to take up its details when it is necessary.

Cost of a second aqueduct from Great Falls.—I have been over Mr. Longley's estimates of cost, and in the light of general experience it is my judgment that a new aqueduct, equal in capacity to the present one, with the auxiliary works and connections that would naturally go with it is likely to cost fully $4,000,000.

This estimate is for an aqueduct delivering water at the present level of McMillan Park reservoir, from which level it is pumped to the filters. It is not possible, from Great Falls, to deliver water at McMillan Park by gravity at a sufficient elevation so that this pumping can be dispensed with.

Cost of pumping.—The cost of pumping to the filters at McMillan Park, including the capital charges on the machinery, is probably not less than $2 per million gallons. For 65,000,000 gallons per day average annual use to be ultimately expected from an aqueduct of this size, this amounts to $47,500 per annum, which is 4 per cent interest on $1,190,000.

Possibility of a gravity supply from a higher level.—If water could be obtained at a higher level it might be possible to eliminate the cost of pumping the new water at McMillan Park, and also if the elevation of the water at the source were great enough, it would be possible to build the new aqueduct on a steeper slope; and if this could be done water would flow in it more rapidly and a smaller aqueduct would bring the same quantity of water, and the cost of the aqueduct per foot would therefore be reduced.

The fall from Great Falls to McMillan Park reservoir is less than 1 foot per mile, an extremely flat slope for the economical construction of an aqueduct. A source higher than the Potomac at Great Falls would be more desirable in these respects.

Other sources of supply.—If the point of intake were moved from Great Falls to a more distant point on the Potomac, the water could be secured at a higher elevation. There are also various tributaries of the Potomac which would be available at higher elevations. Mr. Longley has studied one or two such possible arrangements in a preliminary way, but the distances involved to secure an increase in elevation that is worth going after are so great that the projects are not financially attractive. There does not seem to be any reason for considering the Potomac further up or the upper tributaries at a considerable distance.

Rock Creek.—Mr. Longley has made surveys for the development of Rock Creek as a source of water supply. The water could be taken within the District of Columbia and carried by a steel pipe about 5 miles long to McMillan Park reservoir and delivered at an elevation great enough so that it would not require pumping to reach the filters. A large dam and reservoir would be required. My calculations indicate that with 12 inches of storage some 40,000,000 gallons per day would be available for supply while leaving a certain amount of water flowing in the stream for park purposes.

This development in many respects is an attractive one, although the dam and reservoir would have to be built in a region being built up and developed to such an extent as to raise a question as to its use for water-supply purposes. The development would consist of the construction of a reservoir with a flow line at about elevation 227. The dam would hold water to a maximum depth of about 77 feet and would be about 700 feet long. The reservoir would have an area of some 1,700 acres and would contain 14,000,000,000 gallons of water. Such a reservoir would be filled by the winter and spring floods from a tributary area of over 60 square miles, and the water contained in it, without further help from the catchment area, would serve to maintain the supply at the present rate of draft through seven months of extremely dry weather. If it were not for the developments on Rock Creek this would seem to be clearly the most advantageous source for an additional supply to the limit of the capacity as above stated. With the developments of roads, railroads, parks, buildings and other structures as they are, it may be seriously questioned whether it will be advantageous to attempt it.

Patuxent River.—This source of supply is not mentioned in Mr. Longley's report, because it was only considered near the end of the investigation, when there was neither time nor money available for Mr. Longley to investigate it adequately. The information concerning it is from the government topographical maps, supplemented by a rapid preliminary inspection in an automobile and on foot, of some of the points involved.

The stream could be taken almost directly north of McMillan Park reservoir, at a distance of about 16 miles, or at about the same distance as the present intake at Great Falls. The present water level at a point about a mile above the Columbia turnpike crossing, indicated by the Geological Survey maps and checked by aneroid barometer, is 250 feet above tide, or 85 feet above the water on the filters at McMillan Park.

The catchment area of the stream at this point, measured from the government maps, is about 130 square miles. For some distance up and down stream both sides are of ledge, and the ledge frequently approaches the stream, so that I estimate that a dam 70 or 80 feet high would not be more than 600 or 800 feet long. Ledge is also exposed here and there in the bed of the stream. The Geological Survey maps, which must be taken as only very rough approximations, indicate that a dam 90 feet in height would flow the water back 9 miles, forming a long and generally narrow reservoir, but with a number of considerable branches on tributary streams. The land in the bottom and sides of the valley is not especially valuable, and only a few small and inexpensive buildings would be flooded.

A reservoir formed by a dam at some site to be selected, probably within a mile of the Columbia turnpike, either up or down, holding 12 inches run-off from the catchment area, would make available in a dry year 100,000,000 gallons of water per day. The water would be available at a sufficient elevation so that it could be taken to the filters at McMillan Park by gravity, and the cost of pumping would be saved.

A tunnel 3 miles long, more or less, through a flat ridge would take the water into a valley, from which a direct and apparently easy route for a steel pipe line would lead to the filters. The head would be sufficient so that a 6-foot steel pipe would carry as much water as could be brought from Great Falls by a 9-foot aqueduct.

