1891

NINTIETH ANNUAL REPORT

OF THE

BUREAU OF WATER,

For the year ending December 31, 1891,

AND

FIRST ANNUAL MESSAGE

OF

EDWIN S. STUART,

Mayor of the City of Philadelphia,

WITH

ANNUAL REPORT

OF

JAMES H. WINDRIM,

Director of the Department of Public Works,

ISSUED BY THE CITY OF PHILADELPHIA, 1892.

1892.

PHILADELPHIA:
DUNLAP & CLARKE, PRINTERS & BINDERS, NOS. 1306-8-10 FILBERT ST.
1892.

APPENDIX H.

PROPOSED SYSTEM OF WATER SUPPLY FROM SOUTHERN NEW JERSEY.

Philadelphia, May 13, 1891.

To Joseph Wharton, Esq.,

Sir:—In accordance with your instructions to examine and report upon the quantity of water available from the several branches of Mullica River and of the Rancocas, near Taunton, New Jersey, and means for delivering the same to Camden and Philadelphia, I have the honor to report as follows:

These streams belong to a class peculiar to the Atlantic slope of the United States, which have been designated Sand-hill streams by Prof. George F. Swain in his Report upon Water Power for the Tenth Census, which designation I have adopted as descriptive of marked peculiarities of flow which I shall point out hereafter.

The Gathering Grounds.

The water sheds of the upper Rancocas and Mullica River lie in the great pine belt of New Jersey. The soil here is of the Tertiary formation, consisting of sand and gravel, supporting a light growth of pine and cedar timber, with scanty undergrowth. In many places no vegetable mold whatever is to be found, nothing but a clean, white sand. Population is very scanty. From the Physical Descripton of New Jersey, published by the Geological Survey, it is found to be but nineteen to the square mile on the Mullica above Batsto, seven to the square mile on Wading river, and no more on the upper Rancocas.

As a consequence nearly all of the region is a forest. Only from one to five per cent. of cultivated land is found on nearly the whole of the proposed gathering ground.

To those who are familiar with the geography of Southern New Jersey, the region is best described as stretching along the New Jersey Southern Railroad from Winslow Junction to Woodmansie, twenty-five miles northeast, and extending about ten miles on either side. A trip over this line of railroad will give a good idea of the character of the tract.

The nature of the soil is to permit very free percolation of the water which falls upon it in rain. No matter how heavy the fall may be, it is a rare sight to see any surface water flowing; sinking at once into the earth it finds its way gradually through the clean sand and gravel to the streams. The consequence is that there is no carrying of effete vegetable and animal matters into the water courses to lie there and pollute them, such as always occurs when there is a rush of surface waters over steep slopes and impervious soils after heavy showers; nor is there ever the slightest muddiness. Another fact favorable to the continued purity of these waters deserves mention: Once the bed of a reservoir is thoroughly cleaned of its scanty vegetable growth there is little tendency to renew it. A very slight depth of water serves to check it entirely, and the sand remains clean, as upon the seashore. This fact may be observed in many existing shallow ponds. The tendency of water to keep pure and sweet in this region, under conditions which would, in many places, cause serious trouble, has been frequently remarked. Even where great tracts have been flowed to a depth of only a foot or so, without destroying the vegetable growth, miasmatic diseases are unknown.

It is seen, therefore, that conditions of unusually small population, slight vegetation and a most efficient natural

filtration exist, all favorable to preserve these waters in their present condition of purity and freedom from those deadly animal and vegetable organisms which modern research has shown to be justly dreaded, and nowhere more carefully guarded against than in our public water supplies.

Quantity of Water Available.

