SKETCH

OF

THE CIVIL ENGINEERING OF NORTH AMERICA.

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CHAPTER X.

WATER-WORKS.

Fairmount Water-works at Philadelphia—Construction of the Dam over the River Schuylkill—Pumps and Water-wheels—Reservoirs, &c.—The Water-works of Richmond in Virginia—Pittsburg—Montreal—Cincinnatti—Albany—Troy—Wells for supplying New York and Boston—Plans for improving the supply of Water for New York and Washington.

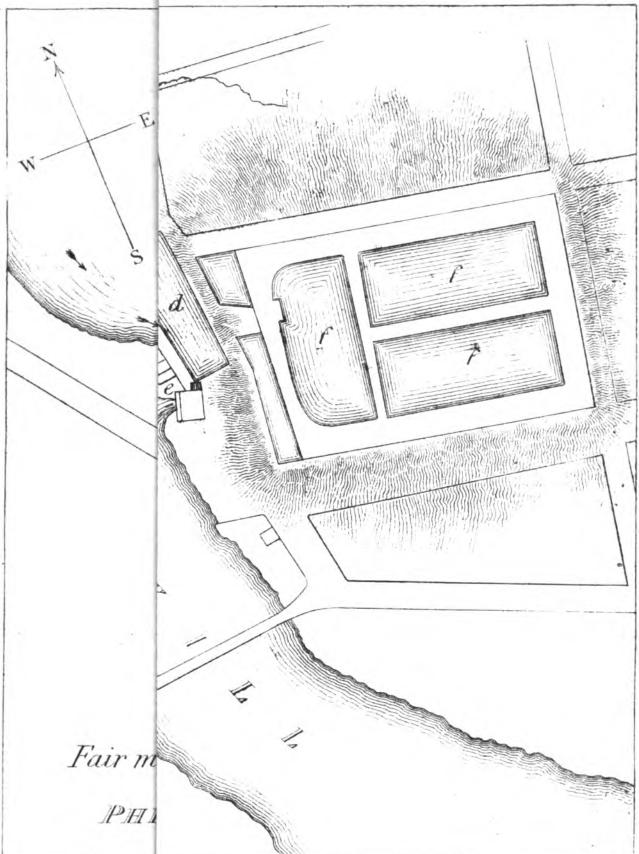
The Fairmount Water-works are situate on the east bank of the River Schuylkill, about one mile and a-half from the town of Philadelphia. They are remarkable for their efficiency and simplicity, as well as their great extent. They were commenced in 1819, and were in a working state in 1822. According to the Water Company's Report for the year 1836, the whole sum expended in their execution, up to that date, was L.276,206.*

The water of the River Schuylkill, with which the town of Philadelphia is supplied, is raised by water power into four large reservoirs, placed on a rocky eminence near the bank of the river; and after passing through gravel filter-beds, it is conveyed in two large mains to the outskirts of the town, and thence led into the various streets by smaller mains and branch-pipes.

Plate XIII. is a ground plan of the water-works, including part of the River Schuylkill and the adjoining country. Letters *a*, *b*, *c* represent a dam which has been thrown across the river in order to obtain a fall of water for driving the water-wheels. Letter *d* is the mill-race, *e*, *e* the buildings in which the water-wheels and force-pumps are placed, and

* Annual Reports of the Watering Committee to the Select and Common Councils of the City of Philadelphia.

PLATE XIII.



been found to stand remarkably well. The dam just alluded to, at the Fairmount Water-works, withstood a great flood which occurred at the breaking up of the ice, on the 21st February 1832, without sustaining the smallest injury. On that occasion the water of the Schuylkill flowed over the top of the dam in a solid body no less than eight feet eleven inches in depth. As the erection of the dam impeded the navigation of the river, the Water Company had to compensate the Schuylkill Navigation Company by forming a canal, marked *hh* in Plate XIII., for the passage of their coal barges. This canal is about 900 feet in length. It has two locks of six feet lift each, and one guard-lock at the upper extremity.

The water is admitted into the mill-race *d*, by three archways at *c*, which have a water-way sixty-eight feet in breadth, and, when the river is in its ordinary state, admit a body of water six feet in depth. These archways can be shut by means of gates, and the whole of the water can be drawn off from the mill-race, if required, by opening a sluice communicating with the part of the river below the dam. The mill-race, which is excavated in solid rock, was a most laborious and expensive work. It is 419 feet in length, and 140 feet in breadth; its depth varies from sixteen to sixty feet.

