THE FUTURE WATER SUPPLY

OF THE

CITY OF PHILADELPHIA.

By JAMES F. SMITH, C. E.

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BY JAMES F. SMITH, C. E.

So much has been said and written on the subject of the water supply of Philadelphia that one may well feel a delicacy in making any further reference to it. The writer has, however, devoted some leisure time and study to its consideration, and, in common with others, appreciates the great importance to the city of Philadelphia of a never-failing and abundant supply of pure and wholesome water.

In the year 1875, when the Commission of Engineers had under consideration the water supply of the city, the writer made certain suggestions, namely: First, the creation of a system of storage dams in the Schuylkill, where the river was not already occupied by the Schuylkill Navigation Company's works, and the use of several dams of the upper navigation, and the reservoirs now existing or to be created in the valley of Tumbling Run, near Pottsville; second, utilizing more fully the water-power at Fairmount and at Flat Rock dams, by raising these dams and increasing the volume of water from the storage dams when required; third, the building of an aqueduct to lead the water from the Flat Rock dam to the pumping stations at Spring Garden, Belmont and Fairmount, so that pure water might be supplied free from the contaminations and impurities of the Fairmount pool.

These plans were adapted to the wants of the existing water supply from the Schuylkill, and to the increase and improvement of the same. This supply is dependent upon steam-pumps with high lifts and inadequate water-power. Coupled with these disadvantages is the liability to breakage and derangement of pumps and power; whereas the people of a great city with dependent manufacturing establishments need a constant, reliable and ample supply of water of a purity that may not be questioned. Purity of supply can only be had by a resort to streams of water originating in the hills or ridges where the population is sparse and the country not extensively under cultivation. For

* A portion of this article appeared in the *North American*.

Philadelphia, the Perkiomen creek and its tributaries, rising in the spurs and ridges of the South mountain in Berks county, and in the elevated water-sheds of Bucks county, midway between the Delaware and the Schuylkill, is the source from which the water must come, and gravity the mode of its conveyance.

The citizens of Philadelphia have been made somewhat familiar with the question of a gravity supply from the Perkiomen by the consideration of Mr. Birkinbine's plan as given in the "Report of the Commission of Engineers" in 1875, and in his reports and papers on the subject.

The plan proposed by Mr. Birkinbine for an impounding reservoir is, indeed, favorable for the creation of a large lake, by the erection of a dam seventy or seventy-five feet in height, except in one particular, namely, the great length of the mound dam that would be required. The Commission of Engineers regarded this project with considerable favor, and gave credit, not improperly, to Mr. Birkinbine for his foresight in suggesting it. But at the site selected the water surface of the proposed lake would be too low for the city, except for the supply of the East Park Reservoir and the basins below its level, namely, Schuylkill, Corinthian avenue, Delaware and Fairmount; and from what has been said by the Commission, it will be observed that the conduit from this lake was not designed to deliver water into a receiving basin in the city at a greater elevation than 133 feet above city datum. This is manifest from what they say, namely, "that thorough and careful surveys should be made of the location of the line of conduit from the Perkiomen dam to the East Park Reservoir."

This deficiency in elevation, it must be admitted, is fatal to Mr. Birkinbine's location, as it would not be wise to build an aqueduct line to bring in the water of the Perkiomen, only to deliver it into the East Park Reservoir, at an elevation too low to supply Belmont, Frankford, or the proposed Cambria basins. The surfaces of the two former of these are respectively 212 and 168·40 feet above city datum, or 217·38 and 173·78 feet above mean tide, Delaware river, and the proposed Cambria basin about 170 feet above city datum.

My attention has but lately been called to an article on the subject of a gravity supply from the Perkiomen, by Chas. G. Darrach, C. E.*

Mr. Darrach proposes, instead of Mr. Birkinbine's lake, an inter-

* *Proceedings of the Engineers' Club of Philadelphia*, Vol. 1, No. 3, p. 162.

cepting canal around the valley, the supply for which is proposed to be taken from impounding dams to be erected on the main stream and its branches. This plan is ingenious and an improvement on that of Mr. Birkinbine in several particulars, namely, increased elevation, a delivery into the receiving basin of the city at an elevation of 170 feet instead of 133, and saving from destruction the Perkiomen railroad and the improvements in the valley which would be submerged by the lake.

