3.—PUMPING TO STAND-PIPE.

BLOOMINGTON, ILLINOIS.

Bloomington contains a population of 17,180, and is situated 126 miles south-southwest of Chicago and 154 miles from Saint Louis. Its business interests are principally agricultural. Topographically the city is but slightly irregular, and the streets intersect each other at right angles. The city introduced a water-supply in 1875 by pumping to a stand-pipe, the water being derived from a well sunk in sand, loam, and clay soil. The well is situated about 600 feet northwest of the corporation line, in a plat of six acres of land owned by the city, and is 28 feet 5 inches deep by 40 feet internal diameter. The first 5 feet was loam clay, and the remaining depth was sand and gravel; underlying this is 7 feet of blue clay with a substratum of fine sand. The latter, containing a strong vein of water, was brought into communication with the main part of the well above by a pipe 18 inches in diameter and 9 feet long, the top extending 3 feet above the bottom of the well. The average depth of water in the well is 14 feet, and the supply, 2,714,000 gallons per day. The well is lined with brick-work 12 inches thick. It was sunk on an iron shoe, tied to the brick-work by vertical iron rods. The brick-work was built up in courses as the shoe was sunk. The well is covered by a frame roofing, and is situated a few feet back of the engine-house. The latter is 28 by 28 feet, with a boiler-room 28 by 44 feet, and the coal-room 20 feet square. A stack in the latter is 65 feet high by 4 feet interior diameter, brick-work 2 feet thick.

A Worthington duplex pump of 1,000,000 gallons daily capacity, erected in 1875 with the works, is run at high pressure, and has steam-cylinders 20 inches in diameter, pump-plungers 12 inches in diameter, and a stroke of 14 inches. It is operated at an average of 44 double strokes per minute during 18 hours per day. No duty-trial has ever been made. Each pump-cylinder contains 22 inlet and 22 discharge rubber disk valves 3 inches in diameter. Steam is supplied by two boilers, one a multitubular, containing forty-four 3-inch tubes, and 16 feet long by 5 inches diameter of shell. The other is 22 feet long by 5 feet in diameter, and contains five flues, three of which are 10 inches and two 12 inches in diameter. They are run at 70 pounds pressure with Illinois soft coal mined in the vicinity. Their evaporation is unknown. The engine cost $3,300. It is to be assisted by a Blake pump placed near it, and having a 30-inch steam- and 15-inch pump-cylinder with a 24-inch stroke.

From the engine-house the water is forced through 600 feet of 10-inch cast-iron main into the stand-pipe. This consists of a cylinder of wrought iron 8 feet in diameter and 200 feet high, encased in a brick tower, with walls 7 feet thick at base by 12 inches thick at the top. A spiral staircase encircles the pipe. There is one inlet and one outlet, each 16 inches in diameter, connected with the force-main in the adjacent street by two short branches furnished with valves, by which the pipe can be shut off from the system and direct pressure exerted. From here the water flows by gravity through a little over 10 miles of cast-iron mains. A statement is made by the superintendent in the annual report of 1877, to the effect that the net cost for running the water-works by direct pressure before the introduction of the stand-pipe, for the month of January, 1876, was $479 50, while the average monthly cost for 1877 was only $168.

The distributing mains are of 10, 8, 6, and 4 inches in diameter, the greatest length being of 4 and 6 inches. There are 124 hydrants, the majority of the Matthews patent, with a few of Chapman's and Flowers. The average consumption is estimated at 300,000 gallons per day, distributed among 515 takers.

The first cost of the works is given at $75,000. Of this amount the items are somewhat as follows:

Engines	$3,300 00
Buildings at the pump-station	2,850 00
Stand-pipe	28,570 00

The remainder was expended for the ground on which the buildings are located, the force- and distributing-mains, boilers, well, etc. The total cost to date amounts to $113,000. The annual repair and maintenance cost for 1880 was $5,000.

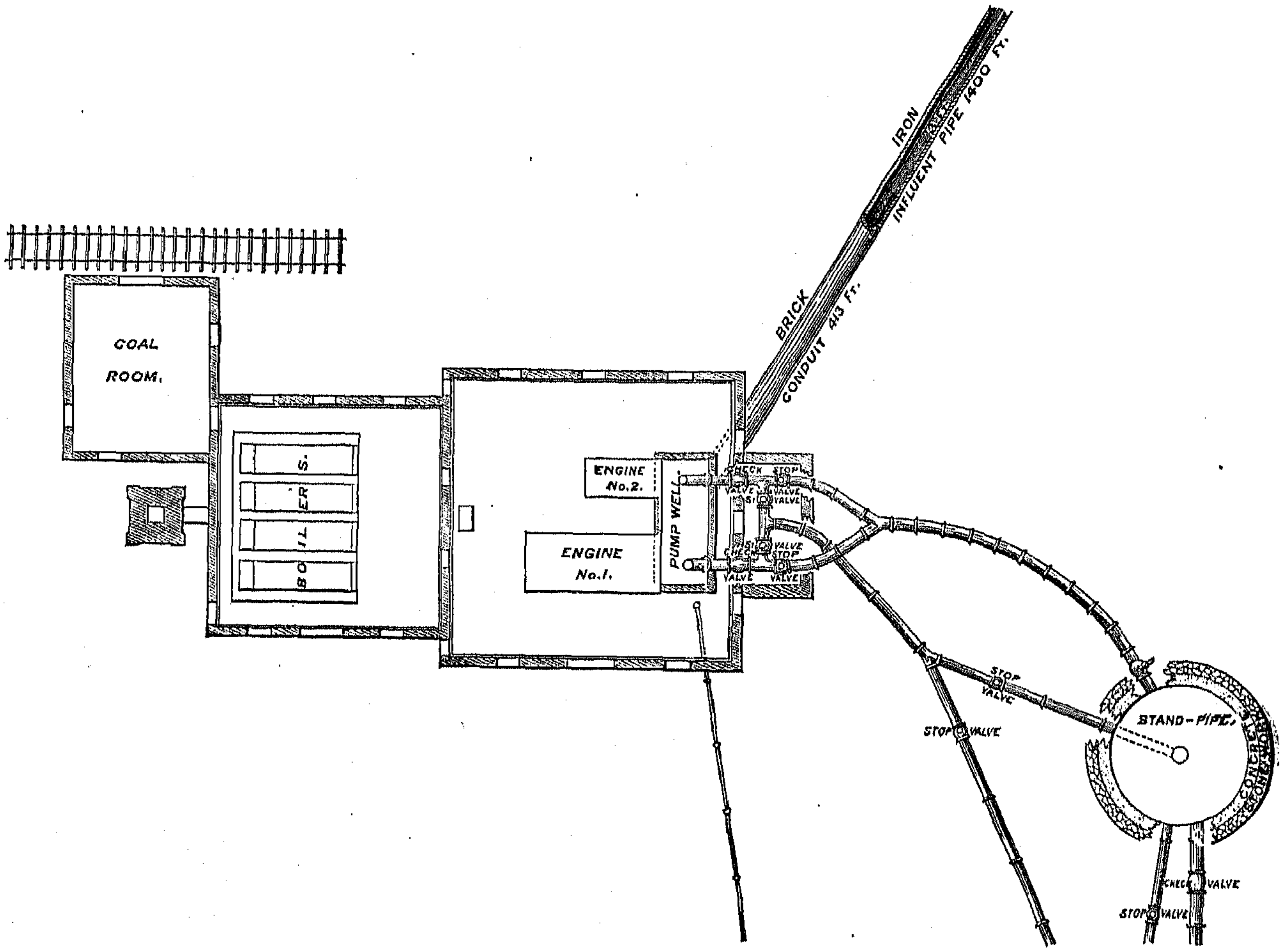
The head of water on the mains varies from 75 to 100 pounds with a full stand-pipe. An analysis made by Dr. D. S. Dyson gave the following results:

	Grains per gallon.
Total solids	76
Carbonate of magnesia	24
Carbonate of lime	8
Carbonate of iron	12
Chloride of sodium	Trace
Sulphur by precipitation	32

The control of the works is in the hands of M. X. Chuse, superintendent.

SANDUSKY, OHIO.

Sandusky contains a population of 15,838, and is located on a bay of the same name of lake Erie, its site sloping southward from the bay. The interests of the city are chiefly commercial.



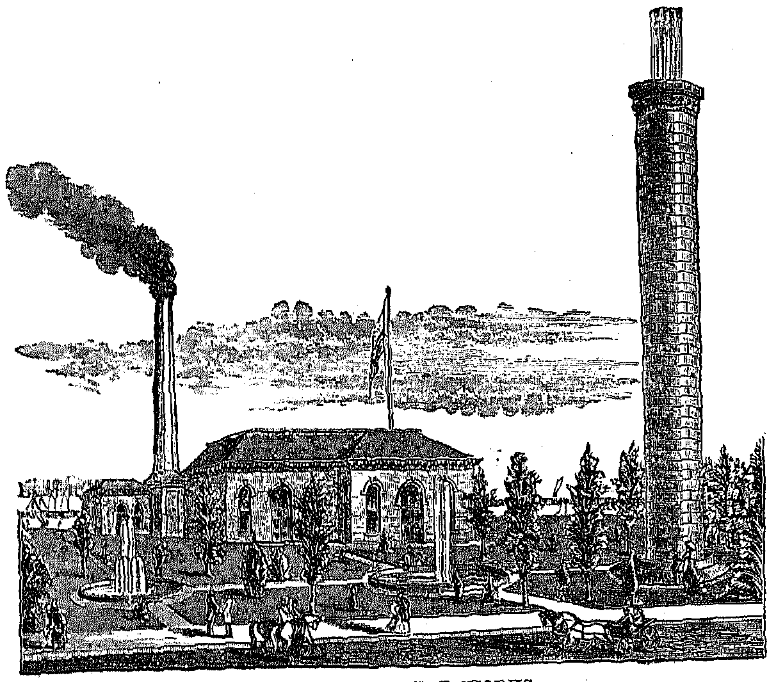
SANDUSKY WATER-WORKS PUMPING STATION.

Water was introduced in 1876 by the city authorities, and is derived by pumping from Sandusky bay. By an arrangement of stop-gates in the mains the pumping is either direct into the mains, to the stand-pipe, or a combination of both of these systems. The crib from which the water is taken is situated 1,800 feet from the shore-line of the bay. It is octagonal in plan, with an inner diameter of 25 and an outer of 45 feet. Two rows of sheet-piling, driven to rock-bottom, are 8 feet apart, and the intervening space is filled with broken sandstone. Through this the water of the bay passes to reach the mouth of the inlet-pipe, as in the case of Toledo. The top of the crib is 6 feet above high-water level in the bay.

The inlet-pipe is of wrought iron, 3 feet in diameter, 1,800 feet long, and buried in water 12 feet deep. The crib end is turned vertically, and its mouth protected by a perforated copper-plate screen. The joints are made with a half-sleeve riveted to the end of each section, with flanges which are riveted to each other. From the termination of this pipe on the shore a brick conduit, 413 feet long and 3 feet in diameter, leads the water to the pump-well of the engine-house. A stop-gate is arranged in this conduit near the well, in order to cut it off if it becomes necessary to empty the well. The latter is an excavation in the rock 22 by 8 feet by 21½ feet deep, lined with brick throughout. Above this is an engine-house, of bluestone, 50 by 50 feet, with a height of 28 feet; the boiler-house connected therewith is 40 by 40 by 28 feet, flagged, having a chimney-stack 100 feet high and 3 by 3 feet on the inside.

The pumping machinery consists of two sets of Worthington engines, one a duplex compound and the other a high-pressure, both built in 1876, the former having a capacity of 3,000,000 and the latter of 2,000,000 gallons per day. The duplex engine has a low-pressure steam-cylinder of $43\frac{3}{16}$ inches diameter, high-pressure cylinder of 25 inches diameter, pump-plungers 17½ inches diameter, and a stroke of 3 feet. Average engine duty in 1880, 43,000,000 foot-pounds. The high-pressure engine has steam-cylinders of 24 inches diameter, pump-plungers of 16 inches diameter, and a stroke of 26 inches. Average speed, 34 double strokes per minute. The total cost of these engines was $32,500, and the repairs to date have amounted to less than $100, although run during twelve hours per day all the year round.

From the pumps a 20-inch cast-iron force-main connects with the stand-pipe, 70 feet distant. The head on the pumps is equivalent to 180 feet for domestic and 229 feet for fire pressure.



SANDUSKY WATER-WORKS.

The stand-pipe is unique. It consists of a shell of wrought steel 180 feet high and 25 feet in diameter, containing an inner column of steel 229 feet high and 3 feet diameter, used as a stand-pipe in case of fire, to give additional head. The outer shell is known as the reservoir, and is leaded into a shoe of cast iron in segments bolted together. Twelve iron 1¼-inch rods fastened to the second course of the outer shell have their lower ends leaded into the rock 8 feet below ground and spread by wedges. The foundation of the whole structure is upon limestone-rock, and was built by J. & T. McGregor, of Detroit. The metal has a tested strength of 67,000 to 87,000 pounds per square inch. Valves regulating the admission of water to the inner or outer shell are controlled by gearing and rods operated from the engine-house.

From the stand-pipe the water is distributed through 108,126 feet of cast-iron pipe of the following lengths and sizes:

	Linear feet.
20-inch	4,370.8
16-inch	3,263.7
12-inch	10,989.0
8-inch	32,932.4
6-inch	48,430.8
4-inch	5,078.7
3-inch	601.0
2- and 1¼-inch	2,460.0
Total	108,126.4

Attached to these there are 47 Lowry and 99 Matthews hydrants and 141 gates. The performance of the engines for the year 1880 and the relative cost of pumping for the last four years are given in annexed tables:

Cost of pumping and amount received from 1,000 gallons.

Year.	Cost of pumping each 1,000 gallons.	Amount received in water-rents for each 1,000 gallons.	Cost of pumping 1,000,000 gallons 100 feet high.
	Cents.	*Cents.*	
1877	2.29	4.17	$14 80
1878	1.83	4.12	11 25
1879	1.10	2.94	8 33
1880	1.17	2.77	7 00

Details of operation.

Months, 1880.	Coal consumed while pumping.	Coal consumed banking fires.	Ashes and clinkers removed.	Head.	Water pumped.	Water raised 100 feet high with 100 pounds of coal.	Duty in pounds raised 1 foot high with 100 pounds of coal.	Cost of coal.	Salaries of engineers and firemen.	Cost of oil, gas, packing, waste, etc.	Total cost.
	Pounds.	*Pounds.*	*Pounds.*	*Feet.*	*Gallons.*	*Gallons.*					
January	120, 500	28, 600	15, 258	104. 3	31, 313, 300	42, 605	35, 570, 100	$197 83	$159 03	$22 73	$379 59
February	106, 600	25, 100	12, 500	170. 1	30, 337, 800	48, 410	40, 341, 666	214 11	160 83	23 31	398 25
March	90, 400	23, 500	11, 229	164. 5	26, 542, 700	48, 200	40, 240, 166	177 67	160 83	23 55	362 05
April	81, 500	22, 200	9, 410	168. 1	24, 420, 250	50, 369	41, 074, 366	162 33	160 83	22 13	345 29
May	110, 700	24, 200	9, 105	166. 1	33, 784, 200	50, 601	42, 242, 500	205 43	160 83	19 00	386 16
June	113, 900	18, 100	6, 320	166. 2	33, 420, 600	48, 707	40, 639, 166	198 64	160 83	19 96	379 43
July	116, 000	13, 200	3, 968	169. 8	35, 992, 550	52, 680	43, 905, 000	184 80	160 83	20 11	365 74
August	121, 800	19, 400	11, 720	169. 2	34, 552, 150	48, 210	40, 182, 500	218 63	160 84	21 75	401 22
September	110, 500	19, 500	11, 800	170. 2	33, 383, 300	51, 410	42, 840, 166	211 25	160 83	22 50	394 58
October	116, 900	21, 800	10, 648	170. 2	34, 300, 300	49, 938	41, 615, 000	227 60	160 83	23 36	411 79
November	153, 500	24, 800	14, 444	167. 0	45, 770, 800	49, 706	41, 406, 666	294 20	172 83	26 93	493 96
December	156, 530	25, 800	16, 116	170. 2	47, 936, 800	52, 123	43, 435, 833	296 29	200 83	28 54	525 66
Total	1, 398, 330	266, 200	132, 633	....	411, 754, 810	....	....	2, 588 78	1, 980 17	274 77	4, 843 72

The total consumption in 1880 amounted to 1,128,300 gallons per day, delivered to 1,200 consumers.

The first cost of the works was $375,000, and the total to January, 1881, amounted to $387,189 76. The items may be seen in the table. The cost of maintenance and repairs in 1880 amounted to $8,322 50, as follows:

Paid for fuel (including $11 75 for office)	$2, 600 53
Gas, waste, ice, and oil (including gas and ice for office)	227 75
Salaries of superintendent, engineers, and firemen	3, 190 09
Salaries of secretary and trustees	1, 099 92
Office rent, expense of printing, stationery, etc	305 16
Tools, hose, etc	96 26
Sundries, extra labor, drayage, freight, papering and painting office, etc	242 12
Repairs on valves	59 67
Repairs on hydrants	56 91
Repairs on pipe-line	22 31
Repairs on influent-pipe	319 84
Repairs on stand-pipe	27 25
Repairs on engine-house	16 85
Repairs on boilers and engine	57 84

The receipts for water-rents in 1880 were $11,141.