The catchment area is mostly good farm land, under general cultivation. It is rolling, the high points being comparatively flat, with the valleys deep cut between. All of the villages and the best farm buildings are on the summits. The villages are small and are scattered along the rim of the catchment area, in general about one-half of each village draining toward the stream. There are no considerable villages on the catchment area, and no lines of steam railroad or trolleys running through it. I estimate the population very roughly at 30 per square mile, and probably not increasing.

The indications are that a steel pipe line and tunnel from this source could be built for very much less than the cost of an aqueduct from Great Falls. On the other hand, it would be necessary to build a dam and storage reservoir, and to acquire the property to be flowed, and to raise various roads and build bridges for them, and large and undetermined amounts of money would be required for these purposes.

The information now at hand is not sufficient to determine whether or not such a supply could be more advantageously obtained than to build an additional aqueduct from Great Falls. The project is sufficiently promising, so that it would not seem wise to determine upon the construction of an additional aqueduct from Great Falls until the possibilities of the Patuxent River are determined by preliminary surveys, covering the sites for a dam and reservoir and a tunnel and pipe line, and until estimates of the cost of the required work are made.

A comparison of the quality of the water to be obtained with the quality of the Potomac water should also be made. From a sanitary standpoint, the use of water from an impounding reservoir fed by a sparsely settled catchment area would have advantages over the use of Potomac water. The questions of the amount of turbidity in the water collected by such a reservoir, and the rate at which it would settle out, and of what preliminary treatment, if any, would be required before taking the water to the filters at McMillan Park, present problems that can certainly be solved, but which will require considerable study to insure solving them in the most advantageous ways.

Capacity of the present filters.—The filters were designed to purify the water that could be secured through the present aqueduct when filtering at the rate of about 3,000,000 gallons per acre daily. Mr. Longley has shown the need of preliminary chemical treatment of Potomac water at times. With preliminary chemical treatment adopted as part of the system, there is no question but what the results of filtration would be as good, and in some respects better, with the filters operated at a six-million rate than as they now are, with the filters operated at one-half that rate. If the new source should be an impounding reservoir upon the Patuxent, there is also little question that the water could be filtered at a six-million rate with satisfactory results. Whatever the source of the new supply, it therefore seems possible, with suitable preliminary treatment, to count on increasing the rate of filtration as may be necessary, so that the whole of the supply to the extent indicated may be filtered at the present works.

Increasing the rate of filtration in this way will no doubt involve some changes in the piping and other arrangements at the filter plant. The present piping and arrangements are sufficient for the treatment of much more water than can be delivered through the present aqueduct, and it would only be necessary to make these changes when there was need for doing it. This question is therefore one of a future so remote that there is no occasion for going into it further at the present time.

Other measures suggested.—There are a few things which, it seems to me, can be done to advantage to the system, and although perhaps not strictly covered by your instructions, it may be well to mention them.

(1) *Reconstruction of the Georgetown reservoir.*—This has been considered at various times, and preliminary plans have been made for doing it. Reconstructing it will make it more efficient as a sedimentation basin, especially in connection with the preliminary chemical treatment of Potomac water, which has been recommended.

(2) *Preliminary chemical treatment.*—This has been considered as a part of the system of purification from the start. It was a part of the process as originally recommended by Messrs. Hering, Fuller, and the writer. The plant has never been completed in this respect. Completing the plant at this time involves the expenditure of only a small amount of money, and would have the great advantage that it would allow bright, clear water to be delivered at all times. At present such water is delivered for the greater part of the year, but at times of turbid water in the Potomac the filtered water as delivered in the city is more or less milky and unsatisfactory to people accustomed to the use of perfectly clear, bright water.

(3) *Covering the high-service distributing reservoirs.*—Filtered water deteriorates when stored in the sunlight. For this reason the distributing reservoir for the low service, built in connection with and as a part of the filtration plant, is covered. The older distributing reservoirs connected with the several high-service systems are not covered. When raw Potomac water was used in the city there was no advantage in having the distributing reservoirs covered. Under present conditions there are at times growths of microscopical organisms in all of these high-service reservoirs which impart to the water which passes through them tastes and odors that are disagreeable and unsatisfactory to the consumers. This condition could be entirely corrected by covering these reservoirs, and, in my judgment, this should be done. These reservoirs belong to and are operated by the District of Columbia and not by your office.

(4) *Inspection of present aqueduct.*—A careful inspection of all the structures on the present line of the aqueduct, with special lookout for any signs of weakness, and followed up by such repairs and strengthening as may be indicated at any time.

(5) *Meters.*—A continuation of the meter system until all services are metered. This is the only adequate way of stopping unnecessary and constant waste through defective plumbing and fixtures.

(6) *Leakages.*—A continuation of the present work of Mr. McFarland in discovering and stopping leaks from mains and service pipes.

Some of the matters above enumerated are under way and are being continued, while others have not yet been taken up. In my judgment all of them should be taken up and followed to completion, together with such additional surveys as are needed to show whether or not the Patuxent River or any other source may be a better source for additional supply than the Potomac River.

With all these measures under way there is no reason for undertaking at the present time the construction of an additional aqueduct. The money that would otherwise be required to pay the interest alone on the cost of a new aqueduct will pay many times over the cost of all that is herein suggested.

Respectfully,

ALLEN HAZEN.

Maj. J. J. MORROW,
Corps of Engineers, Washington, D. C.

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