Among the objections to the plan is still the want of elevation. A gravity supply to meet the future wants of the city of Philadelphia should deliver the water into the receiving basin at a much higher elevation than 170 feet of city datum, in view of the certain future extension of improvements and spreading of population over those parts of the city which are now suburban.

The plan for a gravity supply by aqueduct from Perkiomen, which I now propose, meets the objection of the want of height of Mr. Birkinbine's location. It will not require any alteration in the line of the Perkiomen Railroad, which would be necessary should a dam be erected near Schwenksville, and a large amount of valuable property in the valley of the main stream between that point and Green Lane would be saved from destruction.

The Location.

On the main stream of the Perkiomen, a few hundred yards above the Green Lane station of the Perkiomen Railroad in Montgomery county, eighteen miles above the mouth of the creek, there is an admirable site for a dam, at a point where the stream has broken through a ridge of hard rock, leaving a gap of little more than three hundred feet across with precipitous sides and solid foundations, just adapted to the erection of a safe and durable structure. At this place the dam may be 90 to 100 feet high, backing the water several miles into a valley, with favorable slopes bounded by hills and ridges.

From this dam I propose to carry the water by an aqueduct into the city, and the aqueduct would be so located as to command from 45 to 50 feet in depth of the storage water of the dam.

The Course of the Aqueduct Line—its Length, Terminal Basin and Elevation.

The route may be thus described: Commencing at the storage dam

or lake, and crossing the Perkiomen Railroad at a sufficient elevation above it, the aqueduct pursues a course nearly straight to the Plymouth Valley, passing a little west of the dividing ground between the waters of the Wissahickon and Plymouth creek, about twenty miles from the starting point at Green Lane.

Advancing from this point, after crossing the Plymouth Railroad, the line reaches Barren hill and passes through it into the Wissahickon valley; thence down that valley on the eastern slope of the ridge, crossing the stream, not far from Hermit's lane, to the high ground in the vicinity, where a distributing reservoir, of very moderate dimensions, in connection with the several existing basins of the water-works and the East Park Reservoir when completed, would suffice, and furnish a storage capacity of nearly one billion of gallons. The length of the proposed aqueduct line is about 27½ miles, and the location such that the water may be delivered into a receiving reservoir, the surface of which might be 240 feet above city datum, with a free delivery from the aqueduct itself, the water surface of which when running in its full capacity would be nearly 249 feet above city datum, or 254 feet above mean tide Delaware river.

It may be stated here in regard to the line of the conduit, that whilst none of the valleys to be crossed will require long and elevated structures of masonry, there will be several tunnels, mostly through sandstone. Below Barren Hill the work will encounter mainly gneiss rock. This feature is deemed favorable, as tunneling at the present time, owing to improved methods and explosives, can be done with such great facility that in most cases the expense will be less than for an aqueduct of masonry, and especially so where the rock encountered is found to be of a character to justify the omission of interior brick linings.

Tributaries of the Perkiomen Intercepted.

In the first 10½ miles a number of important streams are passed. Three of them are main branches of the Perkiomen, and three affluents of these branches. They originate chiefly in the hills dividing the waters of the Delaware from the Schuylkill in Montgomery and Bucks counties, more than 500 feet above tide, and extremely favorable for maximum precipitation. It is part of the plan that these streams shall be made tributary to the water supply by the erection of impounding dams or small lakes upon them, with dams of the heights and capacity

suited to their drainage areas and the quantity of water required to be stored. The cost for all of them will not, it it is believed, be more than for the dam, and the land and improvements that would be submerged and destroyed by the lake at Schwenksville and the reconstruction of ten miles of railroad would be saved. At first the construction will be limited to the works at Green Lane and the aqueduct line to the city, leaving the improvement of the tributary streams to be undertaken one by one, in the future, as the increase in population of the city may demand more water for consumption.

Capacity of the Perkiomen Water Shed.