Construction account.

Object of expenditures.	Amount paid prior to December 30, 1876.	Amount paid in the year 1877.	Amount paid in the year 1878.	Amount paid in the year 1879.	Total cost.
Water-pipes	$106,827 27	$1,530 95	$98 80	$3,913 39	$112,370 41
Pipe-laying	88,202 30	3,248 58	43 68	1,634 08	93,128 64
Stand-pipe	20,981 87	26,046 20	1,079 98	....	48,108 05
Stand-pipe connections	8,098 70	....	....	....	8,098 70
Engine, boilers, etc	5,543 47	27,137 15	14 00	....	32,694 62
Influent-pipe	19,819 62	12 50	....	....	19,832 12
Bay crib	3,753 03	....	....	....	3,753 03
Pump-well	1,402 28	2 65	....	....	1,404 93
Hydrants	9,135 15	579 50	....	396 48	10,111 13
Gates and valves	7,600 12	398 09	13 50	197 99	8,209 70
Engine-house	11,111 54	2,056 91	....	....	13,168 45
Dwelling-house	....	513 50	757 62	....	1,271 12
Smoke-stack	2,081 45	10 00	....	....	2,091 45
Traveling and telegraph expenses	610 04	8 01	....	....	618 05
Implements and tools	704 87	172 23	34 02	....	911 12
Office and engine-house furniture, including iron safe	477 20	69 63	....	....	546 83
Filling and ornamenting engine-house grounds	769 62	1,177 71	1,061 16	28 50	3,036 99
Office expenses, stationery, advertising, and printing	1,130 16	178 28	12 40	....	1,320 82
Sundries and incidentals, and analysis of water	580 68	288 03	....	....	868 71
Ferrules, stops, boxes, and service connection	2,084 65	5,099 76	1,255 70	1,057 72	9,447 83
Officers' salaries	3,733 00	525 00	....	....	4,258 00
Engineering, superintendence, and inspection	7,016 45	500 00	....	166 64	7,683 09
Total amount paid out	301,740 46	69,555 26	4,356 02	7,408 74	383,061 38
Amount paid out in 1880	....	....	....	....	4,128 38
Total	....	....	....	....	387,189 76

The water taken from the lake was analyzed by Professor S. H. Douglas, of Michigan university, in 1876, when the lake was slightly turbid, and the result is given below:

Appearance perfectly clear and limpid after filtration.

Matter (inorganic) held in suspension rendered it slightly turbid and of a yellowish tint.

Hardness, on Clark's scale, 1° to 16° (16° being the hardest). Before boiling, 4°. After boiling, 2.5°. Oxygen absorbed by organic matter from permanganate of potassium, 65.

Constituents.	Grains per U. S. gallon, 58,328.889 grains.	Parts per 1,000,000.
Chloride of sodium	0.265688	4.5490
Sulphate of sodium	0.883088	15.1000
Sulphate of calcium	0.739536	12.6720
Carbonate of calcium	4.460140	76.3350
Carbonate of magnesium	1.238194	21.1860
Silica	0.321248	5.5000
Iron (ferric oxide)	0.105094	1.8000
Oxygen displaced	0.036518	0.6281
Total	8.049440	137.7800
Total matter held in suspension, separated by filtration	0.803271	13.7500
Total held in solution	7.246169	124.0300
Earthy carbonates	5.698274	97.3140

An account of an accident to the inside stand-pipe on October 20, 1878, is thus given in the report for that year:

During a fire on the afternoon of the 20th day of October, the fire pressure-pipe burst at a point 50 feet below top of large tank. The reaction caused by the water escaping through the rupture buckled over the pipe and forced it against the side of the large tank with great violence, breaking it in a second place, bruising and otherwise injuring a section of about 25 feet. When the damaged parts had been removed it was decided to replace with iron of $\frac{1}{4}$ of an inch in thickness, and as the iron of the pipe as originally constructed had a thickness for the first 100 feet of $\frac{1}{4}$ of an inch, and for the second 100 feet, $\frac{3}{16}$ of an inch, it was thought desirable to remove all of the $\frac{3}{16}$-inch iron below the break and substitute $\frac{1}{4}$ inch, which has accordingly been done. As the pipe now stands the shell has a thickness of $\frac{1}{4}$ inch for the first 140 feet, $\frac{3}{16}$ inch for 60 feet, and $\frac{1}{8}$ inch for the remaining 29 feet.

A spiral staircase has recently been built around the outer shell.

A peculiar occurrence is thus mentioned in the report for 1880:

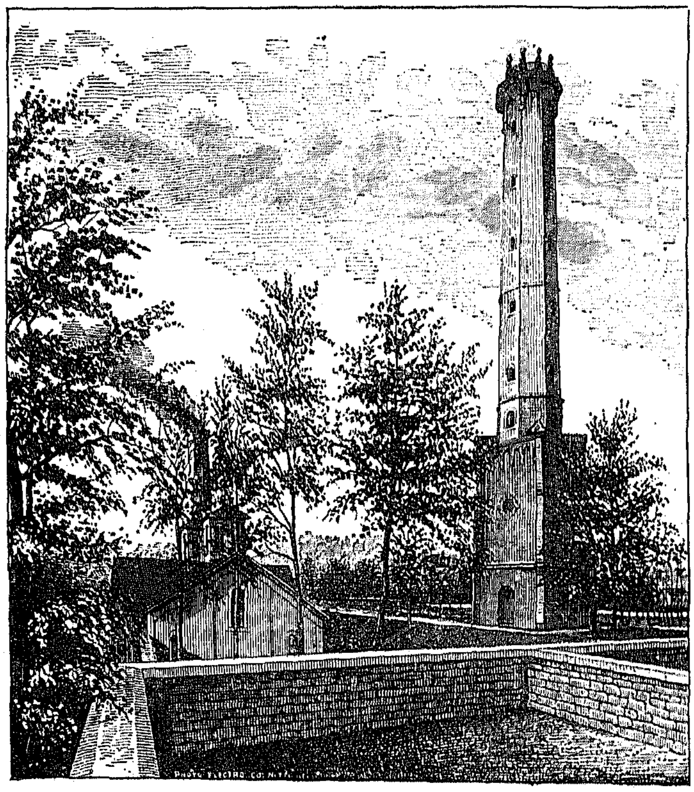
During the month of February, 1880, it was discovered that the water in the pump-well was unusually low, and that the flow of water through the conduit was gradually diminishing, until the 13th of February, when it almost ceased—from no apparent cause, as the valve at the end of the brick conduit was examined and found to be open full head. During the night of the 13th, the difficulty seemed to have been removed and the flow of water was as usual, but very roily and impure. Subsequently it was ascertained that there was a break in the influent pipe near where it joined the brick conduit. It was found that the copper strainer on the end of the influent-pipe inside the bay-crib had become completely enveloped with a peculiar fibrous sediment or fungi, impervious to water, which caused the pipe to rise from its anchorage and separate at a joint near the coffer-dam. This vegetable formation was very tough, impervious to water, and, when dried, was non-combustible.

The works are under the control of a board of three trustees, with a term of office of three years. Erwin Graves is superintendent, and David M. Arndt, secretary.

TOLEDO, OHIO.

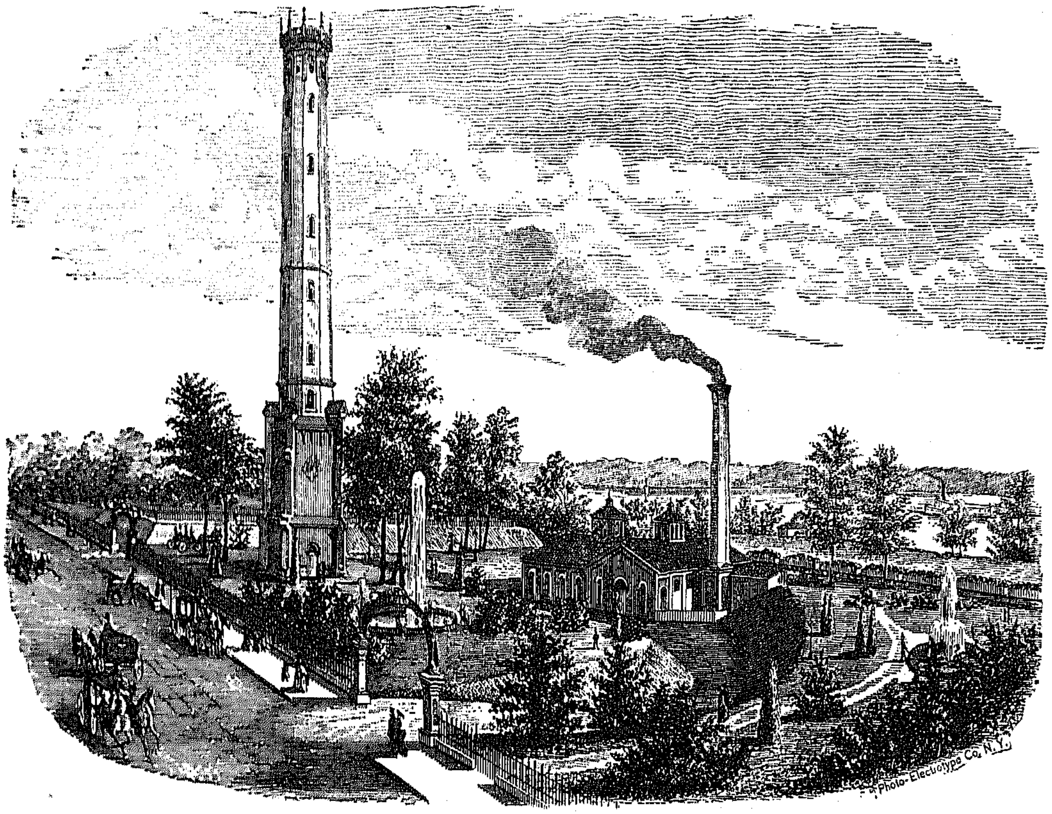
Toledo, containing 50,137 inhabitants, is situated on the west bank of the Maumee river 4 miles from lake Erie, and is on comparatively level ground, with streets intersecting each other at right angles. The site was originally two distinct settlements, one of which is somewhat more elevated than the other. It is chiefly a commercial center with considerable manufacturing interests.

The municipal authorities introduced a supply of water from the Maumee river in 1873, the system employed being direct pumping to stand-pipe. The suction-main is taken from a crib in the river, of the following construction: It is a rectilinear figure, six-sided, with its longer sides parallel with the river, and 80 feet long, the other sides being 37 feet each. It is composed of lines of piling 5 feet apart and 45 feet deep, bound together by 10x12-inch timber; broken sandstone fills the space between the rows of piling, covered with double planking. It required 415 piles, 28,000 feet of timber, 7,600 pounds of iron, and 1,709 cubic yards of broken stone. The river water passing through 5 feet of broken stone enters the wrought-iron influent-pipe from the crib to the influent gate-chamber. At this point a brick conduit enters the pump-well of the engine-house. By an arrangement of valves and a middle main connected with the two rising mains, either engine is made to supply water from the pump-well to a filtering basin, while the other one pumps from the latter into a stand-pipe, there being two engines in use.



INTERIOR OF FILTER-BASIN, STAND-PIPE IN THE DISTANCE.

The suction-main is composed of 250 feet of boiler-iron 5 feet in diameter, connected by 250 feet of brick conduit of the same diameter to the pump-well. The filtering basin, which has been recently abandoned, is one of three originally projected. It is rectangular in plan and 150 by 300 feet, lined with masonry, with vertical interior walls, and a division-wall at one end, partitioning off the clear-water well. The bottom of the latter is connected through the division-wall with the large compartment. The filtering material consisted of a bottom layer of 4-inch stones, 1 foot in depth, with another layer of smaller stones 8 inches in depth above it; the last two layers are gravel and sand each 2 feet thick, making the whole depth of filtering material 5 feet. The water pumped from the river into the basin by one of the engines flows back from the clear well to the remaining engine under a head of 12 feet, from whence it is pumped into the stand-pipe. On the 12th of January, 1875, water was let on to the filter-bed. The filtering area is 18,200 square feet, and, when first used, its actual capacity proved to be 4,500,000 gallons per day, while the best results were obtained when filtering but 2,500,000; at that time the river water was particularly clear. A few months later high water, bringing with it great quantities of clay in suspension, rendered the filtration imperfect and unsatisfactory to such an extent as to render the surface of the sand almost impervious. As a consequence, cleaning was necessary as often as once a week, and as there was but one basin, during the operation water was drawn from the river direct. Financial embarrassment prevented the construction of a needed duplicate basin. The advantages gained from the filtration seem to have been doubtful, if the appended analyses of water before and after filtration can be trusted. The basin was abandoned after a few



PUMP-STATION OF TOLEDO WATER-WORKS.

months. The stand-pipe is a wrought-iron pipe 5 feet in diameter and 243 feet to its top, which is 260 feet above the level of the river, and is inclosed in a brick tower, as shown in the cut. This stand-pipe is connected with the pumps by two mains, each 24 inches in diameter and 80 feet long. There are one 30-inch inlet and three 30-inch outlets; only one of the latter is in use. The tower of masonry is stone, 7 feet thick under the base of the pipe, and 36 feet square at its base, 16 feet below ground. Three feet above the ground, its inner diameter is 16 feet, with the same outer dimensions as before. It contains 682 cubic yards of stone masonry and 1,242,000 brick. It was originally the intention to construct a spiral stairway around the pipe, but a hydraulic lift is to be substituted.

The pumping plant consists of two Worthington duplex pumps, with low-pressure cylinder 50 inches in diameter, high-pressure 29 inches in diameter, pump piston 20 inches in diameter, with a stroke of 4 feet. They run at an average speed of 33 strokes per minute. The ordinary duty averages 37,000,000 foot-pounds, while with good coal it has run up as high as 55,000,000. The condensers are 30 inches in diameter and 5 feet long. The air-pumps of one of the engines are 18 inches diameter, and of the other 16 inches, all having a 2-foot stroke. A poor quality of bituminous coal is used under eight boilers made by the Novelty Works of Toledo, each 16 feet long and 5 feet in diameter, multitubular pattern, with sixty-two 4-inch tubes in each. Average pressure, 50 pounds. Evaporation unknown. The performance of the engines for 1879 is given below:

Pounds of coal consumed	4,316,477
Pounds of coal for banking fires	29,300
	4,287,177
Gallons of water pumped	1,140,625,640
Hours of fire pressure	109
Height in feet	163
	579

Gallons of water 1 foot high with 100 pounds of coal	43, 366
Duty, in pounds, of water raised 1 foot with 100 pounds of coal	36, 169, 244
Cost of coal	$4, 849 58
Cost of engineer, firemen, and helpers	4, 683 04
Cost of oil, waste, and tools	380 89
Engine repairs, gas, and packing	401 49
Total cost of pumping	10, 315 00
Cost of raising 1,000,000 gallons 1 foot high, in cents	5, 54

The ordinary head on the pumps is about 60 pounds, and 120 pounds during fires. Their cost was $89,148.

The consumption in 1879 averaged 3,133,586 gallons per day, distributed through $46\frac{4912}{5280}$ miles of cast-iron main, of relative sizes and lengths, given below:

	Linear feet.
30-inch pipe	15, 847
24-inch pipe	3, 444
16-inch pipe	198
12-inch pipe	20, 180
8-inch pipe	34, 056
6-inch pipe	132, 157
4-inch pipe	41, 610
Total	247, 492

Three hundred and forty-nine hydrants are in use, three hundred being Matthews', and the rest Boston Machine Company's patents. The city has had but little experience with meters, only 41 being in use January 1, 1880.

There are about 2,500 water-takers, and the meter-rates are as follows:

	Cents.
100 to 500 gallons per day, per 1,000 gallons	20
500 to 1,000 gallons per day, per 1,000 gallons	17
1,000 to 2,000 gallons per day, per 1,000 gallons	12
2,000 to 4,000 gallons per day, per 1,000 gallons	10
Over 4,000 gallons per day, per 1,000 gallons	8

An abstract of the cost of the works, giving the different items, is annexed:

For what expended.	1872-'73.	1874.	Total.
Pipe and specials	$176, 607 06	$279, 011 06	$456, 210 02
Pipe-laying	17, 711 29	100, 214 10	117, 925 39
Fire-hydrants	5, 262 66	16, 804 90	22, 067 56
Gates and valves	4, 522 88	19, 630 62	24, 153 50
Filter-beds and crib	308 14	29, 246 89	29, 555 03
Engine- and boiler-house and stack	....	26, 432 58	26, 432 58
Engines	7, 084 01	69, 322 89	76, 406 90
Stand-pipe	9, 865 33	22, 960 05	32, 825 38
Pumping-wells	....	1, 600 77	1, 600 77
Brick conduit	....	3, 996 96	3, 996 96
Influent-pipe	....	4, 696 15	4, 696 15
Sewerage	363 64	1, 425 54	1, 789 18
Engineering, etc	4, 337 79	8, 770 40	13, 108 19
Salaries	9, 388 25	11, 345 24	20, 733 49
Legal services	200 00	50 00	250 00
Traveling and telegraphing	1, 421 37	265 39	1, 686 76
Printing, books, and stationery	1, 084 83	1, 088 53	2, 173 36
Office expenses	1, 554 80	682 59	2, 237 37
Implements, etc	429 49	785 82	1, 215 31
Land	31, 377 54	....	31, 377 54
Telegraph to works	....	220 00	220 00
Coal-house	....	739 24	739 24
Pipe-yard	156 62	23 36	179 98
Interest	44 67	319 05	363 72
Temporary works	308 29	11, 946 77	12, 255 06
Main works	....	561 30	561 30
Ferrules and plumbing	....	1, 772 79	1, 772 79
Water-meters	....	6 94	6 94
Total	272, 029 56	614, 519 93	886, 549 49

This sum has been increased in subsequent years as follows: Construction, exclusive of tools, to December 31, 1876, $930,726 40; in 1877, $1,699 58; in 1878, $28 12; in 1879, $658 48; sand account to December 31, 1876, $31,377 54, making a grand total of $964,490 12 to January, 1880.