The considerations of ready percolation above noted, besides contributing to the purity of the water perform an important office in equalizing the flow. As the water cannot rush over the surface to the streams, great floods are almost unknown. The most casual observer may notice this fact from the limited bridge openings, the long, low embankments of sand thrown boldly across the valleys with slight provision for flood overflow, and the general absence of signs of destructive floods. The water being stored up in the sand and fed out gradually to the streams, the summer flow is well sustained. The streams are far less flashy than those of Northern New Jersey and Eastern Pennsylvania. For instance, in 1878 Mr. H. P. M. Birkinbine found the flow of the Schuylkill at Fairmount to be 307 cubic feet per second, or at the rate of 0.17 cubic foot per second per square mile of watershed, the area at the point of gauging being 1,800 square miles; the flow of Great Egg Harbor River, at May's Landing, from 216 square miles of watershed, never falls below 70 cubic feet per second, or 0.32 cubic feet per second per square mile, being nearly double the dry season flow of the Schuylkill. The latter stream is subject to violent floods.

Having been engaged in studying these stream-flows for the Geological Survey of New Jersey during the past year, the writer has collected some important data as to the amount of water available from Southern New Jersey water sheds. The results appear in the report of the State Geologist for 1890, from which I have abstracted what is necessary for this report. Gauges were set up upon some typical streams and read throughout the year. As these gaugings are the basis for our estimates of quantity of water, I give herewith the results on Great Egg Harbor River and the Rancocas:

FLOW OF GREAT EGG HARBOR RIVFR AT MAY'S LANDING, 1890.

Drainage Area 215.8 Square Miles.

Month.	Rain.	Flow.	Flow in Cubic Feet per Second.	
	Inches.	Inches.	Greatest.	Least.
January	1.70	1.25		
February	3.70	1.80	710	322
March	6.06	2.39	723	327
April	3.37	2.44	734	268
May	3.71	1.88	491	270
June	2.33	1.26	352	126
July	5.13	1.33	302	201
August	5.31	1.45	541	97
September	6.06	1.05	366	114
October	6.30	1.67	346	270
November	0.71	1.32	325	207
December	4.49	1.52	438	180
Total	48.87	19.36		

FLOW OF RANCOCAS AT PEMBERTON, 1890.

Drainage Area 111.7 Square Miles.

Month.	Rain.	Flow.	Flow in Cubic Feet per Second.	
	Inches.	Inches.	Greatest.	Least.
March	5.48	3.21	590	161
April	2.18	1.93	329	118
May	3.20	1.53	189	132
June	3.76	1.84	244	129
July	5.38	1.37	211	82
August	4.49	1.25	144	97

Comparing the same six months on the two streams we have:

Comparison of Flow from March to August.

	Rain.	Flow.
Great Egg Harbor	25.91	10.75
Rancocas	24.49	11.13

The flow given in inches in these tables represents the number of inches of rain which flowed off in the stream in each case.

It is seen that the Rancocas shows a larger flow than the Great Egg Harbor. There was a leakage at the point of gauging the Rancocas which could not be measured, and which amounted to not less than five per cent. of the flow, so that the above figures do not do this stream full justice. Our streams on the Mullica probably approach closely to the Rancocas; yet to be entirely conservative I have adopted the Great Egg Harbor as a typical stream, and drawn conclusions from its flow. The flow for January is estimated at a rate known to be low, probably considerably within the truth.

It will be noticed that there is no direct relationship between the rain falling and the water flowing in any given month. A careful study of the gauging and comparison with longer series of gaugings on the Croton, Sudbury, and other streams, has shown that when the ground water is full on this stream, at the beginning of a month, the flow will be about 1.25 inches for that month, even if practically no rain should fall. This is illustrated in June and November of the table. In June evaporation is usually four inches, and the rain falling was only 2.33 inches, none of which could have been available to increase the flow. Likewise in November the rain was less than the normal evaporation, but in both cases the flow exceeded 1.25 inches. So I find that the second month of deficient rain-fall will yield a flow of 0.90 inches, by careful examination of the records of daily flow. Careful inquiry develops that at May's Landing the wheel plant in use up to the beginning of 1890 required about 140 cubic feet per second to run it, and there was always enough water with a little waste over the dam at night. In fact, it was deemed best to increase the wheel plant, and this was done early in 1890. Now this shows the flow of the stream in extreme dry seasons to be 70 cubic feet per second. These gaugings and the study of longer records on other streams lead to the conclusion that from December to May we can depend on the flow amounting to 50 per cent. of rain. The summer flow will be determined by the following rule: When the ground water is full at the beginning of a month, the flow (in case the rain-fall is less than evaporation plus the flow of the stream) will be for that month 1.25 inches; for the second dry month it will be 0.90 inches; for the third, 0.60; fourth, 0.50; fifth, 0.40; sixth, 0.35 inches.