The water shed of the Perkiomen above Green Lane station is about seventy-three square miles, and with the tributary streams crossed by the aqueduct line added there is not less than 200 square miles. If 59 per cent. of the annual rainfall of 47·82 inches be taken as collectable (being one-fifth greater than that of the year 1858 at Philadelphia, and which Mr. W. J. McAlpine, C. E., has taken in his calculations for the Perkiomen, *vide* report of Commission of Engineers, 1875), it would give daily 272,000,000 gallons. Of this quantity it may be assumed that 165,000,000 gallons daily average supply to the conduit may be taken, leaving, after deducting for soakage, evaporation and waste of the impounding dams, nearly 100,000,000 gallons to pass away as surplus or flood water. From the Perkiomen above Green Lane village 60,000,000 gallons daily of the supply may be furnished, and when the consumption of water is greatest, in July or August, 72,000,000.

The drainage areas of the streams above the aqueduct line have been determined from measurements and calculations based upon a corrected map of the townships of Montgomery and parts of Bucks and Berks counties, which was specially prepared for the purpose. The results are believed to be fair approximations, and are given in the following table:

Table 1.

	Square miles.
Perkiomen Creek at Green Lane,	73·00
Great Swamp Creek,	34·47
Ridge Valley—affluent of Swamp Creek,	9·64
East branch of Perkiomen,	46·00
Indian Run—affluent of east branch,	6·04
Skippack Creek,	21·48
Towamencin—affluent of Skippack Creek,	10·55
Total,	201·18

Macoby Creek, a stream having a drainage area, above the aqueduct line, of 17½ square miles, flows into the Perkiomen at Green Lane, south of the railroad, but is omitted to avoid any interference with the road, which occupies the valley for several miles. This stream may be utilized to the extent probably of 10 square miles of its drainage area without injury to the railroad.

In the annexed table is given both the annual and the average daily flow of the seven streams, based upon the utilization of 28·41 inches of the rainfall upon the Perkiomen water shed; also the reservoir capacity required above the limit of draught in the impounding dams for a given consumption.

TABLE 2.

Name of Stream.	Collectable annually—Million U.S. gallons.	Daily average gallons.	Daily average demand for consumption—Million gallons.	Deficiencies to be provided for by storage dams—Million galls.
Perkiomen Creek,	36,041	98,742,466	60	3,996
Great Swamp Creek,	17,053	46,720,548	28	1,832
Ridge Valley,	4,751	13,016,438	8	560
East branch,	22,735	62,287,671	38	2,530
Indian Run,	2,959	8,106,849	5	365
Skippack Creek,	10,465	29,164,383	18	1,215
Towamencin,	5,193	14,227,397	8	592
	99,377	272,265,752	165	11,090

This table is constructed upon the basis of 47·85 inches annual rainfall, or one-fifth more than that of the year 1858 at Philadelphia, as assumed by Mr. McAlpine.

There are no records of rainfall upon the Perkiomen in years past with which comparison might be made to establish the correctness of the above assumed data. We have, however, actual results obtained from storage reservoirs in constant use in Eastern Pennsylvania, one example of which will suffice.

The Silver Creek reservoir of the Schuylkill Navigation, on the Broad Mountain in Schuylkill county, has a drainage area of $1\frac{275}{1000}$ square miles. This water shed is rolling table land, not rising in any part to the dignity of a hill, and therefore not very favorable to the flow of a large percentage of rainfall into the reservoir. Notwithstanding this fact it is filled at least twice every year, and this has been the experience of many years. Its capacity is 320,000,000 gallons, and the total quantity stored and utilized for supplying the navigation

is 320,000,000 × 2 = 640,000,000 gallons, = 28·82 inches of rainfall over $1\frac{275}{1000}$ square miles.

Upon the basis of this quantity utilized from $1\frac{275}{1000}$ square miles, applied to the Perkiomen drainage area of 201 square miles, we have 101,000 million gallons, as against 99,377 million gallons collectable from 28·41 inches of rainfall (Table 2).

It may be said that the region of Silver Creek, being at an altitude of 1500 feet above the level of the sea, is more favorable for rainfall than the Perkiomen district.

Distances and Fall of Aqueduct Line (circular).