From *d*, the water flows to the wheel-houses *e*, which have been built of a sufficient size to admit of eight wheels and eight force-pumps being employed to raise the water. In 1837 only six of the wheels and six force-pumps had been put up. The average daily quantity of water raised by each pump during the last year was 530,000 gallons, and the whole quantity of water distributed from the reservoirs per day, to 19,678 householders, was 3,122,664 gallons. It has been calculated that thirty gallons of water, acting on the wheel, raised one gallon into the reservoir.

The water-wheels vary from fifteen to sixteen feet in diameter. They are fifteen feet in breadth, and make thirteen revolutions per minute. The spokes, rims, and buckets are formed of wood, but they revolve on cast-iron axles, weighing five tons each. The working of the wheels is impeded during spring tides, by the water rising upon them; but it has been found that their motion is not materially affected until the back-water rises about sixteen inches on the wheel. They are stopped, however, on an average, about sixty-four hours every month from this cause.

The pumps are common double-acting force-pumps, having a stroke of six feet, worked by cranks attached to the axles of the paddle-wheels. The height to which the water is forced is ninety-two feet, and the most substantial work is necessary to insure the stability of the pumping apparatus, under the pressure of a column of water of so great a height.

A cast-iron main, sixteen inches in diameter, leads from each of the force-pumps to the reservoirs. The communication between the force-pumps and the reservoirs, can be cut off by a stop-cock, placed on the main, so that, when the pumps are not in motion, they can be relieved from the pressure of the column of water. The shortest main is 284 feet in length.

The reservoirs for containing the water are placed at an elevation of 102 feet above the level of low water, and fifty-six feet above the highest part of the streets of Philadelphia. There are four reservoirs, the aggregate area of which is about six acres. The reservoirs are founded on an elevated rock, but the water is retained by means of artificial walls and embankments. The side walls of the reservoirs are built with stone, behind which there is a backing of clay puddle, two feet in thickness, and the whole is surrounded towards the outside, by an embankment of earth, sloping at the rate of one perpendicular to one horizontal, and covered with grass sods. The reservoirs are paved with bricks, laid with lime-mortar, on a layer of clay-puddle, and well grouted, to prevent leakage. The depth of water in the reservoirs is twelve feet three inches, and, when filled, they contain upwards of twenty-two millions of gallons of water. There is a considerable advantage in having four reservoirs. The water, after being discharged from the force-pumps into one of them, passes through all the other reservoirs, between each of which there is a filter, so that any impurities in the water are extracted during its passage from one cistern to another, and prevented from entering the pipes, which distribute it to the town.

The water is conveyed from the reservoirs, and distributed through the town, in cast-iron pipes $98\frac{3}{4}$ miles long. About one-half of these pipes was cast in America, and the remainder were imported from England. The two mains leading from the reservoirs to the town measure twenty-two inches in diameter. The small mains and pipes which have been laid in the streets measure from three to twelve inches in diameter. The pipes are formed in the usual manner, and the different lengths are connected by spigot and faucet joints. The average cost of the whole of the pipes and mains laid down was 7s. $1\frac{1}{2}$d. per lineal foot.

The very small cost at which the town is now supplied is an ample ground for having substituted, even at considerable outlay in the first instance, the system of raising by means of water instead of steam power; steam having been used at the Fairmount works previous to the year 1822. The expenditure, including repairs and salaries connected with the works, for distributing a daily supply of 3,122,664 gallons of water was, in 1836, L.2800. The following information regarding the details of this most interesting and efficient work are drawn up by Mr Graffe, the superintendent, and printed in the Water Company's annual report for the year 1836:—

	Gallons.	Gallons.
The Reservoir No. 1 was finished in 1815, and contains,	3,917,659	
The Reservoir No. 2 was finished in 1821, and contains,	3,296,434	
The Reservoir No. 3 was finished in 1827, and contains,	2,707,295	
Containing, . .		9,921,388
The first section of Reservoir No. 4 was finished in 1835, and contains, ...	3,658,016	
The second section of Reservoir No. 4 was finished in 1836, and contains, ...	4,381,322	
The third section of Reservoir No. 4 was finished in 1836, and contains, ...	4,071,250	
		12,110,588
The Reservoirs contain together, . .		22,031,976

	Dollars.
Reservoir No. 1 cost,	32,508.52
Reservoir No. 2 cost,	9,579.47
Reservoir No. 3 cost,	24,521.75
First, second, and third sections of Reservoir No. 4 cost,	67,214.68
Total,	133,824.42

The whole expense of the reservoirs amounted to 133,824 dollars, which is equal to about L.26,765.