Now the year 1890 was one of average rainfall in Southern New Jersey. The average yearly rainfall at Philadelphia for the period from 1825 to 1887 was 43.03 inches. During 1890 the rainfall at Moorestown was 43.40; at Woodbury, 41.17; and at Rancocas, 45.03 inches. Nearer to the sea the fall is always considerably greater than at Philadelphia.

The river at May's Landing is said to have been lower in 1890 than for three years previous. We may, therefore, assume the above to be an average flow. It amounts to 19.36 inches. To have utilized 18 inches of this, or 1.50 inches per month, we should have needed only a storage capacity equal to one inch on the water shed. The capacity is determined, however, not by average years, but by years of extreme dryness. The years 1880 and 1881 are generally recognized as the severest dry years of the century. I have calculated the flow from Great Egg Harbor water shed for these years by means of a method based upon thirteen years observations on the Croton, five years on Sudbury, and many gaugings of New Jersey streams, and which is described in my preliminary report on water supply and water power, Annual Report of the State Geologist of New Jersey, 1890, to which I have already referred:

Computation of Flow of Southern New Jersey Water Sheds, based on Observed Flow of Great Egg Harbor River, 1880 and 1881.

MONTH.	Rain.	Evaporation and Flow.	Excess or Deficiency.	Computed Flow of Stream.
December, 1879 to April, 1880	14.59	....	....	7.30
May	0.54	4.25	—3.71	1.25
June	1.67	4.90	—6.01	.90
July	8.64	4.60	—0.47	.60
August	6.64	4.50	—1.79	1.50
September	2.94	4.90	—1.96	.90
October	2.75	2.35	—1.07	.60
November	4.44	1.75	—1.89	1.55
December, 1879 to November, 1880	42.21	....	....	14.60
December, 1880 to March, 1881	25.21	....	....	12.60
April	1.30	3.25	—1.95	1.25
May	3.53	3.90	—1.83	.90
June	4.57	4.60	—1.40	.60
July	2.96	4.50	—2.59	.50
August	0.65	4.40	—5.69	.40
September	2.35	3.35	—5.27	.35
October	2.12	2.10	—3.93	.35
November	3.08	1.60	—1.47	.35
December	3.23	1.35	—0.78	.99
December, 1880 to December, 1881	49.00	....	....	18.29

These estimates are based upon the observed rainfall at Vineland for these two periods, as this station best represents the average for Southern New Jersey. During the period from the first of December to the beginning of the dry season in the Spring our reservoirs must be filled, and consequently I have begun my years with December 1st. In 1880 the drought began with May, and while the total rainfall was much lighter than in 1881, it was more evenly distributed, so that a flow of 1.25 inches per month could have been sustained through the dry period, from May to October, with a storage capacity of 1.75 inches on the water shed.

In 1881 more rain fell during the year, but the drought set in in April, and was sustained through November. It was the severest on record. In order to have tided over this period and kept up a flow of 1.25 inches per month we should have needed a storage capacity of six inches on the water shed. The period from December 1, 1879, to November 30, 1880, shows but 14.60 inches of flow, but this is a marked exception, and taking into account the conservativeness of these estimates and the larger yield of the Rancocas, we may safely assume that at all times our gathering grounds will yield fifteen inches of the rainfall with a storage capacity of six inches. In other words, with a storage equal to 14 million cubic feet per square mile of drainage, we can control 713,000 gallons daily per square mile.

An average year, such as 1890, will yield 30 per cent. more than the above figures. We have based our quantities upon the driest year, but in the following table the supplying capacity is given for an average year also.

This table gives the water sheds from which we shall draw our supply, classified by levels in accordance with the proposed plan of utilizing the flow, shown upon the accompanying table:

Water Sheds and their Supplying Capacity.