NAME OF STREAM.	Distance from the reservoir.—Miles.	Total distance (per map).—Miles.	Total distance with allowance for deviation.—Miles.	Fall or descent.—Feet.	Total fall.—Feet.	Assumed level of water surf. in the aqueduct above C. D.—Feet.
West branch (Perkiomen), .	0	0	0	0	0	275·
Great Swamp Creek, . .	1·375	1·375	1·39	$\frac{1}{3400}$	2·159	262·84
Ridge Valley, . . .	0·500	1·875	1·89	$\frac{1}{4075}$	2·445	272·55
East branch, . . .	1·875	3·750	3·80	$\frac{1}{4253}$	4·720	270·28
Indian Run, . . .	1·250	5·000	5·05	$\frac{1}{4978}$	5·350	269·65
Skippack Creek, . .	3·875	8·875	8·95	$\frac{1}{5000}$	9·450	265·55
Towamencin Creek, . .	0·875	9·750	9·85	$\frac{1}{5400}$	9·630	265·37
Stony Creek Railroad, .	4·625	14·375	14·52	$\frac{1}{5597}$	13·690	261·31
1st branch crossing Stony Creek,	0·875	15·250	15·40	$\frac{1}{5597}$	14·530	260·47
2d " " "	1·000	16·250	16·40	$\frac{1}{5597}$	15·470	259·53
3d " " "	1·500	17·750	17·93	$\frac{1}{5597}$	16·910	258·09
Plymouth Railroad Summit, .	2·250	20·000	20·20	$\frac{1}{5597}$	19·050	255·95
Wissahickon, . . .	6·875	26·875	27·15	$\frac{1}{5597}$	25·610	249·39
School Lane (high ground), .	0·375	27·250	27·50	$\frac{1}{5597}$	25·940	249·06

I need only refer to so eminent an authority on climatology as Lorin Blodget in support of the contrary opinion. Mr. Blodget places the Schuylkill county region within the range of 40 inches mean rainfall, as against 42 inches in the Berks, Montgomery and Philadelphia districts, and, in an article on the climatology of Pennsylvania, says, fur-

ther: "The heaviest rainfall is in the southeast, where the annual mean is 48 inches, and the greatest quantity in any one year is about 60 inches. This represents the first range of hills back from the Delaware River, on which more rain falls than on the plains of New Jersey and Delaware, nearer the sea. West of the hills, and in the Susquehanna Valley, the quantity of rain falling is much less, only about 38 inches."

The first range of hills referred to by Mr. Blodget are those in which the Perkiomen and its branches take their rise, and in this connection it may be stated as a fact that freshets on this stream are more frequent, and higher in proportion to the drainage area, than on the upper Schuylkill.

Quantity of water required for consumption in the month of July, based upon the rainfall of the year 1858, *augmented by* $\frac{1}{6}$ *for the Perkiomen, as per table, and increased from the average daily consumption by* 120 *per cent., being the assumed percentage for that month.*

NAME OF STREAM.	Average daily consumption.—Million gallons.	Quantity for consumption to be carried by the aqueduct.—Million gallons.	Total quantities.—Million gallons.	Diameter of aqueduct and increased in size for each stream taken in.—Feet.	Capacity of aqueduct running full.—Million gallons.	Velocity per second.—Feet.
West branch (Perkiomen),	60	72·1	72·1	8·000	73,244	2·25600
Great Swamp Creek, .	28	33·6	105·7	9·625	106,177	2·25800
Ridge Valley, .	8	9·6	115·3	10·042	115,545	2·25800
East branch, . .	38	45·6	160·9	11·750	158,236	2·25800
Indian Run, . .	5	6·0	166·9	11·917	163,475	2·26800
Skippack Creek, . .	18	21·6	188·5	12·750	185,491	2·25388
Towamencin Creek,	8	9·6	198·1	13·184	195,000	2·25388
	165	198·1				

This table has been computed for the velocity, from the formula of Robert K. Martin, C. E., and used by him for the air-line conduit 12 feet diameter, for the permanent water supply of the city of Baltimore from the Great Gunpowder Falls. This work is a tunnel 36,495 feet long, from the dam on the Gunpowder River to an artificial reser-

MAP

SHOWING

The Line of the Proposed

AQUEDUCT

FROM THE

PERKIOMEN CREEK

TO

PHILADELPHIA.