The annual cost of maintenance and repairs for 1879 amounted to about $17,000, not including interest.

The analyses of Toledo water previously mentioned are given herewith as made in 1874 by Professor Silas H. Douglas, of Michigan university:

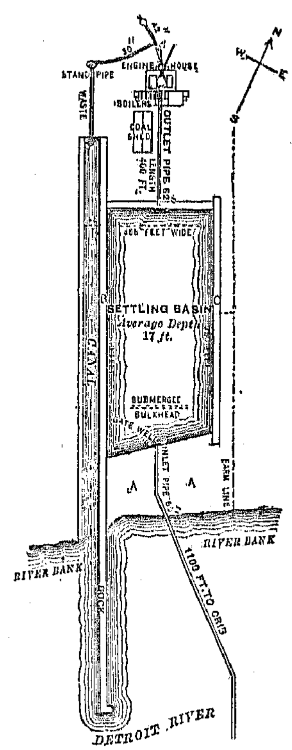
Constituents.	FILTERED.		UNFILTERED.	
	Grains per United States gallon.	Parts in 1,000,000.	Grains per United States gallon.	Parts in 1,000,000.
Oxygen absorbed by organic matter from permanganate of potassium	0.0063	1.6	0.1176	2.0
Total solid contents	16.32659	283.2413	17.44070	299.3638
Consisting of { Volatile and combustible matter	1.16378	19.9503	1.20525	20.6458
Consisting of { Fixed salts	15.35281	263.291	16.23554	278.718
Earthy carbonates	9.65747	165.310	10.54020	180.637
Fixed salts, consisting of—				
Chlorine	0.84110	14.40	0.84110	14.40
Sulphuric acid	2.14020	36.395	2.14020	36.395
Nitric acid	Trace.	Trace.	Trace.	Trace.
Carbonic acid	4.67938	80.00	5.03020	86.24
Soluble silica	Trace.	Trace.	Trace.	Trace.
Lime	3.99036	68.32	4.73581	81.20
Magnesia	2.44118	41.801	2.22805	38.108
Potassa and soda	1.26059	22.285	1.26050	22.285
Oxide of iron	Trace.	Trace.	Trace.	Trace.
Total solids	15.35281	263.291	16.23554	278.718

Filtered.—Sediment slight, but containing, as shown under the microscope, abundance of infusoria. Hardness on Clark's scale from 1° to 16° (16° being the hardest).

Unfiltered.—Sediment slightly increased from filtered, and showing under the microscope a great variety of infusorial animalculæ. Hardness on Clark's scale, 12°.

DETROIT, MICHIGAN.

Detroit introduced a supply of water in 1827 under the control of a private individual, who sold his rights to the city in 1836. A new site was selected and new works were erected. These contain two small engines of 10,000,000 gallons capacity, and an 18,000,000-gallon engine built by the Dry Docks Engine Company of Detroit in 1871. In 1877, owing to the fact that the supply of water, which was then pumped from the Detroit river opposite the heart of the city, was much contaminated by sewers, a new set of works was completed at a point 4 miles above.



In 1880 the city contained a population of 116,340. Situated on a river of like name 7 miles below lake Saint Clair, it extends from 3 to 4 miles along the river and $2\frac{1}{4}$ miles back from its banks. Its streets are laid out at right angles to each other, with the exception of several which radiate from the Grand Circus.

Topographically it is comparatively flat, having a slight rise from the river of about 50 feet per mile. It is chiefly a commercial center with considerable manufacturing interests.

The water is taken from the river through a cast-iron pipe 60 inches in diameter and 1,100 feet long, the river end of which is supported on the river bottom in 22 feet of water on a crib of timber filled with stone. This pipe enters a settling basin 400 feet from the engine-house, as shown in the cut.

This basin is trapezoidal in plan, 800 by 750 feet long on the sides, 365 by 370 feet on the ends, with an average depth of 17 feet. It is 200 feet from the river-bank, and the river-end of it has a submerged bulkhead 75 feet from the bank. On the western side is a canal 45 feet wide, extending parallel with and beyond it, and from which it is separated by two rows of sheet-piling filled in between with 14 feet of puddled clay supported by piles driven 7 feet into blue clay. On the engine-house end there is another wall similarly constructed; natural clay soil extends from the back of this wall to the engine-house, a distance of 400 feet. The east wall is of the same character, but 11 feet thick, and the natural clay soil beyond. The inlet-pipe enters the basin 6 feet above its bottom, and is 15 feet lower at its river-end than at its discharge into the basin. From the opposite end another 60-inch pipe, 400 feet long, conveys the settled water from a point 6 feet above the bottom into the engine-house pump-well. From this joint it is drawn by two compound condensing beam-engines with double-acting pumps and forced into the stand-pipe, whence it is conveyed to the reservoir. Both engines were designed by John E. Edwards, esq.

The first engine was built by the Detroit Locomotive Works in 1876, and the other by the Riverside Iron Works in 1880. They are alike in most respects, a description of one sufficing for the other.

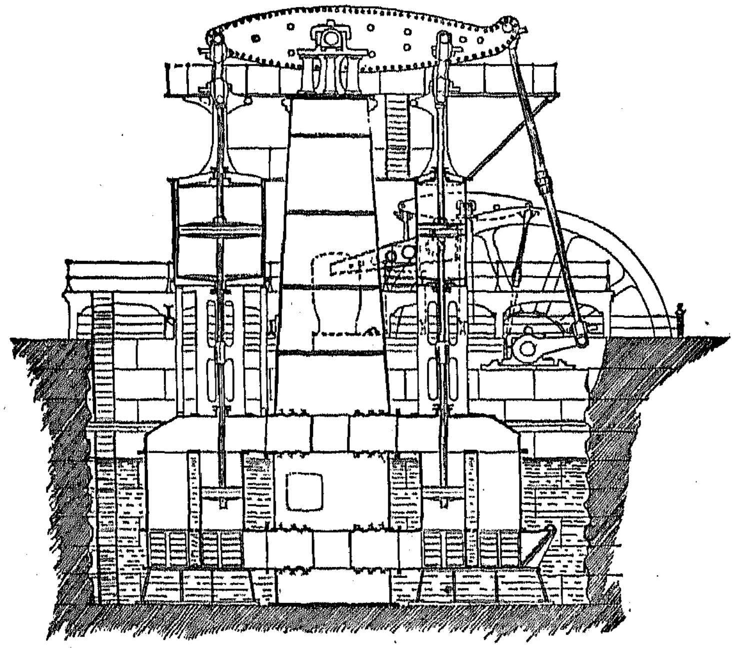
The old, or No. 1, has a low-pressure cylinder of 84 inches diameter, a high-pressure cylinder of 42 inches diameter, pump-cylinder 40¼ inches diameter; stroke, 6 feet; fly-wheel, 24 feet diameter; speed, 8 revolutions per minute; air-pump, 36 inches diameter and 30 inches stroke, operated by an auxiliary engine. The jet-condenser is 3 feet 9 inches diameter and 5 feet 9 inches high; vacuum, 26 inches. The steam-valves are puppet-valves operated by cams and plug-rods; cut-off at ⅓ stroke.

There are two pumps to each engine, of the plain piston type, each pump-cylinder having 116 discharge-valves of rubber 1 inch thick at each end, 9 inches diameter, and lifting from 1 to 1½ inch. There are also 48 suction valves at the end of the cylinders 19 by 7½ inches, rectangular, and lifting from 2 to 3 inches.

A battery of four marine boilers is used with each engine. They are of steel, 8 feet diameter by 17 feet long, with 4-inch return-flues, making steam at from 50 to 54 pounds pressure with anthracite coal. Evaporation unknown. The engine cost, with platform foundations and the like, $108,000, and gives a duty of 68,835,000 foot-pounds, and the following table will give its work during 11 months of 1879:

Time run, in hours	6,552.25
Number of revolutions made	3,008,431
Number of gallons pumped	4,693,152,900
Duty, in gallons of water raised (average)	69,000,000
Cords of wood consumed	20¼
Pounds of coal (*a*) consumed	5,033,742
Pounds of screening	632,364
Cost of wood	$57 05
Cost of coal	$9,216 51
Cost of screening	$454 18
Total cost of all fuel consumed	$9,727 74

The number of gallons pumped for 1 cent cost of fuel consumed for the year 1879 is 4,572.03.



COMPOUND PUMPING-ENGINE OF THE DETROIT WATER-WORKS.

Engine No. 2, erected in 1880, has a low-pressure cylinder of 84 inches diameter, a high-pressure cylinder of 46 inches diameter, a pump-cylinder 41 inches diameter; stroke, 6 feet. Other details as before. The boilers are also four in number and of the same description as the last. The cost of No. 2 was $83,000. The pumping capacity of each engine is 12,000,000 gallons. Details of the duty and operation of engine No. 2 are not yet published. Of the 18-million gallons engine in the old works, which was started in 1871, few details are at hand, but the following record will give its work in January, 1879:

Time run, in hours	744	Pounds of screening	90,001
Number of revolutions made	469,297	Cost of wood	$6 51
Number of gallons pumped	436,446,210	Cost of coal	$1,431 40
Duty, in gallons of water raised	43,135,700	Cost of screening	$53 86
Cords of wood consumed	2¼	Total cost of all fuel consumed	$1,491 77
Pounds of coal consumed	755,356		

a Anthracite, except 425,800 pounds bituminous used in January.

From the pumps a 42-inch main extends to the reservoir, a distance of 15,240 feet. An offset from this, a short distance from the pump-house, and 30 inches diameter, extends to a wrought-iron stand-pipe 132 feet high, the top being 128 feet above river-surface and 60 inches diameter at bottom. It tapers to 30 inches diameter at top, and is inclosed in a brick tower 17 feet 6 inches diameter at base by 12 feet at top. The walls are 3½ feet thick at base and 21 inches at top. This tower rests on a stone base 16 feet high, with walls 4 feet thick at top and 5 feet at base. The waste from this stand-pipe empties into the head of the canal by the side of the settling basins. A new force-main, 42 inches in diameter and 23,000 feet long, is being laid.

There is but one reservoir, and this is situated 4,500 feet from the old pumping-works, at an elevation of 77 feet above the river at level of high-water surface in said reservoir; it is rectangular in plan, with a wall dividing it into two basins, each 200 feet square; the depth is 26 feet and capacity of the two basins 7,592,700 gallons; it is puddle-faced, with a riprapping of stone, slopes 1½ to 1 outside and inside, making the bottom 114½ feet square; width of banks at top, 15 feet. It was built in 1858.

The distribution system is composed of pipe varying from 30 inches to 3 inches diameter, amounting to 210 miles in 1880. This length consists of 86½ miles of wooden bored logs, some of which were laid as late as 1880, though in very small quantity, and the remainder are of cast iron.

There seems to have been considerable reason in the continued adoption of this system of log pipes. Their period of efficiency has proved to be about 16 to 20 years, and as their cost was only one-fourth that of iron pipe they were laid in the sparsely settled portions of the city. By the time that they were worn out the population on the street had grown sufficiently to defray the expense of a new cast-iron main. As a general rule, the former were paid for, principal and interest, by the time they had to be removed.

The iron pipe is divided about as follows:

	Linear feet.
45 inches diameter	50
42 inches diameter	16,244
30 inches diameter	4,313
24 inches diameter	34,564
20 inches diameter	406
16 inches diameter	1,510
12 inches diameter	2,050
10 inches diameter	49,302
8 inches diameter	63,586
6 inches diameter	175,985
4 inches diameter	243,170
3 inches diameter	34,238

Iron pipe laid in the year 1879:

	Linear feet.
10 inches diameter	1,839
8 inches diameter	4,773
6 inches diameter	20,439
4 inches diameter	15,980
3 inches diameter	7,802
Total feet	50,833

Equal to $9\frac{3153}{5280}$ miles.

Connected with these systems of wood and iron pipe there were, in 1880, 746 hydrants, of which 605 were Matthews' patent, the rest being plain wooden-box hydrants. In addition to these there are 5 other reservoirs, 167 large wooden tanks, and 141 smaller ones, making a total of 313 tanks.

There are about 1,200 Flower's patent stop-valves. The iron mains are laid 5 feet below the street-surface.

About 25,000 water-takers on the register consume an average of 16,000,000 gallons per day, at the meter-rates of 1 cent per 100 gallons.

The purity of the supply from the old works becoming questionable, owing to contamination by sewage and refuse from manufacturing establishments, the suction-pipe at the old works was extended into the river, and most of the water is pumped from the new works. The following analyses are of water from the river at various points, by A. B. Lyons, chemist, of Detroit:

Analyses of samples of water taken from Detroit river at various points.

[Parts to 1,000,000 parts of water.]

Where obtained.	Date.	Condition of water.	Free ammonia.	Albuminoid ammonia.	Chlorine.	Alkalinity estimated as carbonate of lime.	Condition of weather.
	1879.						
In river, American channel, at mouth of inlet-pipe	Aug. 25	Turbid	0.053	0.120	2.1 }		{ Strong S. W. wind.
In basin, nearest pumping-works	Aug. 25	Somewhat turbid	0.055	0.125	.... }	88	{ Weather dry. Temp. of air, 72° F. (nearly).
In basin, near bulkhead	Aug. 25	Pretty clear	0.056	0.125	.... }		{ Temp. of water, 71° F.
From hydrant, Stearns' drug store	Aug. 28	Slight sediment	0.045	0.120	2.1	88	
In basin, near pump-works	Sept. 1	......do	0.042	0.110	....	89	{ Air calm, smoky.
In basin, near inflow end of inlet-pipe	Sept. 1	......do	0.043	0.110	....	....	{ Weather very dry.
From hydrant at Stearn's drug store	Sept. 3	......do	0.045	0.110	....	....	{ Temp. of air, 82 F°.
In river, in middle Canadian channel, Belle Isle	Sept. 5	Moderate sediment	0.226	0.121	....	86	{ Just after a heavy rain. Temp. of air, 67° F.
From hydrant, Stearns' drug store	Sept. 6	Slight sediment	0.205	0.125	....	....	
Do	Sept. 8	......do	0.210	0.131	....	....	
In river, middle American channel, water-works	Sept. 16	Moderate sediment	0.065	0.142	....	88	{ Weather showery. Wind westerly.
In river, middle Canadian channel, Belle Isle	Sept. 16	......do	0.058	0.148	....	....	{ Temp. of air, 72° F.
Off Clark's dry dock, below city	Sept. 15	......do	0.075	0.175	2.5	....	
Foot of Twenty-second street, inshore, still water	Sept. 15	Clear	0.071	0.198	....	....	

Small as is the quantity of chlorine at present found in the river-water, it is considerably greater than it was a few years ago.

The following table shows the inorganic constituents of water of Detroit river, as taken from the hydrant, September 10, 1879:

Constituents.	Parts per 1,000,000.	Grains in wine-gallons.
Potassium sulphate	Trace.	Trace.
Sodium, chloride (salt)	3.93	0.229
Sodium, carbonate	5.75	0.394
Magnesium carbonate	20.73	1.209
Calcium carbonate	57.40	3.353
Calcium sulphate	17.80	1.048
Alumina	4.13	0.241
Ferrous carbonate (iron)	Trace.	Trace.
Silica	5.24	0.306
Total solids	115.16	6.775

These results compare favorably with those from Boston water.

The original cost of the works is difficult to ascertain, as they have been frequently changed and rebuilt. The total cost to the city amounts to $2,665,000 to October, 1880, and will amount to $2,915,000 to complete them as projected. Below is given an itemized statement of the cost of the new works up to January 1, 1878, and such as can be derived from sources of information at command up to 1880:

Items.	1874.	1875.	1876.	1877.	Total.	1879.
Land	$35,000 00	....	....	....	$35,000 00	$601 00
Force-mains	....	$138,211 37	$137,322 67	....	275,534 04	32,850 14
Inlet-pipe	....	10,469 05	5,675 40	$2,960 08	25,104 53	....
Docks, basin, and canal	....	63,706 50	40,344 63	1,168 92	105,220 05	66 67
Conduit and conduit-well	....	....	8,023 81	3,160 98	11,184 79	52 00
Engine-, boiler-, and coal-houses	....	....	58,464 28	41,351 87	99,816 15	391 34
Stand-pipe and tower	....	....	7,057 72	22,746 43	29,804 15	16 32
Pump-wells	....	22,209 53	12,482 29	420 65	35,112 47	396 80
Engine	....	55,935 51	43,850 46	2,341 51	102,127 48	44,385 45
Boilers	....	....	15,335 41	5,063 80	20,399 21	124 65
Engineer's house	....	....	....	3,009 99	3,009 99	49 50
Sewer	....	....	3,587 69	33 24	3,620 93	386 65
Grounds	500 00	689 98	3,257 14	11,354 50	15,801 62	3,233 51
Inspection	....	728 25	801 31	708 52	2,207 88	....
Miscellaneous	1,781 88	1,052 91	229 87	528 53	3,593 19	750 00
Wood, pipe, and sundries	....	....	....	....	....	1,905 00
Total	37,281 88	298,994 10	336,492 68	94,857 82	767,626 48	84,728 62
Grand total	....	....	....	....	....	852,355 10

The expenditures on construction in 1878 amounted to perhaps $90,000, making a total to date of about $942,454, while the bonded indebtedness of the water board is $1,451,000 up to 1880.