"The water of the reservoirs covers a surface exceeding six acres. The reservoirs are each twelve feet three inches deep, and are elevated above the water in the dam ninety-six feet perpendicular.

"The water flowing from the reservoirs for the supply of the city and districts, per day, at different periods of the year 1836 was as follows:—

	Gallons.
From February 1st to 21st, in very cold weather,	1,769,800
... February 21st to March 20th,	2,113,257
... March 20th to June 3d,	3,046,120
... June 3d to July 22d,	3,942,643
... July 22d to September 9th,	4,152,917
... September 9th to October 28th,	3,679,800
... October 28th to December 31st,	3,154,114

"The average daily supply, in 1836, was 3,122,664 gallons. The above supply of water is distributed to 16,678 tenants by private pipes, and to 3000 families by public pumps, making the number of families supplied 19,678.

"The quantity of iron pipes laid for the distribution of the water is as follows:—

	Miles.
In the city,	58
In the district of Spring Gardens,	11⅝
In Southwark,	10¼
In the Northern Liberties,	12⅞
In Moyamensing,	2⅝
In Kensington,	3
Together	98⅜

"The water rents collected for the year 1837 are as follows:—

	Dollars.
In the city, ...	57,080.50
Including rents on the Girard estate, and rent due by H. J. Williams and others at Fairmount, ...	1,048.50
In Spring Gardens, ...	13,674.25
In Southwark, ...	10,517.50
In the Northern Liberties, ...	20,009.37
In Moyamensing, ...	1,956.00
In Kensington, ...	2,146.25
Total, .	106,432·37

Amounting in all to about 106,432 dollars, which is equal to about L.21,286.

	Dollars.
The expenses for the water-power works connected with the applicable parts of the former steam-works were, December 31, 1831, ...	1,138,323.54
Add the expenses for reservoirs, iron pipes, &c., in 1832, .	65,195.58
Do. Do. in 1833, .	37,354.06
Do. Do. in 1834, .	65,163.36
Do. Do. in 1835, .	73,288.38
Do. Do. in 1836, .	71,706.51
	1,451,031.43
From which deduct, for the support of working machinery, materials, salaries, &c., 14,000.00 dollars per annum for the last five years, ...	70,000.00
Leaves the expenditure for the permanent works, up to 31st December 1836, ...	1,381,031.43

The expenditure for permanent works, therefore, amounts to 1,381,031 dollars, which is equal to about L.276,206.

The supply of water for the town of Richmond in Virginia, is procured from the James River, in the same manner as at Philadelphia; but the works are on a much smaller scale. The water is raised 160 feet by two water-wheels into two reservoirs, measuring 194 feet in length, 104 feet in breadth, and ten feet eight inches in depth, which are capable of containing upwards of two millions of gallons of water. Before leaving the reservoirs, the water is purified by passing through two gravel filters. The water-wheels are eighteen feet in diameter, and ten feet in breadth, and the fall is ten feet. The barrels of the two force-pumps are nine inches in diameter, and six feet in length of stroke, and, in the ordinary state of working, when only one wheel is in operation, raise about 400,000 gallons of water in twenty-four hours.

The cast-iron main which leads from the pumps to the reservoir is eight inches in diameter, and about 2400 feet in length. Mr Stein was engineer for the work, which is said to have cost about L.20,000.

Pittsburg, on the Ohio, in the State of Pennsylvania, is supplied with water from the River Alleghany. It is raised by a steam-engine of eighty-four horse power into a reservoir capable of containing 1,000,000 gallons of water, and elevated 116 feet above the level of the river. The main leading from the pumps to the reservoir is fifteen inches in diameter, and the pump raises 1,500,000 gallons in twenty-four hours.

Montreal also is supplied in the same manner from the water of the St Lawrence, which is raised by steam power to an elevated reservoir, and then distributed through the town.