Scale 1/300.000

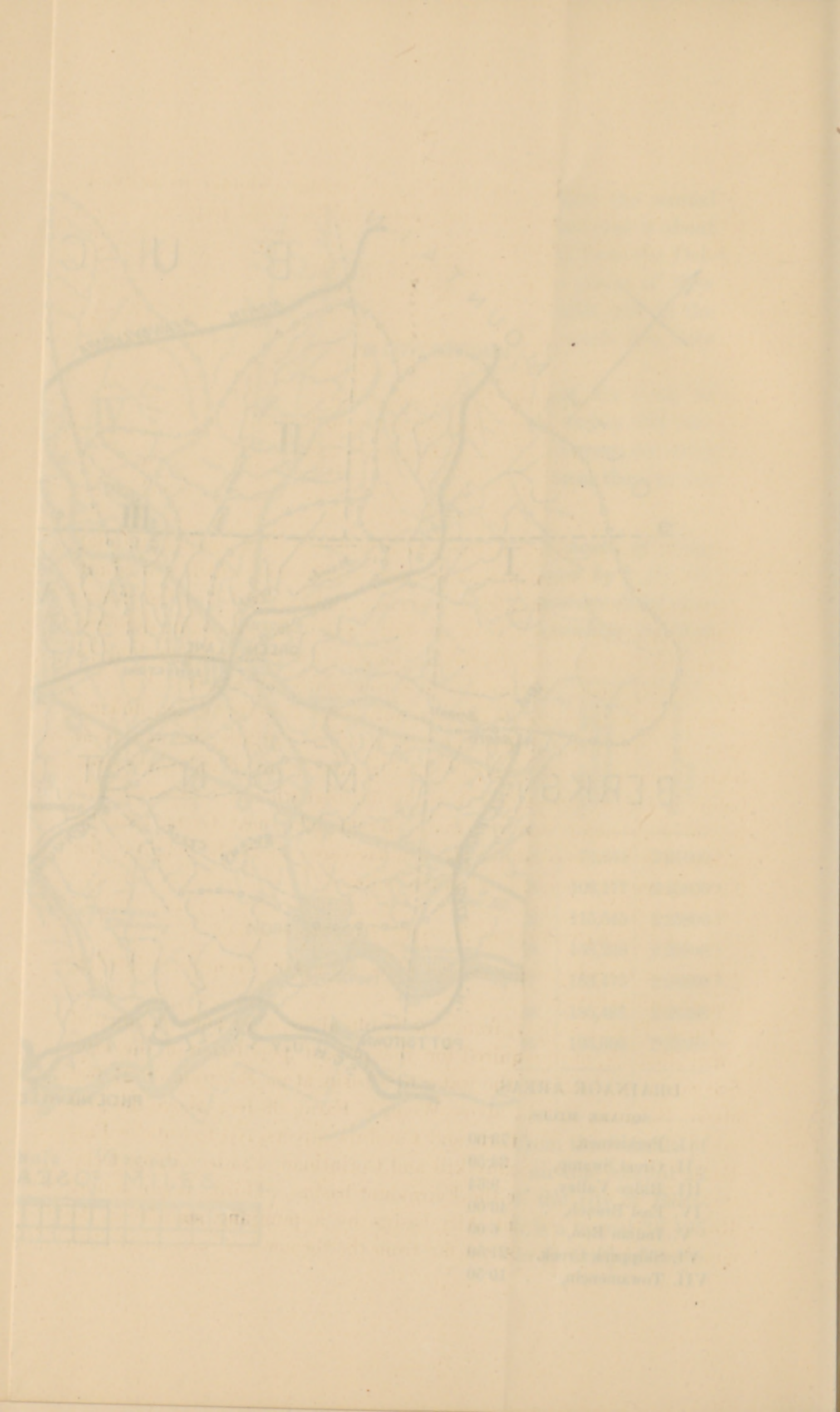
SCALE OF MILES

0 5

DRAINAGE AREAS.

SQUARE MILES.

I. Perkiomen,	73·00
II. Great Swamp,	34·50
III. Ridge Valley,	9·64
IV. East Branch,	46·00
V. Indian Run,	6·00
VI. Skippack Creek,	21·50
VII. Towamencin,	10·50



voir (Lake Montebello, near Baltimore), having a storage capacity of 600 million gallons, and elevated above mean tide 163 feet.