The operating expenses for 1879 were $40,809. The receipts in the same time amounted to $106,045.

Meters are but little used as yet. The new works were designed by D. Farrand Henry, C. E., and the present works are under the control of Chauncy Hurlbut, president, and Henry Starkey, secretary, of the water board.

CHICAGO, ILLINOIS.

Chicago contains a population of 503,185, and is situated on the southwest shore of lake Michigan, at an elevation of only 12 feet above its level. The site of the city is so level that the greatest elevation at any point is but 23 feet.

Water was first introduced in 1840 by a private corporation, and was derived from the lake. In the present water-works the old means of taking water from the lake have been discarded, and a tunnel under the bed of the lake brings water to the pumping-station from a crib placed 2 miles out in the lake.

This tunnel was begun in 1864, and completed, under the direction of E. A. Chesbrough, C. E., in 1867. The pier and crib contain a vertical shaft provided with three gates at different depths. It is connected with the shore—at which is another shaft—by the tunnel, excavated 30 feet below the lake bottom, 5 feet wide by 5 feet 2 inches high, and lined with brick. The excavation was chiefly through clay, and the cost of it, when completed, was nearly $500,000. A second tunnel, of 7 feet diameter, and located 46 feet from the first, was completed in 1874. It runs parallel with the first, and is connected with it at the lake end by means of a cross-tunnel at the crib, and after entering the old or North Side pump-well it extends through the city 4 miles, passing under the Chicago river and entering the well of the West Side pumping-station, which is 44 by 10 feet, built of dressed stone.

The old pump-well is 21 feet deep, and, being sunk in quicksand, was built with a curb of brick 31½ feet in diameter and 2¾ feet wide at the bottom, resting in a shoe of iron 2½ feet deep, having a sharp edge below and sunk by its own weight after the removal of the material below. The bottom is of oak planking in two courses, each 3 inches thick and covered with 10-inch pine timbers with concrete between them. On this was laid a layer of 3-inch oak planking, and the whole is covered with 9 inches of concrete.

Above this were built the engines, of 18,000,000 gallons capacity. They have two cylinders 44 inches diameter each, with 96 inches stroke; pumps double-acting, and 28 inches diameter beneath the steam-cylinders. They are condensing coupled beam-engines, and pump into a stand-pipe of wrought iron 36 inches diameter and 138 feet high, inclosed in a tower 154 feet high, octagonal in form, and built of stone.

There are two other vertical beam-engines, designed by D. C. Cregier, and built in 1871. They are of 18,000,000 gallons capacity each.

At the West Side works there are two condensing compound beam-engines with high-pressure cylinders, 48 inches diameter by 72 inches stroke. Low-pressure, 70 inches diameter and stroke 120 inches.

The pumps, located beneath the low-pressure cylinders, are of the bucket-and-plunger pattern, the latter being 36 inches diameter with 120 inches stroke, and the chamber being 31 inches diameter. These engines deliver water into a wrought-iron stand-pipe 5 feet diameter by 167 feet high, inclosed in a stone tower 190 feet high. The engines were built in 1876.

In connection with the original water-works there were some small reservoirs built, which are now totally useless, and water is no longer forced into them.

The distribution consists of 450 miles of cast-iron pipe, none less than 6-inch being laid. The consumption amounts to about 57,500,000 gallons per day, but occasionally reaches 75,000,000 gallons. The capacity of the works is 100,000,000 gallons per day.

There are about 62,000 services in this system and 2,000 meters, the majority of which are of Worthington's make, with some "Gem" and "Ball & Fitts".

The total cost of the entire works up to 1880 was $8,645,000, and the revenue to the same date, $10,334,600.

The works are in charge of the city engineer, Mr. D. C. Cregier.

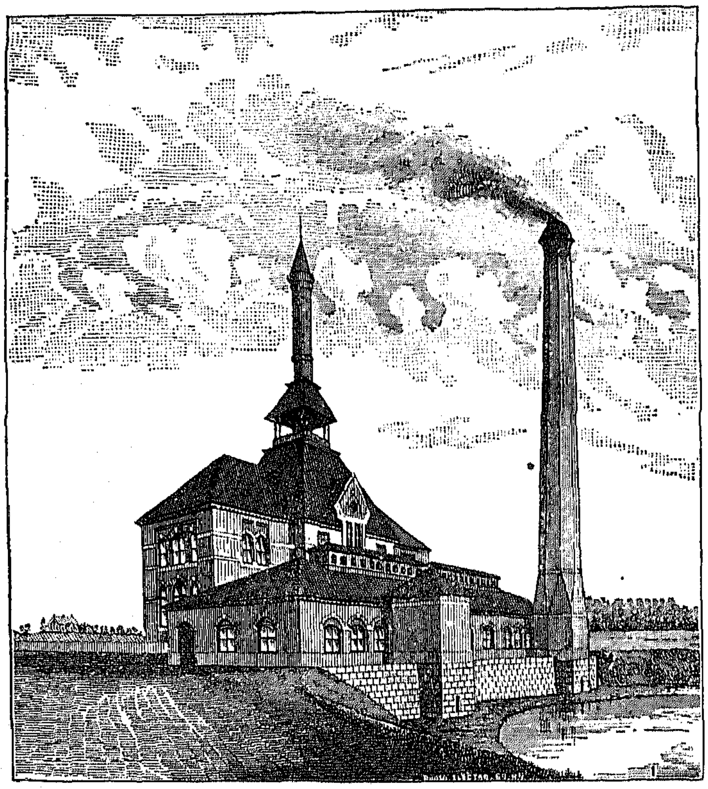
The Chicago works have formed the subject of elaborate reports, which can be found in almost any of the public libraries. They have therefore been but briefly treated here.

4.—PUMPING THROUGH STAND-PIPE—SURPLUS TO RESERVOIRS.

PROVIDENCE, RHODE ISLAND.

This city contains a population of 104,857, and is situated at the head of Narragansett bay, on Providence river. Its streets are laid out with great irregularity. Topographically it is also very irregular, some parts of it being elevated over 100 feet above the rest in the length of a few blocks.

The water-works were begun in 1870, under a resolution of the city council, and were completed in November, 1871. They have always been under municipal control. The system in use is pumping to a distributing reservoir, the water being derived from the Pawtuxet river, near the village of Pontiac, about 6 miles from the heart of the city. This point is known as the Pettaconsett pumping-station, and the main works are located there. The drainage area of the Pawtuxet river is a little over 192 square miles. At the pumping-station the Pawtuxet amounts to a considerable stream, from 15 to 20 feet deep, with a velocity of about 1 mile per hour. The width is perhaps 90 feet. The principal part of its bed is gravel and sand, the water being of fine quality.

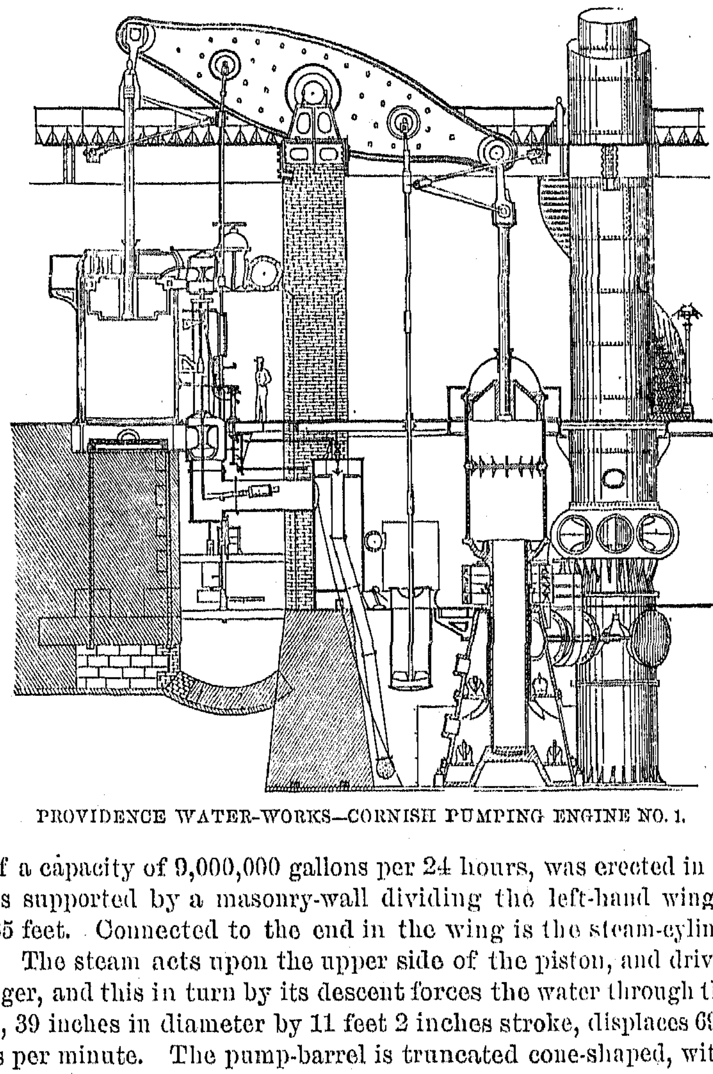


MAIN PUMPING-WORKS, PROVIDENCE, R. I.

At Pettaconsett station there are two distinct pumping-houses, one containing the permanent engines, and the other known as the "temporary works." The latter consist of a low wooden building on the bank of the river, containing a single Worthington engine, with two boilers attached. It was erected in 1871, and supplied all of the water used until the completion of the Cornish engine. The diameter of the pump-plungers in the Worthington duplex is 22 inches; stroke, 47 inches. It is a condensing compound engine, the diameter of the high-pressure cylinder being 20 inches, and of the low-pressure, 36 inches.

The capacity is 5,000,000 gallons per 24 hours. Actual duty, 56,000,000 foot-pounds, and it pumps about 21 hours per day at present. Its guaranteed duty was 50,575,000 foot-pounds. The two boilers used in connection with it are horizontal multitubular, 5 feet in diameter by 17 feet long, making steam under an ordinary pressure of 63 pounds. No experiments have been made to determine their evaporative power.

The permanent works are located a few hundred feet farther from the banks of the river, and consist of an engine-house of granite, iron, and brick, as shown in the accompanying view, 129 feet by 56 feet, with 44-foot wings; a boiler-house 179 by 55 feet, with a repair- or machine-shop of 123 by 70 feet dimensions. Height of engine-house 49 feet, and of boiler-house 13½ feet. Only one chimney has as yet been constructed, and, although there is space for four engines of the Cornish pattern, there is but one erected. The stand-pipe may be seen rising through the center of the roof to the height of 185 feet. It is of boiler-iron, resting on a cylindrical casting 7½ feet diameter, 9 feet high, and 2 inches thick. Upon this base rests the inlet casting, 7 feet diameter, 8 feet high, and from 2½ to 3 inches thick. In this are four inlets 42 inches diameter each (only one being used). Upon this is a reducer 7 feet diameter at base, 3 feet 9 inches high, by 5 feet 6 inches diameter at top. Upon this the casting rests, containing three outlets 36 inches diameter each (two being in use). It is 4 feet 9 inches high by 2½ to 4½ inches thick. To its top the outer shell of the stand-pipe, 8 feet diameter, is fastened. The inner shell, 5 feet 6 inches diameter, is secured to the flange of a circular opening in the bottom. The inner shell is 184 feet and the outer 189 feet high. The latter is ½ inch thick at bottom to a height of 54 feet, ⅜ inch thick for the next 56 feet, the remaining height being ¼ inch thick. A brass and composition check-valve, 12 inches diameter, is placed in the interior pipe.



PROVIDENCE WATER-WORKS—CORNISH PUMPING ENGINE NO. 1.

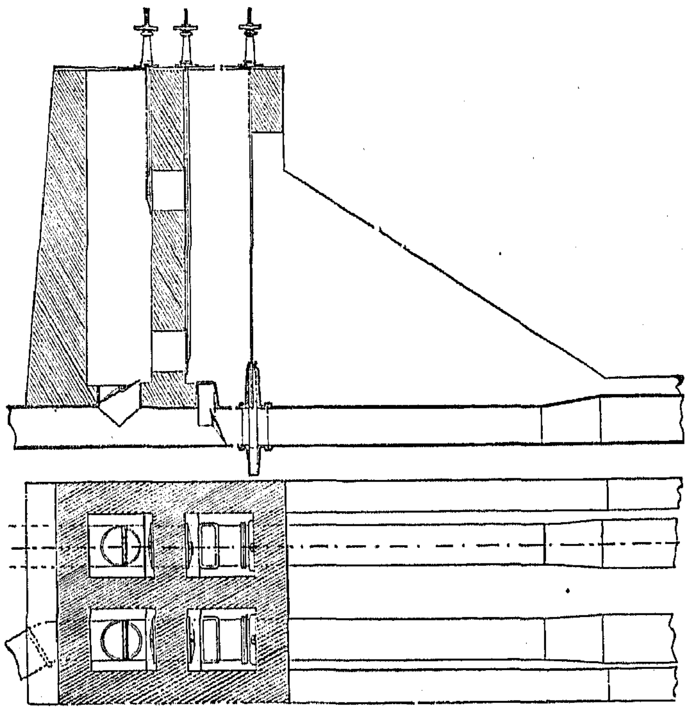
The Cornish engine, of a capacity of 9,000,000 gallons per 24 hours, was erected in 1876. The beam, weighing 60 tons, rotates on an axis supported by a masonry-wall dividing the left-hand wing of the building from the main part; total length, 35 feet. Connected to the end in the wing is the steam-cylinder, 100 inches in diameter by 11 feet 2 inches stroke. The steam acts upon the upper side of the piston, and driving it down raises a weight attached to the pump-plunger, and this in turn by its descent forces the water through the mains into the reservoir. The pump-plunger is plain, 39 inches in diameter by 11 feet 2 inches stroke, displaces 695 gallons per stroke, and is run at about 6 to 7 strokes per minute. The pump-barrel is truncated cone-shaped, with the suction and delivery valves arranged about the plunger in a circle, the latter above the former. There are 12 suction- and 9 delivery-valves. They are double-beat puppet, 16 inches in diameter, with a maximum lift of 1⅝ inch. The discharge-pipe empties into the foot of the stand-pipe through one of the four openings therein, the other three being closed until the remaining engines are placed.

The air-pump is 40 inches in diameter, with 5 feet 5 inches stroke, and the spray-condenser 4 feet 5 inches diameter by 11 feet 10½ inches long. The duty of this engine was guaranteed at 65,000,000 foot-pounds, but by actual trial a duty of 90,000,000 foot-pounds has been obtained.

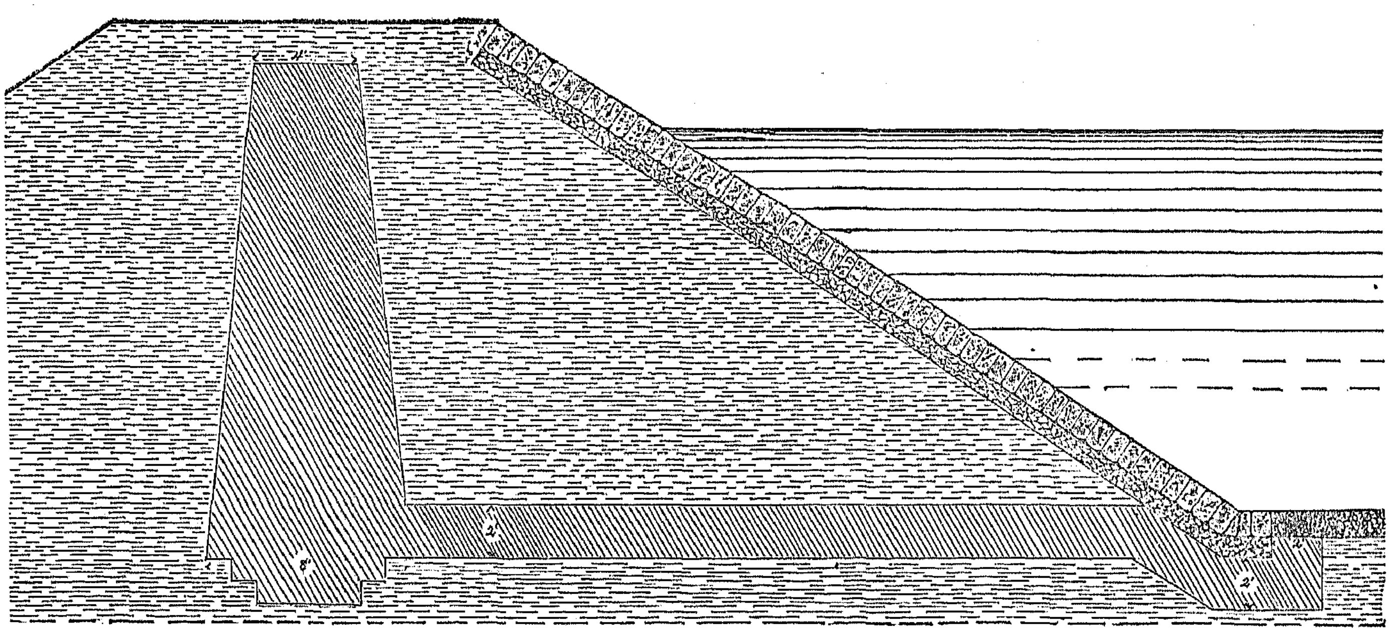
The boiler-house contains a battery of five Lancashire boilers, 7 feet in diameter by 28 feet long, each containing two flues, and run at a pressure of 40 pounds per square inch. Their average evaporative power is 8 pounds of water to 1 pound of anthracite coal.