Areas Delivered by Gravity.	Area in Square Miles.	Daily Supply in Million Gallons.	
		Driest Year.	Average Year.
North branch, Cooper's creek	10.24		
South branch, Rancocas, above main canal	20.48		
Atsion and Mechescatauxin, above seventy feet	41.97		
Nescochague, above seventy feet	16.72		
Batsto, above seventy feet	36.67		
Seventy feet level exclusive of Wading river	126.08	89.89	116.86
West branch, Wading river	56.58		
East branch, Wading river	50.35		
Wading river, seventy feet level	106.93	76.24	99.11
Friendship creek, upper reservoirs	25.62	18.27	23.75
Total for gravity, or seventy feet level	258.63	184.40	239.72
Fifty Feet Level:			
Water shed of Taunton reservoir	16.94		
Water shed of Friendship canal	10.12		
Water shed cf Friendship reservoir	5.60		
Total of Rancocas at fifty feet	32.66	23.29	30.27
Atsion and Mechescatauxin	12.00		
Nescochague	9.16		
Total for Atsion at fifty feet	21.16	15.09	19.62
Total for fifty feet level	53.82	38.38	49.89
Good Water, or Thirty Feet Level:			
Hammonton Brook	17.62		
Nescochague	6.85		
Atsion and Mechescatauxin	17.86		
Batsto	31.27		
Total on Upper Mullica	73.60	52.48	68.22
Thirty Feet Level, Wading River:			
Batsto, Harrisia canal	12.87		
West branch, Wading river	39.94		
East branch, Wading river	16.10		
Beaver brook	6.05		
Total, Wading river	74.96	53.45	69.48
Total for thirty feet level	148.56	105.93	137.70

It is seen that we have an available supply of 328 million gallons in the driest year which is ever likely to occur, and for half the years our supply will exceed 427 million gallons. Of the minimum supply, 184 million gallons daily will be delivered by gravity, the remainder being pumped from the fifty and thirty feet levels.

The population of Philadelphia increased 19.3 per cent. from 1860 to 1870; 25.7 per cent. from 1870 to 1880, and 23.6 per cent. from 1880 to 1890. The consumption of water for 1890 was about 116 million gallons daily, or 110 gallons per capita. This is a very high rate, and should not be much exceeded in the future. If we suppose the population and consumption to increase at a rate of 25 per cent. in each decade, we shall have the following consumption:

1890——116 million gallons daily.
1900——145 million gallons daily.
1910——181 million gallons daily.
1920——226 million gallons daily.
1930——283 million gallons daily.

This would be the limit of the supply under discussion. Opportunities exist for still further increase to a large amount, but these have not been considered in this report.

It is but just to state that gentlemen of large experience with the utilization of flow of Southern New Jersey streams consider my figures much too low.

I acknowledge that they are very conservative, as I have based them upon the most accurate data obtainable, and when there was any reasonable doubt, have always taken the lowest figures in order to be entirely safe. It would not be surprising, therefore, if the actual yield should prove considerably in excess of these estimates. The large storage in the sand and gravel which controls the flow of these streams renders them much steadier and more constant than streams like the Sudbury, Croton, Schuylkill and others, with which engineers are more familiar.

Method of Utilizing the Supply.

Reference to the accompanying map will make clear the following description of the method by which it is proposed to utilize the above supply of water.

At a point on the north branch of Cooper's Creek, three-quarters of a mile above the bridge on the road from Haddonfield to Moorestown, a heavy embankment will be thrown across the valley, creating a reservoir, with its top water surface 61 feet above mean tide, and having an area of 1,400 acres, and a capacity down to a level of 56 feet above mean tide of 2,000,000,000 gallons. The site chosen is admirably adapted for the erection of an embankment. A natural bank projects from the south side more than half way across the valley; the soil underlying the valley is of a clayey and very retentive nature, well adapted for a foundation, and the water shed immediately tributary to the reservoir, from which we have to anticipate flood flows, is less than five times the area of the reservoir itself, so that even so heavy a flood as four inches upon the catchment area in forty-eight hours would raise the water surface but twenty inches, an amount which could be readily provided for without any waste weir whatever.