Mr. Martin's formula is:

$$V = \sqrt{\frac{180 \times H \times D}{l}}$$

$$= \sqrt{\frac{2\,g\,H}{0{\cdot}007454\frac{l}{r}}}$$

in which H = head, in feet
D = diameter, in inches
l = length, in feet
$r = \frac{d}{4}$

The diameters given in the above table are for a conduit running full. For the Perkiomen, another form is preferred, which will admit of a maximum flow limited to a surface sufficiently below the crown of the arch; $17\frac{1}{2}$ miles to be of the full capacity for maximum delivery (about 12 feet wide by 13 feet in height), the remainder varying to meet requirements, beginning with 8 feet width and height.

Swamp Creek, rising in Berks county, near Boyertown, and flowing into the Perkiomen below the village of Zieglerville, has not been been included in the general plan, because many years must elapse before it will be needed, but it can be utilized whenever required, and its waters brought into the main storage lake near Green Lane by means of a branch conduit. Its drainage area above the height of the Green Lane lake is about 30 square miles.

Advantages of the Proposed Plan.

Some of the advantages of this plan will appear from the following considerations:

First. It will supply, from one point alone, a greater quantity of water than is now required for the present population of the city. Second. It will deliver the water to a basin at an elevation of 27 feet above Belmont, 72 feet above Wentz's Farm, 69 feet above the proposed reservoir at Thirtieth and Cambria streets, 104 feet above East Park, 119 feet above Schuylkill and Corinthian, 125 feet above Delaware and 145 feet above the Fairmount basins. Third. It can supply Roxborough and Mount Airy basins by a pumping station at the aqueduct where it passes not far from the former, and save more than

200 feet in the lift encountered at the present Roxborongh pumping works, beside permitting them to be discontinued, and the long line of pipes in the pumping main taken up and utilized elsewhere. Fourth. It can supply a basin, which may be provided for the service of Manayunk, by a pipe line or branch conduit, tapping the aqueduct line in the Wissahickon Valley, and obviate the necessity for a supply, as at present, from the Roxborough reservoir. Fifth. It will obviate the necessity for all the present steam-pumping stations with their expensive and, in some cases, troublesome monster pumps, and leave Fairmount and its water power, when disconnected from the basins, to be run moderately in the summer, to feed lakes and fountains in the Park or for flushing main sewers.

It remains now only to say that the correctness of my statements as to the route for the aqueduct and the capacity and availability of the water sheds are subjects for investigation by submission to instrumental examinations by competent parties in the field, and when this is done, the cost, to which I have not referred, may be estimated very closely. The work, as far as possible, should be monumental in its character, and whilst no money need be spent for mere show or unnecessary ornamentation, yet nothing should be left undone that may contribute in the least degree to strength and durability. In the tunnels we shall have the everlasting rocks; along the slopes rock cuttings, and over streams and valleys permanent structures of stone or iron. The impounding dams must be of undoubted strength, as they certainly may be if founded upon the rock and built of solid impermeable materials, and so on with all other parts.

The cost of the work would not be so large as that of the Croton Aqueduct—40½ miles long—which cost originally $8,575,000; but as the completion for a full capacity of aqueduct will not be required for many years, neither will the full expenditure. The cost, whatever it may be, can be spread over several years, and will not be so much of a burden that it cannot be borne by a people who steadily look forward to the time when the city of Philadelphia will embrace within its limits a population of two million souls.

Perkiomen Creek above Green Lane.