There is room in the pumping-station for the erection of three more Cornish engines similar to the one already in position, and sixteen boilers—eleven besides those at present used.

From the engine-house two iron force-mains, 36 inches diameter, convey the water into Sockanosset reservoir, 1 mile north. The exact length of these two parallel mains is 10,084 feet, and the pressure at the pumps is due to



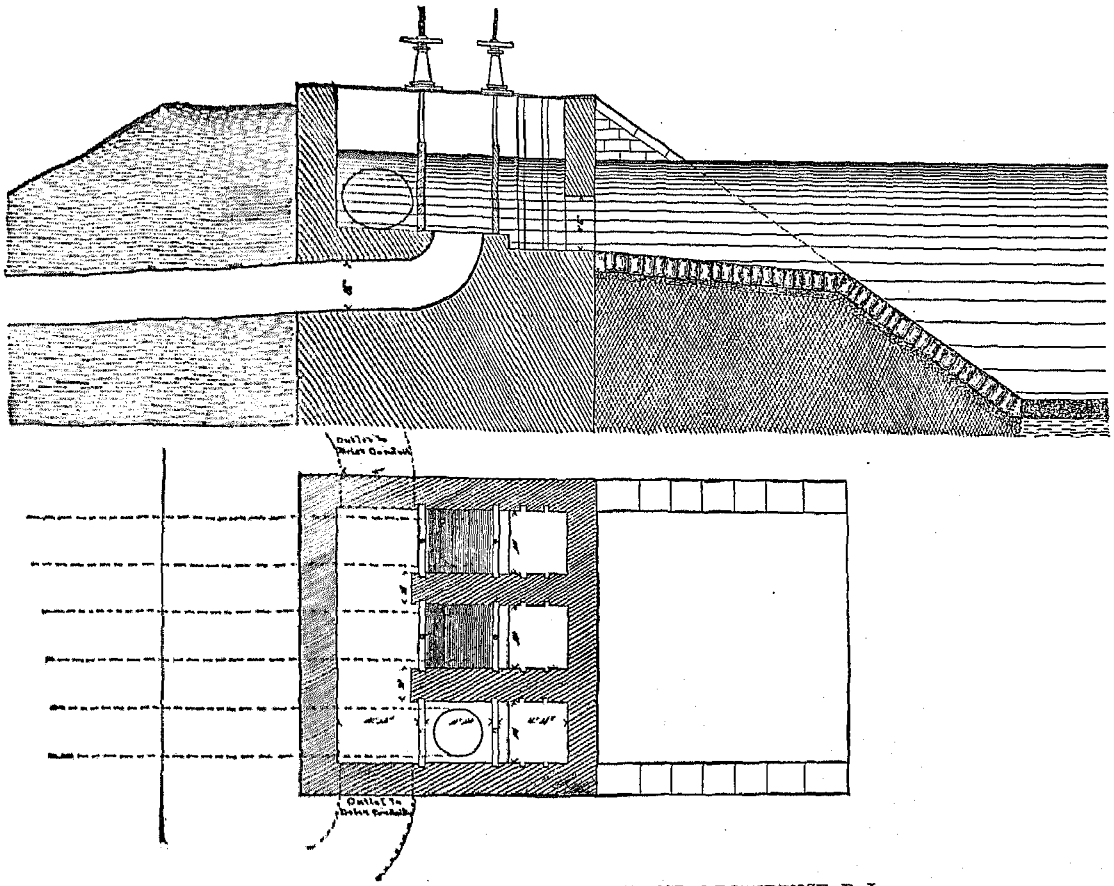
a head of 180 feet. They enter the reservoir at the inlet-chamber on the southern bank. This chamber is shown in the diagram annexed. By adjustable gates, arranged as seen, the water can enter the reservoir direct, or can be discharged backward into the brick conduit connecting the inlet- and outlet-chambers without passing through the reservoir. The reservoir in plan has the shape of a pear, owing to peculiarities in the ground. It is 1,000 feet long



RESERVOIR AT PROVIDENCE, R. I.

by 860 feet wide at the base, with a water-surface of 10.9467 acres when full and a bottom area of 9.5383 acres. Slope of banks, 1½ to 1 inside and out; width of banks at top, 15 feet; depth from level of banks, 19 feet. The sides are entirely in embankment, with a puddle priming-wall 4 feet thick at top and 8 feet thick at bottom, as shown in the annexed diagram.

The outlet-chamber on the northern bank is connected with the inlet-chamber by a brick conduit 900 feet long and 4 feet in diameter, passing around the embankment outside of the puddle-wall, by which the water may be supplied directly to the mains without entering the reservoir. The inlet- and *outlet-chambers have three* compartments each, as shown. In the former the 36-inch force-mains from Pettaconsett, passing through the embankment, terminate in separate compartments, so that the water can be sent into the reservoir or direct into the 900-foot conduit above mentioned. From the similar compartments in the outlet-chamber the 30-inch pipe-mains



OUTLET-CHAMBER OF RESERVOIR, PROVIDENCE, R. I.

to the city pass through the banks. They are parallel, two in number, and of a total length of 59,076 feet. In the city, at Mathewson street, one diminishes to 24 inches diameter, crosses the river under Exchange Place bridge on iron piles, and terminates at Hope reservoir and the Hope engines. At Dorrance street the other 30-inch main diminishes to 24 inches, and crosses under Great bridge on iron piles; at Waterman street a 30-inch branch connects it with Hope reservoir.

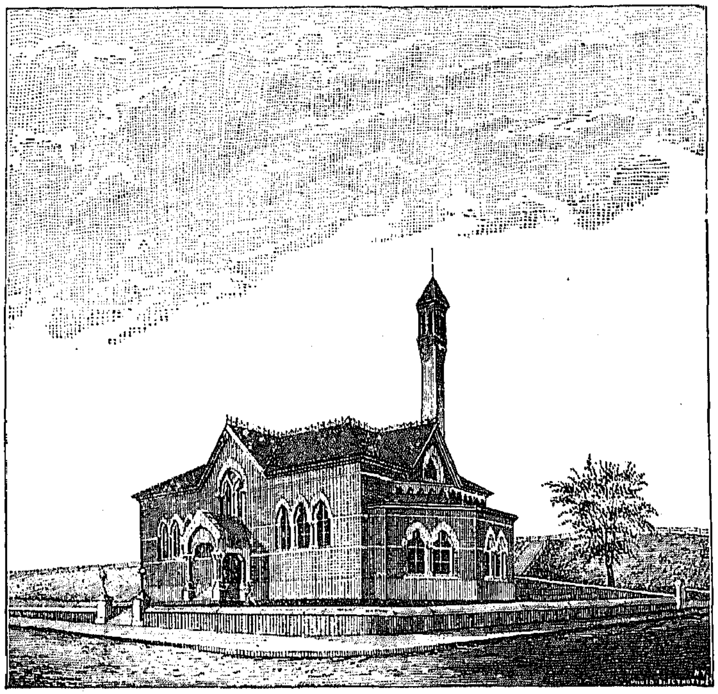
Hope reservoir, located in the city limits, on Olney street, is irregular in outline, 950 feet long, 840 feet wide, and 24½ feet deep. Area of reservoir bottom, 10.6 acres; area of high-water surface, 12.6 acres; area covered by embankments, 5 acres. Elevation at high water above mean high tide in Providence river, 162.5 feet; capacity, 76,000,000 gallons. The banks have a puddle-wall 4 feet thick at top and 8 feet at bottom, with section exactly similar to that of Sockanosset, as shown, and are 15 feet wide at the top. Slope, 1½ to 1 inside and out. The inner face of the banks is riprapped with granite blocks from 12 to 14 inches thick. The main from Sockanosset reservoir enters Hope reservoir at the bottom, near the center. The water leaves it through two chambers in the embankment, one at the northerly and one at the southerly side. These gate-chambers are provided with gates, by which water may be drawn from top or bottom.

An overflow waste-way is constructed at the northeast corner of the reservoir. The force-main, during the inactivity of the engine or diminution of pressure from it, acts, by means of the automatic valves, as a supply-main, the gate at top or bottom being opened.

Hope reservoir, as before stated, receives its supply by gravity from Sockanosset reservoir with an elevation of 18 feet above high-water mark in the former. From one of the mains entering Hope reservoir the high-service pumping-engines at "Hope Station" take their supply and force it direct into the distribution mains of the higher levels. The engine-house is of brick, with granite trimmings, as shown in the annexed illustration. The coal is stored in vaults at the rear. The engine-house is 73 by 50 feet, with a boiler-room in the rear 27 by 45 feet. It contains two high-service engines, automatically adjusting themselves to the pressure, varying at different times in the day. One, erected by George H. Corliss, in 1873, is of peculiar pattern. The other was designed by

Mr. A. F. Nagle, and built by the Providence Steam Engine Company, in 1876. It might be well here to say that, although not well constructed as to strength, the Nagle engine has shown a high duty and has done efficient service. The peculiar nature of the service required of these two engines renders it difficult to obtain a fair duty trial of either, as the head or pressure against which they pump is ever varying.

The Corliss engine, of 5,000,000 gallons daily capacity, consists of five individual pump cylinders, arranged around a common center, with a steam-cylinder between each two, or ten cylinders in all. The connecting-rods from the pistons of both the steam- and pump-cylinders are fastened to a movable horizontal disk of steel, at the center of the circle formed by the arrangement of cylinders, as shown. One complete circuit by this disk represents a total discharge of 135.42 gallons. The pump-plungers are 12 inches diameter by 30 inches stroke, plain pistons.



HOPE STATION.

The water-valves are made up of a large number of leather disks, 4 inches diameter, placed side by side on a steel rod, making a sort of leather rod, 4 inches diameter and 16 inches long, fitting into a semi-cylindrical cavity or seat and closing itself by gravity after the passage of the water. The valve-chambers, two for inlet and two for discharge, are seen above and below the pump-cylinders. The steam-cylinders are 20 inches diameter by 30 inches stroke, condensing the steam in a circular-pipe condenser, 50 feet long and 12 inches diameter, extending almost completely around the central pit. This 12-inch pipe contains within it another of 3 inches diameter, carrying the cold water. The air-pump, with a diameter of 23 inches and a stroke of 8 inches, is located in a pit on the left of the engine.

This pump underwent in 1874 a severe duty trial, and was found to work favorably at a speed of a quarter of a revolution per minute, and was tested to a velocity of 27 per minute. It draws the water from the low-service mains, as mentioned, under a back pressure of about 40 feet, and the average height to which the engine pumps (calculated from the average pressure) amounts to about 80 feet. The duration of the test was 48½ hours.

Average height pumped .... feet..	88.2882
Average number of gallons raised per minute	1,424.7
Average number of gallons raised per hour	85,482
Total number of gallons raised during run	4,145,877
Number of gallons raised at same rate per 24 hours	2,051,568
Full capacity of pump first 24 hours .... gallons..	2,064,535
Percentage of lost action of pump	3.36
Number of gallons actually raised first 24 hours (deducting for lost action of pump)	1,982,635
Coal consumed per minute .... pounds..	4.02
Total coal consumed .... do	11,700
Ashes dropped .... do	1,028
Number of gallons raised per pound of coal (full contents of pump)	354.4
Actual number of gallons raised per pound of coal	342.49
Cost of coal per annum	$7,352
Length of stroke .... inches..	30
Revolutions per minute (average)	10.167

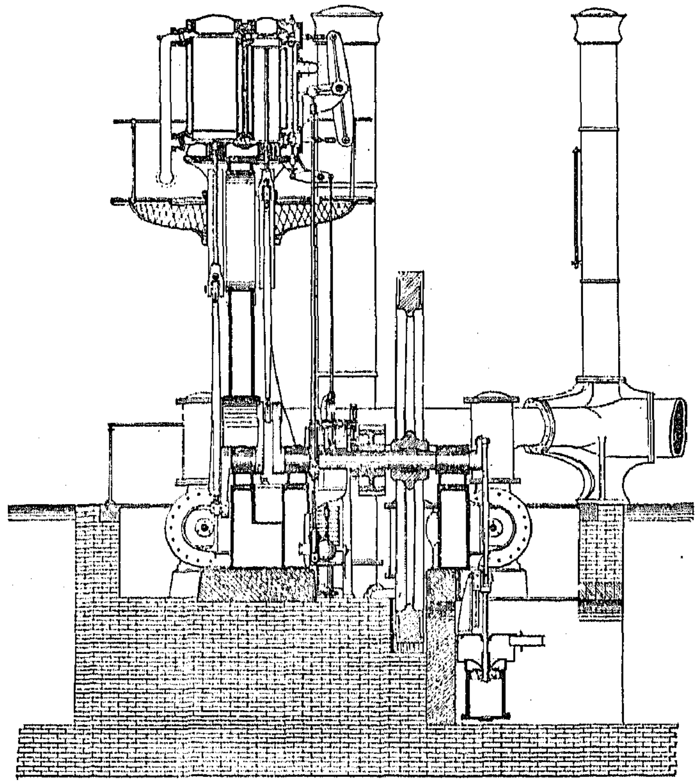
Temperature of water	degrees..	41
Weight of one gallon at 41°	pounds..	8.326
Duty, calculating resistances	foot-pounds..	25,865,740
Duty, actual water delivered at 41°	do....	25,176,384

During this duty trial there was, at the higher velocities, considerable noise from lost motion in connecting-rods, etc., and a visible expansion and contraction of the flat surface of the sides of the pump at each alternation of the pistons.

The actual daily duty of the engine is given by the engineers at about 15,400,000 foot-pounds.

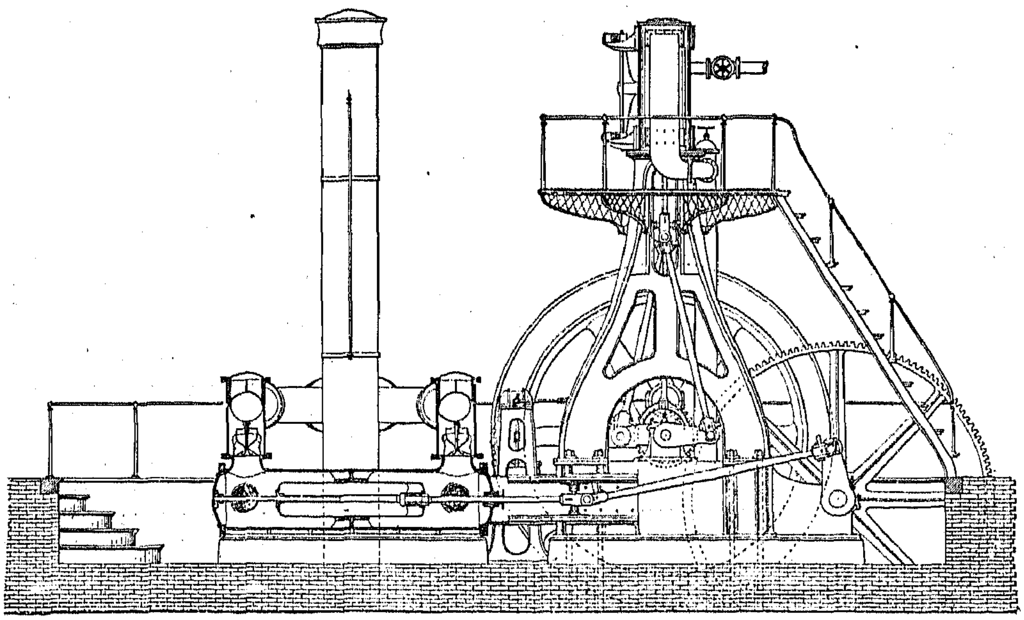
Steam is supplied from a single upright multitubular boiler, 7½ feet in diameter by 21 feet high, with 248 2-inch tubes, 10 feet long, arranged around a central hollow, used as a manhole or waterleg. The average pressure is 50 pounds; horse-power, 140; evaporation, 8 pounds water to 1 pound coal.

The Nagle engine, erected in 1876, is shown in the elevation and sections accompanying.



SECTIONAL ELEVATION THROUGH CENTER OF CYLINDERS.

It is a geared compound-condensing engine, with two horizontal double-acting pumps receiving their plunger motion as shown.



NAGLE ENGINE.