No such flood flow as this is to be anticipated on Cooper's Creek, consequently we enjoy complete immunity from danger from this cause.

This reservoir will be subdivided by embankments one mile and two miles above the main dam for further security, although it is intended to make the main bank of the most liberal proportions and of the best material, an abundance of which exists in the vicinity. An overfall will be provided at one side, over the natural surface, and the pipes for drawing off the supply will also be carried through the natural earth, and kept free from the embankment.

Pipe Lines and Conduits.

Three plans are substituted for connecting this reservoir with Camden and Philadelphia. The first is by three lines of

72-inch steel pipe ⅜-inch thick to the Delaware river shore at Pavonia, 36,700 feet distant, thence across the Delaware 7,000 feet, 3,400 of which are beneath the river, by three lines of 60-inch steel pipe ½-inch thick, laid in a dredged trench on the river bed, and covered by three feet of rip-rap, the top of the stone being kept thirty feet or more below the surface of the river. This line will terminate at Kensington Pumping Station. The 72-inch pipe will deliver 53 million gallons daily, each, with a loss of head of 18 inches per mile; while the 60-inch pipes will deliver about the same amount, with a loss of one foot in 1,500. The total loss of head will be for the 7,000 feet of 60-inch pipe 5 feet, and for the seven miles of 72-inch pipe about 11 feet, or 16 feet in all, which will enable us to deliver the water in Philadelphia at 45 feet above mean tide, with a full reservoir, or 40 feet when the water is drawn down five feet.

Any two of the pipe lines will deliver 100,000,000 gallons daily, so that with the large storage of over 800,000,000 gallons in the City Reservoirs, ample time would be given for cutting off one line of pipe for repairs when needed. This system of pipes is designed with a view to supply at first of 150,000,000 gallons daily, to be increased to 200,000,000 gallons by an additional line when needed.

This plan has the merit of allowing a rapid construction of the works, should time be limited, and a ready increase of capacity as the demand increases, and it affords all necessary security and other requisites of an efficient service. The conditions are very favorable to the use of steel pipe. The pressure will nowhere exceed that due to a head of 60 feet, and the grades will be uniform with nearly all of the line below 20 feet above mean tide. The use of such pipe is comparatively recent in the United States, although common in England. Wrought iron has been largely used in a very bold way in our Western Mining Works with complete success. The confidence which competent hydraulic engineers repose in steel pipes is well illustrated in the works now being

installed for the supply of the City of Newark, New Jersey, where the supply will be entirely dependent upon a single line of 48-inch pipe, part of which is under a head of nearly 300 feet. The thickness of this pipe is one-quarter of an inch for heads up to 100 feet, and it is deemed amply secure for the service.

Masonry Conduit and Tunnel.

A second plan proposed for the connection of the reservoir with Philadelphia is by a masonry conduit 31,000 feet in length from the reservoir, passing to the east of Merchantville to a point near Delair Station, thence by 3,000 feet of pipe lines and 3,000 feet of tunnel under the Delaware river to the opposite bank. This is the only practicable route for a masonry conduit, and will enable us to keep the line entirely in excavation, excepting about 1,300 feet northeast of Ellisburg, which will be on an embankment with the bottom of the aqueduct not more than five feet at the highest point above the surface of the ground. The line crosses the river at the best point for a tunnel, and terminates near the Frankford pumping station, which is of much larger capacity than that at Kensington. The loss of head will not exceed ten feet, so that water can be delivered at the west bank of the river at a minimum head of 46 feet above mean sea level.

It would be necessary to build the conduit and tunnel of a capacity of not less than 200,000,000 gallons at once, as this plan does not afford opportunity for gradual increase, with the facility offered by the system of steel pipes. This will necessitate an aqueduct of 14 feet internal width and 13 feet high to the crown of the arch. It will have a covering of not less than four feet of earth. The tunnel will be of cast iron, similar to the one now being driven under the Hudson River by the Greathead system, and will contain a steel tube of nine feet internal diameter and three-eighths of an inch thick, which will be sufficient, as it will not be subject to shock, and has only to sustain the pressure of the water.