	Rainfall at Philadelphia in 1858.	Rainfall on Perkiomen, estimated one-fifth greater.	Percentage of the rainfall collectable in each month.	Inches of rainfall collectable.	Millions of gallons collectable from 73 sq. miles.	Inches of evaporation from reservoirs per month.	Evaporation in millions of gallons.	Waste and loss from all sources.—Million gallons.	Percentage of consumption per month.	Consumption at an average of 60 millon gallons per day.—Million gallons.	Total demand from reservoir.—Million gallons.	Surplus.—Million gallons.	Deficiency. — Million gallons.
January, . .	2·60	3·12	90	2·81	3,564	1·15	17	12	82	1,525	1,554	2,010	
February, . .	2·29	2·75	80	2·20	2,791	1·65	24	12	83	1,394	1,430	1,361	
March, . .	1·09	1·31	70	0·92	1,167	0·82	11	12	85	1,581	1,604	.....	
April, . .	4·64	5·57	60	3·34	4,237	2·07	30	12	94	1,692	1,734	2,503	
May, . . .	5·01	6·01	50	3·00	3,806	1·62	24	12	105	1,953	1,988	1,818	
June, . .	4·50	5·40	40	2·16	2,740	7·10	105	12	115	2,070	2,187	553	
July, . . .	1·35	1·62	30	0·49	622	6·75	100	12	120	2,232	2,344	.....	1722
August, . .	4·94	5·93	20	1·19	1,510	7·79	117	12	115	2,139	2,268	.....	758
September, . .	1·49	1·79	40	0·72	913	5·41	87	12	109	1,962	2,061	.....	1148
October, . .	1·83	2·21	60	1·33	1,687	7·40	109	12	104	1,934	2,055	.....	368
November, . .	5·62	6·74	80	5·39	6,838	3·95	58	12	100	1,800	1,870	4,968	
December, . .	4·50	5·40	90	4·86	6,166	3·66	54	12	88	1,637	1,703	4,463	
Aggregates & Averages, ...		47·85	59⅙	28·41	36,041	49·37	736	144	100	21,919	22,798	17,676	3996

Aggregates and Averages for all the Streams, based upon the drainage areas which may be utilized for the supply of the Aqueduct.

Names of Streams.	Drainage areas. — Square miles.	Rainfall at Philadelphia in 1858.	Rainfall on Perkiomen, ⅓ greater.	Percentage of the rainfall collectable per annum.	Inches of rainfall collectable per annum.	Million gallons collectable from drainage area.	Inches of evaporation from reservoir per annum.	Evaporation.—Million gallons per annum.	Waste and loss from all causes, per annum.	Consumption, daily average. —Million gallons.	Annual consumption.—Million gallons.	Total demand from reservoirs.—Million gallons.	Surplus.—Million gallons.	Deficiency. — Million gallons.
Perkiomen (Green Lane),	73·	39·85	47·85	59⅓	28·41	36,041	49·37	736	144	60	21,919	22,798	17,676	3,996
Great Swamp Creek,	34·5	39·85	48·85	59⅓	28·41	17,053	49·37	308	120	28	10,228	10,656	8,432	1,832
Ridge Valley,	9·64	39·85	47·85	59⅓	28·41	4,751	49·37	99	72	8	2,913	3,084	2,301	560
East branch,	46·	39·85	47·85	59⅓	28·41	22,735	49·37	465	120	38	13,893	14,478	11,120	2,530
Indian Run,	6·	39·85	47·85	59⅓	28·41	2,959	49·37	65	60	5	1,836	1,961	1,395	365
Skippack Creek,	21·5	39·85	47·85	59⅓	28·41	10,645	49·37	207	96	18	6,577	6,870	5,142	1,215
Towamencin,	10·5	39·85	47·85	59⅓	28·41	5,193	49·37	104	84	8	2,912	3,090	2,645	592
Totals,	201·14	39·85	47·85	59⅓	28·41	99,377	49·37	1,984	696	165	60,278	62,937	48,711	11,090

In this connection there is now one other matter that deserves the most serious consideration, and which should be an incentive to early action by the people. It is this, that long before the population shall have reached the figure named, the waters of the Schuylkill will have become so contaminated by sewage, in consequence of the great increase in population along its banks, as to be totally unfit for domestic purposes; even the next decade may produce a marked change, hence there is no time to be lost in determining the course that should be adopted to secure pure water for domestic as well as for manufacturing purposes. Much time must necessarily elapse, in any event, before a work adapted to the wants of the city can be brought into use. All the Delaware schemes are too costly, as was shown by the commission in 1875, and require no further consideration.

So, after all that has been said and written upon the subject of the water supply for the future, if not notably for the present, there is no other stream, in my judgment, of equal purity with the Perkiomen within reasonable distance from which an adeequate, pure and never-failing supply can be brought; and in closing this paper I must remark that I very cheerfully resign to Mr. H. P. M. Birkinbine the credit of pointing out that stream, and for myself only claim the plan of tapping it at a higher and more favorable point and intercepting and utilizing the headwaters of its principal branches, which fortunately lie in the track and cross a direct aqueduct line to the city over high ground.

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