The diameter of the plungers is 17 inches; stroke, 8 inches; total capacity of engine, 5,000,000 gallons per day, with a displacement of $184\frac{1}{2}$ gallons per revolution. Diameter of pump-barrel, 24 inches. This engine is also self-regulating to the pressure. The pump-valves, eight in number, four to each pump, two suction and two discharge, are brass double-beat puppet-valves, 1 foot 3 inches diameter. An air-chamber is connected with both the suction and discharge mains, as seen in the cut.

The engine has two cylinders, vertically placed—the high-pressure, 11 inches diameter by 42 inches stroke, and the low-pressure, 19 inches diameter with same stroke, the crank being opposite. The steam-valves are of the flat gridiron slide type, operated by sliding cams connected with the rocking levers seen in the cut at top. The condenser is a column-pipe, 22 feet by 10 inches diameter, with an interior pipe carrying the cold water. The exhaust-ports connect with the main or column pipe at a point $6\frac{1}{2}$ feet above the top of the cold-water pipe within, and the fall of the water over the top of the cold-water pipe carries the steam with it to the foot, condensing it. The air-pump is 15 inches diameter by 18 inches stroke, of the drop-bucket variety, and can be seen in the sectional elevation.

The duty-trial made in December, 1875, showed that the engine was capable of pumping easily 5,106,805 gallons per 24 hours under a head of $125\frac{1}{4}$ feet. It actually pumped 2,000,000 gallons per 24 hours, giving a duty of 84,637,245 foot-pounds for a run of 56 hours. The makers claim 100,000,000 for it if pumping into a reservoir only.

The two boilers supplying steam to this engine are multitubular return-flue, of 12 feet length by $5\frac{1}{2}$ feet diameter of shell, containing fifty-two 3-inch tubes in each, and generating steam at a pressure of 70 pounds.

The Nagle and the Corliss engines are run alternately for about one month at a time.

A system of 30-, 24-, 20-, 16-, 12-, 10-, 8-, and 6-inch pipes of cast iron, with a total length of 155.158 miles, serves to distribute the water through the city to 9,691 water-takers.

The total number of gallons consumed per day averaged 3,110,000 for the year 1879, the maximum being 3,782,000, and the minimum 2,384,000 per day.

About 1,137 fire-hydrants are in use.

Providence has probably had more experience with water-meters than any other city in the country, having tried almost every variety made. The system of testing them in vogue is the most accurate that came under my observation. The accompanying schedule shows the number in actual use in March, 1880:

Kind.	Sizes.							Total.
	$\frac{5}{8}$ inch.	$\frac{3}{4}$ inch.	1 inch.	$1\frac{1}{2}$ inch.	2 inches.	3 inches.	4 inches.	
Ball & Fitts, piston	2,584	403	125	47	8	1	......	3,258
Ball & Fitts, rotary	....	......	13	14	2	5	3	37
Worthington	164	......	......	......	......	......	1	165
Fales, Jenks & Sons	323	214	22	3	11	......	3	576
Total	3,071	707	160	64	21	6	7	4,036

The annual cost of maintenance and repairs, exclusive of interest, is about $74,000. The total cost to date of January, 1880, was $5,442,179. The cost of construction is given in detail in the accompanying statement:

Hope reservoir:	
For land	$117,823 88
For sundries	1,813 60
For labor	6,828 65
For gate-chambers	11,567 48
For gate-houses	3,224 00
For drain	1,947 31
For inspection	8,614 26
For conduit	3,746 18
For slope-wall	43,127 81
For steps	3,103 33
For iron railing	1,418 81
For fence	1,482 18
For improvement of grounds	5,418 28
Hope engine-house	105,462 20
Sockanosset reservoir:	
For construction	177,870 72
For sundries	124 45
For land	14,305 36
For gate-houses	18,641 95
For drain	3,506 01
For inspection	6,819 18
For extra work and materials	189 70
For gate-chambers	19,299 27
Sockanosset reservoir—Continued.	
For improvement of grounds	$13,613 13
For steps	3,235 94
Lincoln reservoir, for land	2,946 54
Line of leading mains:	
For labor and materials	19,950 30
For extra trenching, etc	472 45
For land and damages	1,665 00
Force-main line:	
For land and damages	3,006 35
For labor and materials	6,505 29
For extra trenching, etc	332 56
Office furniture, stoves, gas-fixtures, etc	1,309 95
Rent of offices	2,875 00
Books, stationery, etc	667 59
Fuel and lights	225 10
Horse-hire by commissioners	19 00
Traveling expenses of commissioners	161 92
Janitor of rooms	484 51
Commissioners' salaries	22,042 18
Secretary's salary	2,855 52
Clerks' salaries	4,136 53
Sundries	502 49
Printing	2,275 40

Advertising	$1,935 38
Fences	2,075 38
Rent of wharves and pipe-yards	7,192 78
Stop-valves	74,504 18
Linking curved pipes	232 75
Store-house and work-shop	1,209 64
Tools	11,321 84
Labor on pipes	15,965 80
Cast-iron water-pipes	1,332,967 10
Special castings	103,538 79
Lumber	1,576 30
Fire-hydrants	107,540 46
Sockanosset Hill cross-road	3,855 38
Telegraph lines	2,262 17
Dwelling-houses at Pettaconsett	10,080 63
Culverts and bridge on line of force-mains	6,775 33
Culverts at Pettaconsett	3,557 92
Real estate in Warwick	11,385 86
Water privileges, mill, and other real estate in Pawtuxet	45,557 65
Pettaconsett pumping-station, for land	25,902 41
Pochasset bridge	5,559 82
Wharf salaries	11,624 46
Temporary engine-house at Pettaconsett	9,824 87
Roads, slopes, etc., at Pettaconsett	12,055 30
Engine-house at Pettaconsett	310,570 51
Natural filter-basin	41,518 35
Removing loam	462 95
Iron screw-piles	3,766 46
Hydrant-bolts	1,940 78
Pipe-bolts	1,933 70
Photographs	328 25
Hydrant-heads	7,511 51
Taps and stops	19,239 83
Valve-covers	9,370 72
Service-pipe	50,682 43
Hydrant-boxes	30,191 67
Setting fire-hydrants	10,774 48
Check-valves	3,712 48
Valve-boxes	34,550 42
Air-cocks, boxes, covers, and setting	527 02
Setting blow-offs	331 49
Lobdell & Newmans	188,025 00
A. & W. Sprague Manufacturing Company	2,500 00
Samuel M. Gray	300 00
Paulding, Kemble & Co	109,265 54
Thomas Phillips & Co	4,283 84
James Glass	4,495 26
Providence Steam-Engine Company	47,062 91
Rhode Island Locomotive Works	30,145 71
Architectural Iron Works	30,520 35
French, Mackenzie & Co	3,150 00
Wenscott Reservoir Company	44 45
Akron Sewer-pipe Association	5 25
Sewer department, salaries and office expenses	709 68
City treasurer	282,012 39
City treasurer, for water payments	545,374 12
Testing pipe iron	443 50
Iron drain-pipes and gate	224 21
Carting pipes	$40,301 87
Counsel fees	5,500 00
Inspection of pipes	10,312 23
Testing bolts and composition castings	34 25
Laying water-pipes	406,226 18
Laying service-pipes	32,549 24
Laying suction-pipe, etc	85 00
Drainage pump and engine	5,110 72
Hydrants for street-sprinklers, etc	2,639 50
Inspection of pipe-laying	33,968 14
Temporary boarding-house at Pettaconsett	1,433 23
Public drinking fountains and troughs	3,701 29
Warwick test-pits	1,313 40
Engine-house at Pettaconsett, for drain	2,132 37
Water-meters set, belonging to the city	1,258 72
Worthington pumping-engine	35,522 33
Hope pumping-engine	63,104 67
Cornish pumping-engine	11,545 47
Keeper's house at Sockanosset reservoir	7,088 84
Pipe in river embankment at Pettaconsett	4,067 82
Inspection of engine-work	5,287 08
Alterations at Hope pumping-station for second engine	784 59
Testing second engine at Hope pumping-station	4,779 62
Drain-tiles	489 79
Boilers for Cornish engine	9,449 08
Stand-pipe at Pettaconset	956 89
	4,919,738 13
Engineering department:	
For instruments	3,452 34
Tools	736 87
Furniture, stoves, gas-fixtures, etc	2,893 92
Draughting	3,523 52
Labor	9,945 58
Horse and wagon account	2,814 65
Horse-keeping, shoeing, etc	2,848 94
Horse-hire	5,499 65
Rent of offices	7,081 87
Fuel and lights	749 83
Janitor of rooms	1,308 76
Experimental filter	91 08
Books, stationery, etc	3,619 04
Sundries	3,802 39
Test-wells	1,579 40
Consultations	827 08
Office building at Pettaconsett	567 60
Office building at Sockanosset reservoir	563 22
Stakes and strips	1,318 24
Printing	671 48
Maps	179 17
Service-pipe experiments	296 04
Temporary assistance	11,168 88
Salaries	98,904 50
	164,144 05
Total	5,084,182 18

The annual rainfall at Sockanosset reservoir varies from 45 to 50 inches.

The analysis of Pawtuxet water gives the following results:

	Grains per gallon.
Mineral matter	1.24
Organic matter	1.33
Total solids	2.57

This compares favorably with that of the principal cities in the East.

The water-works are under the general superintendence of Samuel M. Gray, C. E., city engineer, and the direct supervision of his assistant engineer, Mr. E. B. Weston.

5.—PUMPING THROUGH STAND-PIPE TO RESERVOIRS.

NASHVILLE, TENNESSEE.

This city, on the Cumberland river, and on irregular ground, contains a population of 43,350 inhabitants, and is chiefly a commercial city. The manufacturing interests are small. The streets are laid out at right angles to each other. From the river the banks rise sharply to a considerable elevation.

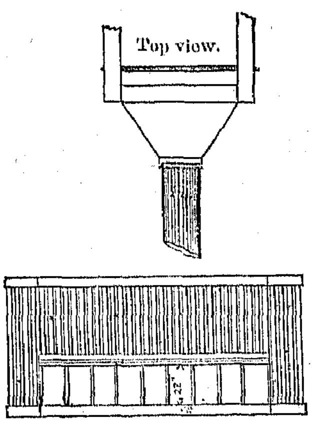
In 1832 a supply of water was introduced from the river by pumping through a stand-pipe into a small distributing reservoir on one of the highest hills in the vicinity, and now included in the city, the works being under municipal control.

The pumping-station is located on the southern river-bank, within the city limits, and derives its supply through 12,000 feet of pipe, 36 inches diameter, from an infiltration gallery located farther up the river, on a low island in the middle.

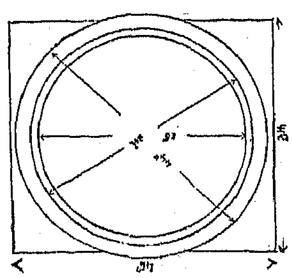
The construction of this gallery is unique. It is 152 feet long, 6 feet high, and 10 feet wide, filled with stones, and is, technically speaking, an infiltration gallery. The island on which it is built is a low-lying strip of sand a few rods in width and 100 acres in extent, and the river-water percolates through its banks into the gallery.

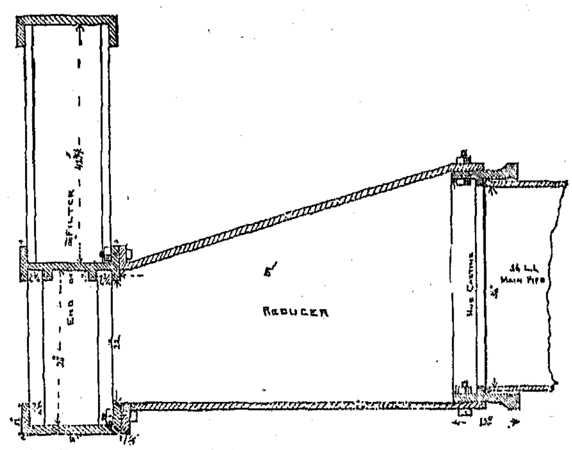
The latter is thus constructed: A couple of 18-inch iron channel-beams are placed vertically one over the other, and united by vertical iron rods placed 2 inches apart and fastened to the flanges of the beams. To prevent longitudinal motion the upper and lower beams are braced with inclined struts, like a truss-bridge. The depth between the upper and lower beams or chords is 6 feet. Another similar construction is placed longitudinally parallel with it in the same trench and 10 feet away. Across the top of the two thus placed, iron rails are put close together, forming a roof to the gallery, the whole of the interior being filled with stones. To prevent the side trusses from being forced together, iron tubes 10 feet long and 2 inches in diameter are placed against the inner flanges of the upper chords and held in place by 13½-foot bolts passing through both flanges of each chord and through the tubes, being fastened at the ends by nuts.

The lower chords are likewise kept apart. The whole construction is 25 feet below the surface of the island. From the lower end of the gallery thus constructed a cast-iron pipe 36 inches diameter is taken as shown in drawing, which extends to the pump-well of the engine-house, 12,000 feet, resting on the river bottom for its whole length.



END VIEW, SHOWING OPENING FOR REDUCER.

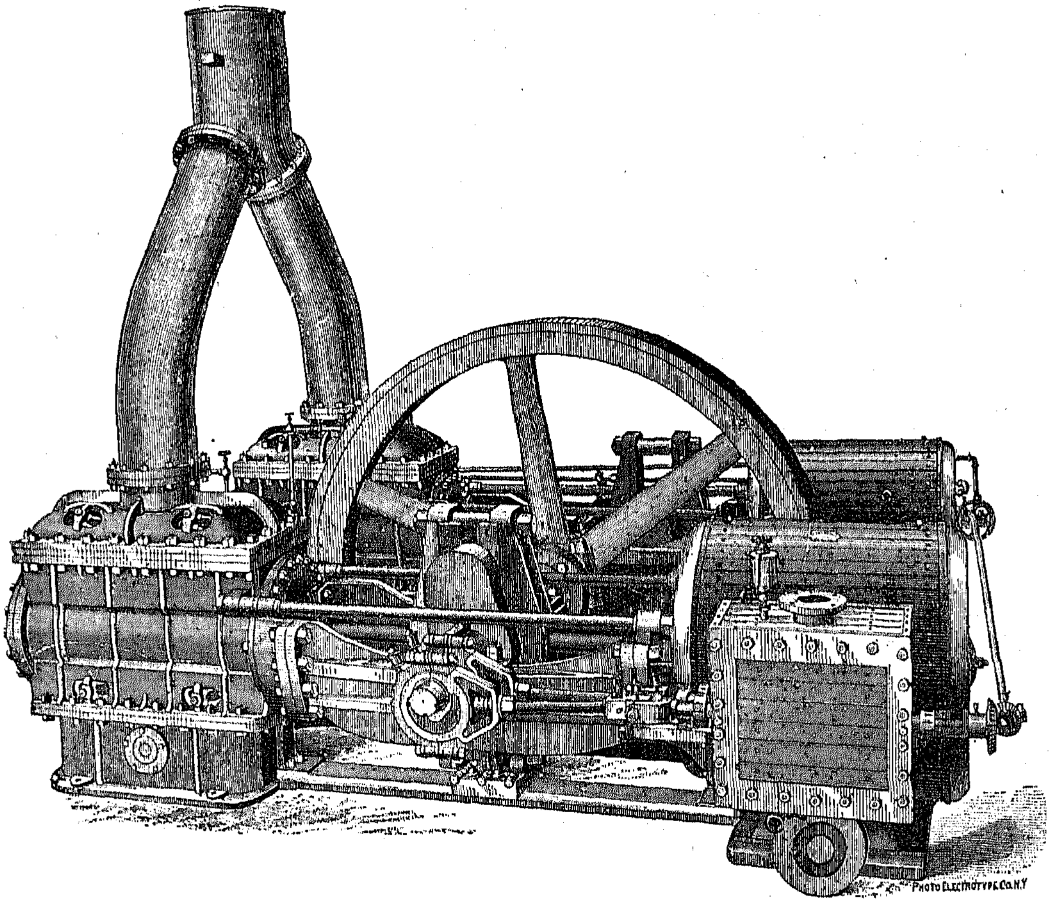

FRONT VIEW OF HUB CASTING.



LONGITUDINAL SECTION THROUGH REDUCER.

The engines are three in number—two of 5,000,000 gallons, Dean duplex, erected in 1877, and one 4,000,000 gallon engine by Nashville Manufacturing Company, in 1854, which is nearly useless. This latter, which is similar to the horizontal engines in the pit of the low-service engine-house at Cincinnati, is a high-pressure single-cylinder engine with steam-cylinder 24 inches in diameter, two pump-cylinders each 13 inches in diameter—stroke of former, 8 feet, of latter, 6 feet; fly-wheel, 24 feet diameter and 12 tons weight; steam-valves of double-beat type. The pumps are vertical, situated in the bottom of a deep pit, and when used run at a speed of 18 revolutions per minute. The pump-valves are circular, 14 inches diameter, free lift, two in inlet and two in outlet; each weighs 78 pounds.