The following account of the water-works, which have lately been established at Cincinnati, on the Ohio, in the State of Ohio, is given by Mr Davies the superintendent:—

"The Cincinnati Water-works were constructed in 1820. The water was taken from the Ohio River by a common force-pump, worked by horse-power, placed upon the bank of the river, sufficiently near low-water mark to be within the usual atmospheric pressure, and thrown from that point to the reservoir, 160 feet above low water-mark, from which it was conveyed to the town in wooden pipes. The town at that time afforded no inducement for a larger supply of water than could be brought through wooden pipes of three inches and a-half in diameter, consequently the works at the river were only calculated to supply a pipe of that size. Only a short time, however, was necessary, to prove the necessity of an increase, and a change from horse-power to steam.

"The works now consist of two engines, one propelling a double force-pump of ten inches in diameter, and four feet stroke, throwing into the reservoir about 1000 gallons in a minute; the other propelling a pump of twenty inches in diameter, eight feet stroke, and discharging about 1200 gallons per minute. The reservoirs are built of common limestone; the walls are from three to six feet thick, and grouted. The water is conveyed immediately to the town, without being permitted to stand or filter. Iron pipes of eight inches in diameter convey it through the heart of the town, from which it branches in wooden pipes of from one and a half to three and a half inches in diameter. From these it is conveyed into private dwellings in leaden pipes at the expense of the inhabitants, who pay from eight to twelve dollars* per annum, according to the purposes for which it is used. Each family, of course, use any quantity they choose, their hydrants communicating freely with the main pipes. The iron pipes are made in lengths of nine feet each, and connected together by the spigot and faucet joint run with lead, which occupies a space round the pipe of three-eighths or half an inch in thickness."

Albany, on the Hudson, is principally supplied with water procured in the high ground in the neighbourhood, and conveyed in a six-inch pipe for a distance of about three miles to a reservoir near the town.

Troy, on the eastern or left bank of the Hudson, about fourteen miles above Albany, is also abundantly supplied with good water collected in the high ground in the neighbourhood. The reservoir stands about one-third of a mile from the town, and is seventy feet above the level of the streets. It is capable of containing 1,900,000 gallons, and the water is conveyed from it to the town in a main twelve inches in diameter. The works are said to have cost L.23,000. The annual expense of conducting them is L.160.

The situation of Boston is somewhat like that of New York. It is surrounded by the sea, and the supply of good water is far from being sufficient for the inhabitants. Mr Baldwin, civil engineer, has made a survey and plan for the supply of the town, in which he contemplates bringing water from some springs in the neighbourhood.†

At present the town is supplied chiefly from wells. Ac-

* From about L.1, 12s. to L.2, 8s.

† *Report on introducing pure Water into the city of Boston.* By Loammi Baldwin, C.E. Boston. 1835.

cording to Mr Baldwin's report, there are no less than 2767 wells in Boston, thirty-three of which are Artesian. Only seven, however, out of the whole number, produce soft water; and of these, two are Artesian.

Great difficulty has been experienced in forming many of the wells on the peninsula of Boston, in some of which, on tapping the lower strata, the water is said to have risen to seventy-five, or eighty feet above the level of the sea.*

The following very interesting remarks regarding two of these wells, are quoted by Mr Storrow in his Treatise on Water-works:—

"Dr Lathrop gives the following history of a well dug near Boston Neck.† 'Where the ground was opened, the elevation is not more than one foot, or one foot and a half above the sea at high water. The well was made very large. After digging about 22 feet in a body of clay, the workmen prepared for boring. At the depth of 108 or 110 feet the augur was impeded by a hard substance; this was no sooner broken through and the augur taken out, than the water was forced up with a loud noise, and rose to the top of the well. After the first effort of the long confined elastic air was expended, the water subsided about six feet from the surface, and there remains at all seasons, ebbing and flowing a little with the tides.'

"Dr Lathrop observes, that the proprietors of this well were led to exercise great caution in carrying on the work, by an accident which had happened in their immediate neighbourhood. 'A few years before, an attempt was made to dig a well a few rods (16½ feet) to the east near the sea. Having dug about 60 feet in a body of clay without finding water, preparation was made in the usual way for boring; and after passing about 40 feet in the same body of clay, the augur was impeded by stone. A few strokes with a drill broke through the slate covering, and the water gushed out with such rapidity and force, that the workmen with diffi-

* *A Treatise on Water-works.* By Charles S. Storrow. Boston. 1835.