This tube will be practically a lining filling the tunnel completely. The plan of several pipes contained in an open tunnel has been considered, but it is believed to be preferable to duplicate the above tunnel at once if necessary, although such a tunnel will deliver 200,000,000 gallons daily, and will be secure from accident or injury.

Pipe Line and Tunnel.

The third proposed plan for connecting the reservoir with Philadelphia and Camden, is by lines of 72-inch steel pipe $\frac{3}{8}$ of an inch thick, from the reservoir *via* Collingswood to a point just south of the old Philadelphia and Atlantic City railroad depot, in South Camden, thence by a tunnel to the western shore of the river. This plan requires 34,800 feet of pipe line and 3,000 feet of tunnel. The water will be delivered with a loss of head of about 13 feet, so that it could be delivered at a minimum head of 43 feet in Philadelphia, or 48 feet with a full reservoir. By this plan three lines of 72-inch pipe would deliver 150,000,000 gallons daily, but the tunnel should be constructed of 200,000,000 gallons capacity, as before. The laying of an additional line of pipe would then be all that would be needed to convey 200,000,000 gallons daily.

Advantages of the Several Lines.

We may compare the plans as follows: The first calls for 36,700 feet of steel pipe line upon land, and 7,000 feet beneath the river and across Petty's Island; or 43,700 feet in all, delivering the water at a head of 40 feet minimum at Kensington pumping station. The second plan requires 31,000 feet of masonry conduit, 3,000 feet of pipe line and 3,000 feet of tunnel, and will deliver the water at the river bank, opposite Delair, at a minimum head of 46 feet above mean tide, convenient to Frankford pumping station.

The third plan will require 34,800 feet of steel pipe line and 3,000 feet of tunnel, and will deliver the water at the

river bank in South Philadelphia at a minimum head of 43 feet above mean tide. Mean tide at Philadelphia is about three feet above low water.

The first line is best adapted to a pipe line throughout. Tunnels could readily be substituted for the pipes beneath the river on this line. The north line is the only feasible route for a masonry conduit, and the best for a tunnel also; it gives the greatest head in Philadelphia. The south line is the best for a steel pipe line and tunnel.

On the whole, the choice of plans is to be determined more by the consideration of which will be the most acceptable point of delivery in Philadelphia, then by any slight advantage in the routes themselves.

Connection of Haddon Reservoir with the Water Sheds.

We have seen what water is available above 70 feet elevation. Our first step is to divert this into the Haddon reservoir by constructing a reservoir on Atsion River, at Goshen, with a top surface level of 70 feet, to be drawn down five feet. This reservoir will be connected by a main canal cut across the divide, *via*. Taunton, to the head of Haddon reservoir. This canal will also receive the waters of Kettle Run, Bethany and Barton's Run, all headwaters of the Rancocas. The cross section of the canal will be such that the velocity of flow may never exceed $2\frac{1}{2}$ feet per second. It will pass through sand, and consequently no trouble from growth of vegetation is to be anticipated, as may be seen by numerous examples of canals in these regions, with velocities as low as one foot per second, which keep for decades as clean as when first constructed. The side slopes of canals will be $1\frac{1}{2}$ to 1; the depth of water 8 feet. Goshen reservoir will receive through a canal the waters from a reservoir on the Mechescatauxin, and another canal will draw from a reservoir on the Nescochague at Iron Mills. On the north a system of canals and reservoirs will control the Batsto and east and west branches of Wading River. Additional storage will be provided as needed on the upper portions of the several streams, as shown upon the accompanying map. This area will give a minimum supply of 166,000,000 gallons daily, and a supply of 216,000,000 gallons in ordinary years. This will suffice for the present.

This water will all deliver by gravity into Haddon reservoir, and thence to Camden and Philadelphia. In its passage through the several reservoirs and canals at low velocity, it will be most effectually freed from any trifling matter which may be carried in suspension, and will be delivered in a state as near absolute purity as it is possible to realize in natural waters.