The Dean pumps are condensing duplex, two cylinders to each, 34 inches diameter by 26 inches stroke, operating two plain piston-plungers 18 inches diameter by 26 inches stroke, run at a speed of 30 revolutions per minute, and connected with a jet-condenser 4 feet square. The air-pumps, one to each engine, are 15 inches diameter by 12 inches stroke. Steam is admitted by slide-valves operated by eccentrics. The daily duty of these pumping-engines averages about 40,000,000 foot-pounds, but has been run as high as 63,000,000 on a duty trial with poor soft coal, a duty of 60,000,000 having been guaranteed by the makers. They are placed in the bottom of a deep well, and are shown in the accompanying cut.



DEAN PUMP.

There are eight boilers, in two batteries of four each, 16 feet long by 44 inches in diameter, with thirty-six $3\frac{1}{2}$-inch tubes in each, burning poor bituminous coal, and maintaining an average pressure of 60 pounds for the Dean engines and 90 pounds for the old horizontal engine. Their evaporation is given at $8\frac{1}{4}$ pounds of water to 1 pound of coal. The old engine cost without boilers $57,000, and the two sets of Dean amounted to $26,000. The former is now used only as an auxiliary. From the pump-house the water is forced into the reservoir through 420 feet of 36-inch cast-iron main under a pressure of 119 pounds.

The stand-pipe, which is connected with this main near the reservoir, is a plain cylinder of wrought iron 36 inches diameter, $\frac{3}{16}$-inch thick, and 115 feet high, with one inlet and one outlet 36 inches diameter. The whole is inclosed in a square brick tower 15 feet square at base by 5 feet at top, and cost complete $42,000. By an arrangement of by-pass and valve the water may flow from the stand-pipe into the reservoir or supply-mains direct.

The reservoir is 185 feet square in plan, and is divided into two sections by a masonry wall 3 feet thick. Its upper section is but 11 feet in depth, while the lower is 21 feet. The walls are of masonry, perpendicular on the inner face, sloping 12 vertical to 1 horizontal on the outer face, and 4 feet thick at top; capacity about 2,250,000 gallons. Bottom of clay covered with masonry. There are two effluent-pipes, one from each division, which unite into one supply-main immediately after leaving the reservoir.

There were, in December, 1880, $42\frac{1435}{5280}$ miles of cast-iron distributing mains from 18 inches to 3 inches in diameter, supplying water to 5,000 takers, with a consumption of 3,736,000 gallons per day. Two hundred and five hydrants are in use, of which perhaps fifty are Matthews' patent and the rest are of home manufacture.

The first cost of the works was $100,000, and total to date $1,371,789. The total expenses and receipts from 1832 to 1880, inclusive, interest not included, were, receipts, $1,215,227; expenditures, $1,371,789. The annual expense of maintenance and repairs amounts to about $26,000.

The city engineer, W. F. Forster, has control of the water-works.

LOUISVILLE, KENTUCKY.

Louisville is on the south bank of the Ohio river, 387 miles above its mouth, and contains a population of 123,758. Its interests are commercial and manufacturing. Chief among the latter establishments are distilleries, breweries, tobacco factories, and founderies. The site of the city is a level plain about 70 feet above low water in the river. The streets are very regular.

Under the auspices of a private corporation a water-supply was introduced in 1860 by pumping from the Ohio river at a point about 1½ mile above the city limits. The city, having purchased a large portion of the shares in this corporation, is represented in the management of the works.

The water is taken from the river by a wrought-iron pipe 50 inches in diameter, with its outer end supported in a crib. The latter is rectangular, of timber filled with stone, and is 70 feet long, 32 feet high, by 12½ feet wide. Its end is parallel with the current, and contains the inlet-opening, which is protected by a coarse grating, finer ones being placed in the pump-wells.

The mouth of this inlet is 5 by 12 feet and 1 foot below low-water level. From here the water is conveyed 300 feet to the two pump-wells beneath the engine-house. They are rectangular in plan, of masonry, and 8 by 22 feet by 11 feet deep.

Owing to defective construction of the crib, stoppages occurred from the clogging of this inlet-pipe in 1866, 1874, and 1877; two from the deposition of sediment in the inlet and one from floating leaves.

From the wells the water is pumped into a stand-pipe by two Cornish beam-engines, designed by Theodore R. Scowden in 1860, and built by Roach & Long, of Louisville. A sectional view of them is given in *Knight's Mechanical Dictionary*, p. 1828, and a view of the valve-gearing in front of the cylinders is also shown.

The engines are alike, and have: Diameter of steam-cylinders, 70 inches; stroke, 10 feet; diameter of pump-plunger, 36 inches.

The steam-valves are of the ordinary Cornish double-beat type. There is but one plain plunger to each engine, and one receiving water-valve, of the Harvey & West double-beat pattern. The discharge-valves are of the same pattern but smaller, and 36 in number. The former is 43 inches and 32 inches diameter of seat, with a lift of 1⅜ inch, and the latter are 6 inches, the lift being ⅜ inch.

The engines are run at an ordinary speed of 8 revolutions per minute, and are of 7,500,000 gallons capacity each. The record of their work during 1878 and 1879 is given below:

	1878.	1879.
Number of pumping days	365	363
Average pumping time per day ....hours..	18.23¼	20.06⅝
Total pumping time per year ....do..	6,656.25	7,281.25
Total number of engine- and pump-strokes per year	3,142,395	3,501,198
Average number of strokes per minute	7.87	8.014
Coal consumed ....pounds..	4,739,639	4,964,335
Ashes, cinder, and clinkers ....do...	326,861	383,635
Quantity of water pumped each year ....gallons..	1,649,757,375	1,838,128,950
Average height of water in stand-pipe above low water in river ....feet..	152.00	152.75
Average stage of river above low water ....do ..	6.65	5.57
Average head against pumps ....do..	145.35	147.18
Annual engine duty in pounds of water raised 1 foot high per 100 pounds of coal....	42,269,481	45,449,566

Each pump has a jet-condenser 32 inches in diameter and 9 feet long, with an air-pump 32 inches in diameter by 6½ feet stroke. The total cost of the engines and boilers was $117,000. The daily duty averages about 45,000,000 foot-pounds. There are two batteries of three boilers each, of the old Cornish pattern, with one 45-inch flue. They are 30 feet long by 6 feet diameter, with an evaporative power of 8½ pounds of water per pound of coal. The latter is the best quality of Pittsburgh coal, and the pressure averages 25 pounds.

From the pumps the water passes into the stand-pipe a few feet from the front of the engine-house. This is a wrought-iron tube 48 inches in diameter and 132 feet high. Its top is 196 feet above low-water level, and the base of the foundation is 22 feet above the same plane. Thickness of metal, from ½ to ¼ inch. Thirty feet below the top there are four 20-inch pipes branching from the main one by means of elbows and expansion-joints, and descending to the base. The water overflowing from the central 48-inch pipe into these four pipes supplies the distributing main direct, without passing through the reservoir. The whole construction is encased in an ornamental wooden tower painted white. The cost was about $50,000. In detail it is described in the eighteenth annual report.

Of distributing reservoirs there are two, one built in 1879, the other in the early stage of the construction of the works. The latter is situated 3,650 feet to the south of the pumping-station. It is 178 by 375 feet at water-line, with a total depth of 24 feet, and depth of water of 19½ feet, the top of which is 141 feet above low water in the river. It is divided into two basins by a wall. Through the center of this wall the 30-inch force-main from the pumps rises and discharges the water from a bell-shaped end. A second 30-inch main discharges into an influent-chamber, and passes into the reservoir over a weir. The banks slope 1½ to 1 on the inside. Springs in the bed and under the embankment have caused considerable trouble from time to time. In 1876, a sediment of 5 feet depth which had accumulated in the course of several years was removed by a system of hydraulic mining, the same as at Saint Louis.

The needs of the city requiring a new one, the Crescent Hill reservoir was completed in 1879. It is 2¼ miles from the stand-pipe, with which it is connected by two lines of 30-inch cast-iron force-main. In 1879, the first and second pumping-mains to the old reservoir were almost entirely taken up, and the supply-mains from the two reservoirs were connected. The water-level in the Crescent Hill basin is 175 feet above low water, and, therefore, 34 feet above the level of the old basin. It is trapezoidal in plan, with embankments of earth faced with 3 feet of puddle; slopes of 1½ to 1 interior, and 2 to 1 exterior; 21 feet width of banks at top; a division-wall rising to the level of the banks, also 21 feet wide, and having both faces puddled. The total depth of the basin is 24 feet, and its capacity 100,000,000 gallons. The average head of water in the city is 110 feet, and the maximum 175 feet.

The dimensions of the two basins forming this reservoir are as follows, measured on the bottom: One basin is rectangular in plan, 589½ feet long by 518 feet wide; the other is trapezoidal in plan, 580 and 640 feet long and 518 feet and 530 feet wide. There are three chambers in the well beneath the reservoir gate-house, the influent- and effluent-chambers being united into one. The first takes the water from the pump-mains and discharges it over weirs into either basin at will, regulated by stop-gates. The second chamber is a dry well containing stop-valves, etc. The third delivers into the three supply-mains, 48, 48, and 36 inches, respectively, in diameter. Along the foot of the embankments, opposite the gate-house side of the reservoir, is constructed a brick conduit, 60 inches diameter, with a 60-inch stop-gate, where it passes through the division embankment, and terminating in an open end half way to the end of each basin. This is merely a circulating pipe. Water is forced by the pumps into one basin, and, crossing to the opposite side, passes through the circulating pipe into the other basin, thence back to the effluent-chamber. It is a very economical arrangement.

The subjoined table shows the length of pipes of all sizes for the supply and distribution of water, laid up January 1, 1880:

	Linear feet.
48-inch	474
43-inch	49
36-inch	12,786
30-inch	45,047
20-inch	25,378
16-inch	37,038
12-inch	6,409
10-inch	10,386
8-inch	30,755
6-inch	165,889
4-inch	227,276
3-inch	12,919
2-inch	291
Total feet	574,697
Total miles	108.844

About 3 miles additional pipe was laid in 1880, making 111 miles in all.

The consumption averages daily about 5,500,000 gallons, delivered to 7,600 consumers.

There are in use 30 hydrants, mostly of Matthews' patent, and about 350 fire-cisterns. The latter are circular brick wells beneath the surface of the streets, containing from 100 to 500 barrels of water each, and so arranged that a fire-engine suction-hose can be readily dropped into them. They are connected with the mains by a short tap.

Three hundred meters of the Worthington, Union, and Gem type are in use.

The cost of the works as originally constructed amounted to $837,000, which has now increased to a total of $3,905,000, as shown in an itemized statement given below:

Cost of works to January 1, 1880.

Real estate	$101,033 16
Inlet and river works	38,279 00
Engines and pumps	187,784 92
Engine-house, chimneys, etc	125,180 52
Stand-pipe and tower	50,035 76
Coal-houses	6,415 41
Improvements around buildings	23,364 66
Reservoir No. 1	89,411 13
Crescent Hill reservoir	569,631 70
Roads, fences, and improvements of grounds	47,152 39
Pipe system	1,937,460 03
Pipe-way	82,740 78
Contingent expenses	60,964 05
Expenses conducting works	572,528 15
Harrod's Creek Precinct bond tax	13,050 00
Total	3,905,031 66

The cost of maintenance and repairs for 1880 was about $42,000.

The annual cost of maintaining works, and revenue for 1879 is as follows:

Interest on city water bonds, paid by city	$82,580 00
Interest on company water bonds, paid by water company	55,080 00
Total interest on bonds per annum	137,660 00
Expenses conducting the works per annum	40,218 37
Repairs and contingent expenses per annum	5,856 00
Total cost of maintaining works per annum	183,734 37
Revenue per annum	176,097 45
Excess of cost for maintaining works over revenue	7,636 92
Interest on bonds per 1,000 gallons of water distributed	$7\frac{29}{100}$
Expenses conducting works per 1,000 gallons of water distributed	$2\frac{13}{100}$
Repairs and contingent expenses per 1,000 gallons of water distributed	$0\frac{31}{100}$
Total cost per 1,000 gallons of water distributed	$9\frac{73}{100}$
Revenue per 1,000 gallons of water distributed	$9\frac{33}{100}$

The water as derived from the Ohio river is almost always very turbid, but after subsidence in the reservoir is much improved. No analysis of it seems to have been made at any time.

The works are at present in charge of Charles Hermany, C. E., as chief engineer.

6.—PUMPING DIRECT TO RESERVOIRS.

BROOKLYN, NEW YORK.

Brooklyn, with extensive commercial and manufacturing interests, and situated on the easterly bank of the East river, has an area of 20 square miles. It is generally elevated above the river from 80 to 90 feet, about 1½ or 2 miles of its water-front being a bluff 70 feet high, overlooking New York harbor. Toward the northern limits the land slopes away to nearly tide-level.

Its population is 566,663. There is little regularity to the plan of its streets. Toward the eastern limits of the city, parts of it attain an elevation of 190 feet, upon which the distributing reservoir for high service is situated.

In 1856 a supply of water was introduced into the city by a combination of pumping and gravity. The supply is derived from a succession of small ponds and lakes at distances of from 4 to 12 miles from the eastern limits of the city, which ponds and lakes draw their supply from the great water-shed of Long Island. This is a ridge, extending from one end of the island to the other and sloping gently toward the ocean, of sand and clay soil, containing bowlders. Hempstead Plains, lying in the western end of this slope, furnishes the chief part of the water used for supply. They are sand and gravel, from 5 to 15 miles wide. On a ridge which separates Hempstead Plains from the city, is situated the storage or the Ridgewood reservoir, at an elevation of 170 feet.

The ponds and lakes mentioned average from 4 to 8 acres in extent, and are from 8 to 10 feet deep. They have been formed by obstructing the flow of the various small streams by earth dams, through which small branch conduits convey the impounded waters to a large main conduit, extending from the most easterly or Hempstead reservoir to the pump-well at the engine house. The different streams are as follows:

Streams.	Miles from ferry.	Elevation above tide.	Estimated flow.
		Feet.	*Mil. gals.*
Jamaica creek	13.75	8	5.00
Nostrand's creek	15.25	13	1.50
Springfield creek	15.75	10	0.25
Simonson's creek	16.00	15	4.00
Shaw's creek	17.25	9	0.50
P. Cornell's creek	18.50	12	2.00
Hine's creek	20.25	9	2.00
L. Cornell's creek	21.00	10	8.00
Seeley's creek	23.00	6	0.25
Baldwin's creek	23.25	1	0.25
Millburn's creek	23.75	7	2.00
Smart's creek	25.50	18	5.00

After the construction of the dams a dry-season measurement of the streams as consolidated gave the following minimum flows:

	Million galls.
Jamaica stream delivery	3.3
Brookfield stream delivery	2.0
Clear stream delivery	0.8
Valley stream delivery	2.6
Rockville stream delivery	2.8
Hempstead stream delivery	8.5

The ten ponds formed and in use at present have a total drainage area of 60.23 acres, and are known as follows:

Basin.	Distance from city line.	Water-surface.	Depth.	Capacity.	Elevation of dam above tide.
	Miles.	*Acres.*	*Feet.*	*Mil. gals.*	*Feet.*
Jamaica reservoir	5.404	40.00	8	....	7.90
Springfield pond	....	....	......	....	....
Cornell's pond	....	....	......	....	....
Brookfield reservoir	7.966	8.75	7	....	16.40
Clear Stream reservoir	8.771	1.07	6-7	....	11.50
Valley Stream reservoir	9.708	17.78	......	....	12.80
Watt's pond	....	....	6-7	....	....
Rockville reservoir	12.343	8.00	......	....	12.05
Smith's pond	....	....	......	....	6.05
Hempstead reservoir	12.89	23.50	5	....	10.60
Storage reservoir	....	231.00	15	1,000	20.00

The conduit which collects and conveys the water of the above ponds is 12.25 miles in length, with a fall of 6 inches per mile for the first 4.75 miles from the pumps, and 6.25 inches per mile for the remaining distance. Through it the water flows by gravity to the pump-well, whence the engines force it into Ridgewood basin.

The works, therefore, as built in 1856–'62, consist of: (1) The 10 supply ponds shown in the map, with corresponding dams; (2) The masonry conduit and branches; (3) The pump-wells, engine-house, engines, etc.; (4) Force-mains to Ridgewood reservoir; (5) Ridgewood reservoir; (6) The supply and distribution mains; (7) The high-service pumping-works; (8) Force-main to high-service reservoir; (9) Mount Prospect or high-service reservoir.

The dams forming the ponds are usually embankments, with a puddle-wall through the center in most cases, and all riprapped with stone, generally rubble in cement. The Jamaica dam, a type of most of the rest, is 15 feet wide at top, 12 feet high; inside slope, 2 to 1; outside, 1½ to 1. Puddle-wall 13 feet high in center and terminating 3 feet below the level of embankment tops. It is 9 feet thick at bottom and 4½ feet at top. The main portion of the embankment is of sand and gravel. On the inner face, at a height of 6 feet from the bottom, there is an offset 6 feet wide. Above this the inner slope is riprapped with rubble in cement. The water-surface is 4 feet below the top of the embankment. The riprap is 9 inches thick, laid upon 3 inches of gravel. At one end of the dam is the sluiceway into the conduit, and the overfall or waste-weir. The latter is a masonry wall about 8 feet high, terminating 4 feet below top of dam, about 5 feet thick at top, with an upstream batter of 1 to 4 vertical; downstream batter, 1 to 5. This wall of cement masonry, 21 feet long, is contained between two wing-walls of masonry, 3 feet thick at top and batter as before, forming a water-way 21 feet wide. The approach and apron or waste-way in front and behind the overfall are thus constructed: Long 8- by 10-inch timbers are laid parallel with the dam, 3 feet 2 inches apart; upon these, at right angles, a flooring of timbers is laid and fastened to them. On the downstream side, which takes the force of the overfalling water, this flooring is paved with 12 inches of loose stone blocks. Beneath the front face of the stone overfall, and at the lower end of the paved apron, sheet-piling has been driven 12 feet deep. Two waste-culverts, 2 by 3 feet, pass through the base of the overfall. Between the wing-wall of the overfall and the end of the dam is a masonry sluiceway, with an entrance 5 feet square, connecting with the branch conduit, 3 feet 6 inches square, to the main conduit line. The mouth of this sluiceway is provided with wire screens.