† *Memoirs of the American Academy of Arts and Sciences.* Vol. 3.

culty were saved from death. The water rose to the top of the well and ran over for some time. The force was such as to bring up a large quantity of fine sand, by which the well was filled up many feet. The workmen left behind all their tools, which were buried in the sand, and all their labour was lost. The body of water which is constantly passing under the immense body of clay, which is found in all the low parts of the peninsula, and which forms the basin of the harbour, must have its source in the interior, and is pushed on with great force from ponds and lakes in the elevated parts of the country. Whenever vent is given to any of those subterranean currents, the water will rise, if it have opportunity, to the level of its source.'"

The only supply of water which the inhabitants of New York enjoyed in 1837 was obtained from wells sunk in different parts of the town. The water was raised from these wells by steam-power to elevated reservoirs, and thence distributed in pipes to different parts of the town. Some of the wells in New York belong to the Manhatten Water Company, and some to the corporation. One well, belonging to the corporation, is 113 feet in depth. For the purpose of collecting water, there are three horizontal passages leading from the bottom of the well, which measure four feet in width, and six feet in height; two of them are seventy-five, and the third is one hundred feet in length. This well cost about L.11,500, and yields 21,000 gallons in twenty-four hours. There are many other wells in the town, some of which are said to produce 120,000 gallons in twenty-four hours. The supply at New York is far from being adequate to the wants of the inhabitants; and the water in most of the wells being hard and brackish, is not suitable for domestic purposes.

New York is built on a flat island, which is nearly surrounded by salt water, so that the method that has been resorted to for the supply of Philadelphia, and most other towns in the United States, by pumping from the river, is altogether impracticable in that situation. Many plans have been proposed, and, among others, that of throwing a dam across the Hudson, so as to exclude the salt water; but as a free passage, by means of locks, must be preserved for the numerous vessels which navigate the river, the success of such a plan seems very doubtful.

Many engineers in the United States of great reputation have made surveys of the country in the neighbourhood of New York, in order to devise a plan for the supply of the city with water; but the scheme which had been ultimately adopted at the time of my visit was that of conveying the water of the River Croton in a tunnel, for a distance of about forty miles, to New York. I had the good fortune to meet with Mr Douglass, an engineer, who, I believe, may be said to have had the merit of originating this gigantic work, with whom I went over part of the ground to be traversed by it, and from whom I received much information relative to the water supply of New York, and other matters of engineering. The works have, since my visit, been completed under the direction of Mr John B. Jervis as chief engineer, and the following short notice of them may prove interesting. Most of the details are from the works by Mr Tower and Mr Schrampe who were engaged in carrying out the work.*

The Croton River flows into the Hudson, about forty miles above New York. It is supplied mainly by several springs and small lakes situated about twenty-five miles from its mouth. Its mean discharge was ascertained to be about fifty millions of gallons in twenty-four hours, equal to 5787 cubic feet per minute. Its minimum flow was found to be twenty-seven millions of gallons in twenty-four hours, or 3121 cubic feet per minute. The following are the works by which this water has been made available for the supply of New York:—

A dam has been thrown across the Croton River at a point about five miles above its junction with the Hudson. The construction of this dam was attended first with failure, and afterwards with difficulty, but it was ultimately completed

* *Illustrations of the Croton Aqueduct.* By F. B. Tower. New York and London. 1843.

Description of the New York Croton Aqueduct. By T. Schrampe. In English, German, and French. New York and Berlin.

satisfactorily. It consists of timber cribs filled with stones, which form the nucleus of the dam. These are covered on the upper side by an earthen embankment, and on the lower side by a facing of masonry. By means of this dam the water of the Croton is raised about thirty-eight feet, and dammed back six miles, forming a store reservoir of about 400 acres, and having a capacity of 600 millions of gallons above the level of the discharge sluices. The whole of the works connected with this dam and its off-lets appear to be executed in a very substantial manner. The water is conveyed from the Store Reservoir to New York in an aqueduct of masonry, excepting at the crossing of Harlem River and Manhatten Valley, where two iron pipes, three feet in diameter, are used; but provision has been made for laying two additional pipes if necessary. These pipes are carried across Harlem River on a bridge of sixteen arches, at a height of 100 feet above the level of the river, to admit of a free navigation. In crossing Manhatten Valley they are laid on the bottom, and are depressed about 102 feet from the level of the aqueduct. On reaching New York the aqueduct discharges into a Receiving Reservoir at the outskirts of the city, which has an area of thirty-one acres, and contains 150 millions of gallons. From thence the water is led in iron pipes to the Distributing Reservoir, which is situated in the heart of the city. It has an area of four acres, and contains 20 millions of gallons. From this point the water is conveyed in service pipes to the different parts of the town.