Extensions.

The first step which will be taken to increase the supply will be the construction of a reservoir at Burr's Mills, on Friendship Creek, at an elevation of 90 feet, to be drawn down to 80; and a smaller reservoir at 80 feet elevation south of Friendship.

These reservoirs will be connected by canals, and a slight deepening of the stream channels with a canal across the divide will deliver the water of the 26 square miles which they control into Hampton reservoir, of the 70 feet level, increasing the supply to 184,000,000 gallons minimum, or 240 average. For practical purposes we may say 200,000,000 gallons is the limit of the gravity supply, which we have now reached.

By constructing the reservoirs of the fifty feet level at Atsion and connecting them by canals, as shown on the map, we control a further supply of 15,000,000 to 20,000,000 gallons. This will require lifting by a pumping plant 20 feet into Goshen reservoir.

Taunton reservoior and Friendship canal and reservoir, on the south branch of the Rancocas, will furnish 23,000,000 to 30,000,000 gallons more at 50 feet elevation, to be lifted into the canal at Taunton from 15 to 25 feet. This will bring the

supply up to 223,000,000 gallons minimum, or 290,000,000 average.

Next, the construction of Goodwater reservoir and Columbia reservoir will add 52,000,000 to 68,000,000 gallons, to be lifted by a pumping plant and force main at Atison into Goshen reservoir, the lift being about 40 feet.

Finally, a canal to Harrisia and a reservoir on Wading river, at a high water level of 37½ feet, will add 53,000,000 to 69,000,000 gallons, and utilize the full supply of 329,-000,000 gallons in extremely dry years, or 427,000,000 in ordinary years.

Engineering Features.

The plan is, on the whole, an extremely simple one. Excepting, perhaps, the Delaware river crossing, the utilization of this supply presents no necessity for difficult constructions or untried methods. The reservoir embankments are all low, and excellent material for their construction abounds. The highest is that at Haddonfield, 48 feet from creek to surface of water in reservoir, but conditions here are such that absolute security is only a question of liberal use of the excellent material at hand in constructing the embankment. The embankment and other constructions on the water-shed proper do not exceed in dimensions existing constructions in that region, which have stood successfully for many years.

In dealing with water-sheds of this character, an entirely different method of treatment from what is met with in ordinary practice becomes necessary. In all of our construction we must take into account the slope of the ground-waters and their movement toward the lower part of the water-sheds. Low embankments and open canals are especially desirable as a means for collecting and retaining such waters. Then, too, the absence of population and its attendant evils, and the clean, insoluble character of the earth, makes especially advisable the adoption of open channels. Another fact which has made the arrangement of canals and reservoirs somewhat peculiar, is the necessity for drawing off the waters in a direction the reverse of their natural flow. This is the reason for the arrangement of the reservoirs in levels, and the connection of all of a given level by canals.

Conclusion.

I have laid before you estimates of the yield of the watersheds, based upon figures which I can vouch for as trustworthy and conservative; also the peculiarities of these sandy watersheds, which contribute to the purity of their waters and regularity of their flow, having been familiar with these features for many years as they are exhibited throughout the great sandy plains of Southern New Jersey and elsewhere. The engineering works, which are needed for utilizing the supply, have been outlined as closely as will be needed for the purposes of this report, and will be readily understood with the aid of the accompanying map. In their design I have followed engineering precedents closely, even where I have availed myself of the comparatively new possibilities of steel hydraulic constructions. But by whatever method they may be delivered, the great advantages of distance (Haddon reservoir being but nine miles from Philadelphia's City Hall) of uninhabited gathering grounds and complete natural filtration offered by this plan of supply, are weighty considerations in its favor.

Before closing I wish to acknowledge my indebtedness to yourself and Mr. J. A. Braddock, for the general features of the plan which I have developed, and for many valuable suggestions in regard to important details.

Respectfully submitted,

(Signed) C. C. VERMEULE,

Civil Engineer.