The construction of these works seems to be very similar to works of a kindred nature in this country. The aqueduct varies in size and design according to the rate of inclination and the soil through which it passes. In order to counteract the effects of frost and the contraction of impurities, it is covered throughout its whole extent of thirty-eight miles. The curves which occur in its course are nowhere less than 500 feet radius. To admit of repair, it is provided with six let-offs and stop-gates. There are also ventillators for air at every mile, and intermediate manholes at every quarter of a mile to allow access to the tunnel, the general size of which is about eight feet high and seven feet broad. The following particulars as to the levels are given by Mr Tower:—

"The bottom of the water-way of the aqueduct, where it leaves the gate chamber at the Croton Dam, is 11·4 feet below the surface of the Store Reservoir, and 154·77 feet above the level of mean tide at the city of New York. The following table shows the length of the different planes of descent from the Store to the Receiving Reservoir:—

	Miles.		Feet.	Inches per Mile.
The 1st plane extends . .	49·43	and the descent is	2·94	$7\frac{1}{8}$
The 2d do. . . .	28·053	do.	30·69	$13\frac{1}{4}$
Length of pipes across Harlem River,	0·261	...	...	...
Diff. of level between extremes of pipes,	...	do.	2·29	
The 3d plane extends . .	2·033	do.	2·25	$13\frac{1}{4}$
Length of pipes across Manhatten Valley, ...	0·77	...	...	...
Diff. of level between extremes of pipes,		do.	3·86	...
The 4th plane extends . .	2·023	do.	1·60	$9\frac{1}{2}$
	38·090		43·63	

"In crossing the Harlem River there is a fall of two feet, and at Manhatten Valley a fall of three feet; more than that would have been had the aqueduct continued across these places with its regular inclination. This extra fall was allowed, to adjust the number and capacity of the pipes (which descend below the level of the aqueduct and rise again), to discharge the full quantity of water as freely as the aqueduct of masonry would have done had it been continued across the valleys. There is therefore a loss of this extra head of water for the city reservoirs, but this small loss of head was not considered of such importance as to induce the building of structures across these valleys up to the plane of the aqueduct grade.

"The surface of the Store Reservoir is 166 feet above the mean level of high water at New York; the difference of level between that and the surface of the Receiving Reservoir is forty-seven feet, leaving the surface of this reservoir 119 feet above high water. The fall from the Receiving Reservoir to the Distributing Reservoir is four feet, its surface being 115 feet above high water. This last is the height to which the water may generally be made available in the city. The surface velocity of the water in the aqueduct when the water is two feet deep has been ascertained to be about 1½ mile per hour, which, taking the width at seven feet, gives a discharge of 1848 cubic feet per minute; which, at 30 gallons to each person, would afford a supply to 532,226 persons. But the works are calculated to convey a quantity sufficient to fill the aqueduct to the depth of four feet, so that this will provide for an enormous population."

The work was commenced in 1837, and opened in 1842. It is stated to have cost L.1,713,000; the service-pipes for the city are stated at L.362,000; making in all L.2,075,000 as the total expenditure. Mr Schrampe says, "that the interest payable on this sum, which ranges from five to seven per cent., is collected by a direct water tax, and some indirect taxes. By means of a sinking fund the capital will be redeemed by degrees. The water tax amounts to L.2 for a house of middle size (the city has over 33,500 such houses); manufacturers, hotels, &c., pay according to their extent."

For farther details regarding this truly useful and magnificent work, I must refer the reader to the interesting books from which I have quoted.

The citizens of Washington have followed the example of their neighbours of New York, and are constructing an aqueduct to supply that city with water from the River Potomac. Its length (as stated in the Report of the Council of Civil Engineers in 1858) is about twelve miles, and the height of the source about 150 feet above high water mark. The aqueduct is circular, nine feet in diameter, and is built chiefly of rubble masonry, fourteen inches in thickness, laid in hydraulic cement. The fall is nine inches in 5000 feet; a bridge, of 200 feet span of iron, crosses the creek between Washington and Georgetown. The iron pipes, forty-eight inches diameter, do duty as arched ribs to support the bridge, and also as mains to convey the water under pressure; and they are lined with staves of wood as a protection against frost. It is expected that the work will be completed in August 1859. The estimated cost was L.510,000.