The cleared bottom of the pond proved to be clean sand. The following table gives a few details of the other ponds:

Pond.	Area of pondage grounds.	Branch conduits.		Overfall.		Waste-sluice.	Con-duit sluice.
		Length.	Diameter.	Height.	Width.		
	Acres.	*Feet.*	*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Jamaica	67.33	2,937	42	7.50	21	2 by 3	5.0
Brookfield	11.88	2,877	24	8.80	15	2 by 3	4.5
Clear Stream	1.80	1,080	24	3.00	8	2 by 3	4.0
Valley Stream	23.20	2,103	30	8.25	18	2 by 3	5.0
Rockville	15.50	1,872	30	8.25	18	2 by 3	4.0
Hempstead	26.58	....	....	8.00	24	2 by 3 2 by 3	6.0

A gate-house covers each sluice-gate, and the branch conduits are circular, of brick, and each provided with a gate at its junction with the main. The ponds are each protected about the margins with sand embankments.

The conduit is built of masonry, the side walls being of gneiss rock, 20 inches thick, with a 4-inch lining of brick-work. Its bottom lies on an average 28 inches below water-level, which much increased the cost. Short lengths, where it passed through marshy ground, were built upon piles. The invert is of brick, 8 inches thick, laid in 8 inches of cement, and the arch of the same, with a radius of 5 feet and thickness of 1 foot. Of the main portion, from the pump-well to Jamaica pond, the width of the inside is 10 feet and the height from invert to crown of arch 8 feet 8 inches. From here to Valley Stream pond its height is only 8 feet 1 inch, and its width is diminished by 4 inches above the junction of each branch conduit. Between Valley Stream pond and Rockville reservoir this width is 8 feet 8 inches, and from thence to Hempstead it is 8 feet 2 inches.

The versed sine of the invert of the smaller portion of the conduit is increased to 12 inches, and the thickness of the invert lining is doubled. The minimum depth of earth over the conduit arch is 4 feet; it never runs full. Within 2,000 feet of the pump-well, 30 openings 4 by 2 feet and about 50 feet apart, were left at the springing line of the arch on the east side. They are from 4 to 5 feet below ground-water level, and by gauge in 1859 showed an infiltration of 1,402,000 gallons per 24 hours.

To prevent undue filling of the pump-well when the engines are not in operation, three waste-gates have been provided, two of which are located about 2 miles from the pumps.

The conduit terminates in an arched basin of masonry 5 feet thick at sides and 2½ feet at bottom, 10 feet wide by 52 feet long, standing at right angles to the conduit. This basin is separated from the pump-well by a 5-foot masonry wall, which has four openings, 4 by 6 feet each, into the pump-well, which lies parallel with it. The latter is one long trough of masonry, 60 feet long by 10 wide, divided into two compartments by a wall with gates, so that two of the engines may be operated while the others are being repaired.

The engine-house is a plain brick building, 68 by 80 feet, with two wings, each 44 by 60 feet, and a coal-shed and boiler-house attached.

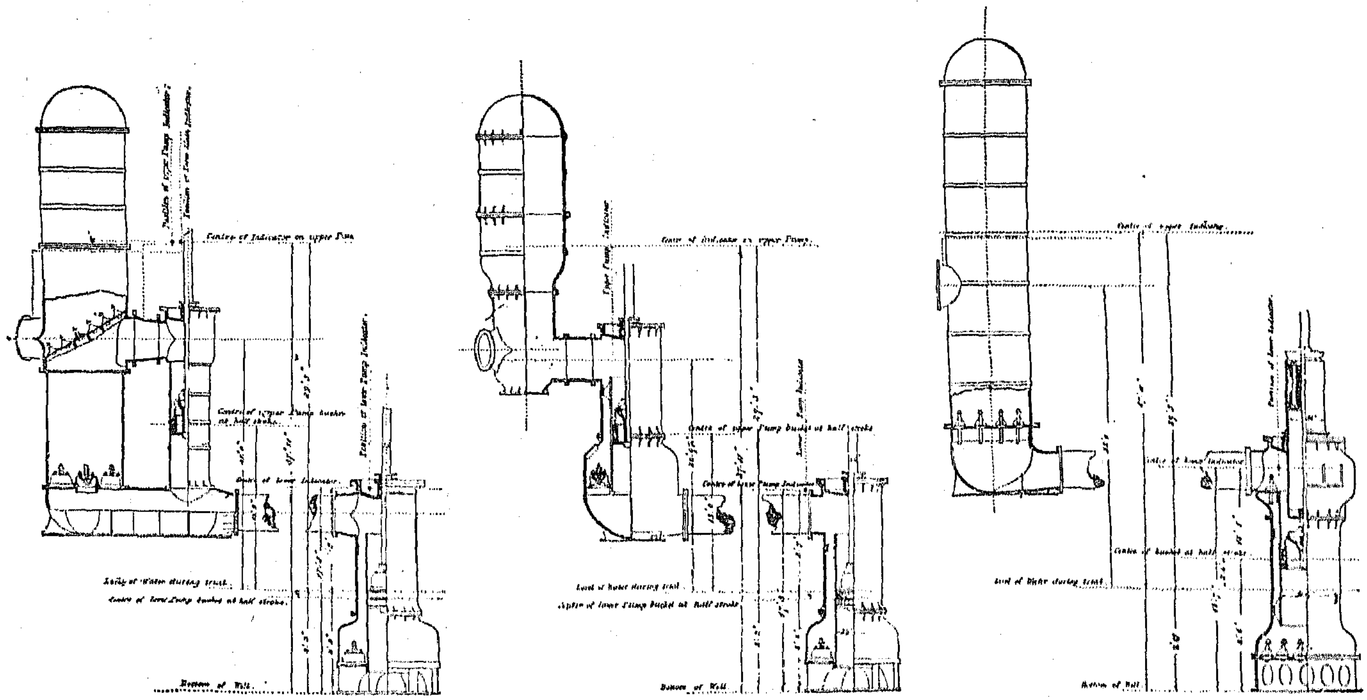
There are in operation three beam-engines of 15,000,000 gallons capacity each. Nos. 1 and 2 were built by Woodruff & Beach, of Hartford, in 1859. No. 1, which was remodeled in 1871, has two lifting-pumps, one beneath the steam-cylinder and the other at the opposite end of the beam, and connected by a pipe 3 feet in diameter with the pump-well. The two are so connected that while the piston of the lower pump under the cylinder is rising and discharging its contents into the force-main through the other pump, the piston of the latter is descending with its valves open. Its principal dimensions are as follows: Diameter of steam-cylinder, 80 inches; diameter of working pump-barrel, 36 inches; diameter of auxiliary pump-barrel, 54 inches; stroke of all, 10 feet.

It is run at about nine revolutions per minute, and two out of the three engines are operated 24 hours per day, the whole three being of late years frequently called into requisition. The water-valves are double-beat puppet-valves, 12¼ by 20½ inches diameter of seats. There are eight in suction and eight in the delivery of lower cylinder and seven each in upper pump. Lift of valves, 2 inches. The engine is condensing, and operates a double-acting air-pump 36 inches diameter by 60 inches stroke. A spray-condenser connected with it is 4 feet diameter by 8 feet high. Further details of engines Nos. 1 and 2 are given in Kirkwood's *Report on the Brooklyn Water-Works*, from which many details have been taken.

Engine No. 2 is like the first, with steam-cylinder 90 inches diameter, and pumps 36 inches diameter, with a stroke of 10 feet. A fly-wheel was added to No. 1, but No. 2 has none, being operated with a heavy counterbalance. The guaranteed duty, while forcing the water through 3,450 feet of 36-inch force-main into Ridgewood reservoir, a lift of 164 feet, was 600,000 pounds per pound of coal. It works at 10½ revolutions per minute. Engine No. 3, erected by Hubbard & Whittaker, of Brooklyn, in 1869, is a double acting condensing beam-engine, 85 inches diameter of cylinder, with a Thames Ditton pump, 51 inches diameter of bucket beneath the cylinder, and a fly-wheel at the opposite end of the beam; capacity, 14,000,000 gallons. The steam-cylinder, which is steam-jacketed, is 7 feet 1 inch diameter by 10 feet stroke; plunger, 3 feet 8 inches diameter. There are twenty foot-valves, each 11¼ inches internal diameter by 2-inch lift, thirteen valves in upper plate, and one bucket-valve of double-beat type, 40¼ by 26¾ inches diameter of seats. The condenser, of jet-pattern, is 4 feet diameter by 5 feet 7 inches high, with an air-pump 36 inches diameter by 54 inches stroke. Figures 1, 2, and 3 show the pumps of the respective engines. To furnish steam for the three engines there are two batteries; in all, twelve boilers. Seven of them are 24 feet long by 8 feet diameter each, and were made by Henry Smith, of Brooklyn. They are drop-flue boilers, with four flues each, 16 inches diameter by 15 feet long, and are operated under 22 pounds pressure, with anthracite coal on the grate. The remaining five boilers, made by Hubbard & Whittaker, are 27 feet long, 7 feet diameter, with grates 6 feet long, 3½ feet wide, and twelve 8½-inch flues, 13 feet 7 inches long each; drop-flue.

From the pump-house to Ridgewood reservoir, a distance of 3,511 feet, there are three 36-inch force-mains of cast iron, one for each pump. They do not pass through the embankments of the reservoir, but deliver into a chamber, their outlets being about on a level with high water. The object of this arrangement was to give access to their whole length without breaking into the bank. There is a check-valve in each main.

Ridgewood reservoir, situated to the north of the pumping station, is polygonal in outline, with a division-wall through the center, dividing it into two basins of 11¾ and 13¾ acres area water-surface, respectively, and total capacity of 161,000,000 gallons. The side embankments are irregular in height, from 8 to 30 feet. They are of earth, of 20 feet width at top, with a puddle-wall through the center, commencing 2 feet below the bank-level, at a thickness of 3 feet and increasing by steps, one foot in thickness for each 5 feet in depth, to a total of 6 feet at the base and 22 feet in total height. A layer of puddle 2 feet thick extends from the base of the wall under the entire bottom of the reservoir. The faces of the banks are covered with 6 inches of gravel, upon which a stone riprap is laid 12 inches thick in cement, with occasional open joints to allow the water to be drawn out from behind the riprap, in the event of the lowering of the water-level in the reservoir; slopes, $1\frac{1}{2}$ to 1. Total depth of water, 20 feet. High-water surface, 4 feet below embankment-level. Height of same above engine-well, 163 feet. The division embankment is similar to the above, but 15 feet wide at top and 3 feet high above high-water level. The influx-chamber of masonry is 19 by 23 feet and 9 feet deep below high-water, from which the water passes into either or both compartments over a weir 4 feet thick and 3 feet below high water.



No. 1. No. 2. No. 3.

PUMPING ENGINES, BROOKLYN, N. Y.

The efflux-chamber at the opposite end of the division-wall is of masonry 4 feet thick. It is square in plan, the dry-well being 25 feet long by 10 feet wide. There are arrangements for three 36-inch iron supply-mains, only one being laid as yet. It is fitted with a stop-gate in the dry-well. Two masonry channels 10 feet wide extend from the dry-well front-wall into the reservoir, one into each compartment. In each of these, about 20 feet from the dry-well, is a 4-foot masonry partition from top to bottom, and in these are four openings to admit water from the reservoir. Two of the four are each 4 by 4 feet square, and 5 feet below high water, and the other two are each 4 by 3 feet and located at the bottom. A drain-pipe from each compartment extends through these partitions and the dry-well and are discharged without the reservoir.

The distribution, which is chiefly carried out in cast-iron pipes, is in length and sizes as follows:

Water-pipe laid for the supply and distribution of water to January 1, 1881.

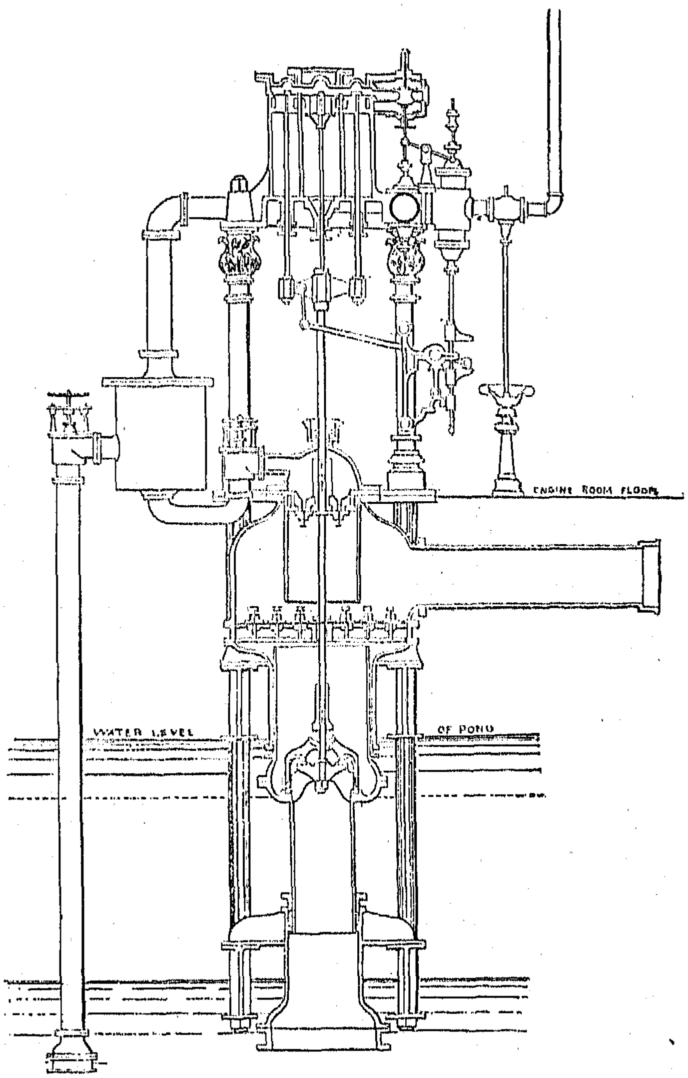
	Original distribution, cast iron.	Original distribution, cement.	Total length in use.	Total length in use.
	Feet.	*Feet.*	*Linear feet.*	*Miles.*
4-inch	....	....	2, 903	0. 549
6-inch	328, 786	6, 182	1, 209, 953	229. 157
8-inch	157, 413	993	327, 761	62. 077
12-inch	63, 369	....	165, 499	31. 340
20-inch	22, 636	....	65, 369	12. 380
30-inch	25, 193	....	25, 193	4. 771
36-inch	26, 397	....	26, 971	5. 108
48-inch	....	....	33, 483	6. 343
Length (original distribution, cement)	....	....	....	120. 069
Total length	....	....	....	351. 723

To supply the highest portions of the city, high-service works were built, consisting of pumping machinery and Mount Prospect reservoir. These pumps draw their supply from the 36-inch supply-main from Ridgewood reservoir, at a distance of 26,062 feet from it, by means of a branch main at Washington and DeKalb avenues, from 20 to 30 inches diameter, and 4,600 feet long.

The engine-house, a plain brick building with stone trimmings, is 40 by 60 feet, with boiler-room 40 by 40 feet, and has space for only two engines, only one being occupied. The engine, which pumps only during the night, so as to prevent diminution of head in the mains for the low service, is a crank and fly-wheel engine, with cylinder 24 inches diameter by 54 inches stroke, and two pumps with cylinders 20¼ inches and stroke of 41½ inches. This engine, which supplies Mount Prospect reservoir, and is located 122 feet above tide-water, has a capacity of 3,000,000 gallons per day, and actually supplies 2,500,000 gallons through the 20 inch force-main, 2,052 feet long, to the reservoir. Its duty at the test-trial in 1862 was 640,577 foot-pounds per pound of coal, 600,000 foot-pounds being guaranteed. Steam is furnished by one drop-flue boiler, 18 feet long, 6 feet diameter, with four upper flues, 13 inches diameter by 11 feet long, and nine lower ones, seven of which are 9 inches and two 7 inches diameter each, and each 9 feet 3 inches long.

Full details of the engine are found in W. E. Worthen's *Report on Brooklyn Water-Works*, page 136, appendix 1.

Mount Prospect reservoir, used for the high service, supplies that portion of the city south of Atlantic street, and is located on Flatbush, Underhill, and Grand avenues, President and Sackett streets. In plan it is square, with one corner cut off, approximately 330 by 340 feet on bottom. High-water surface is 198 feet above mean tide and 28 feet above high water in Ridgewood reservoir. Its high-water surface covers an area of 3.43 acres, with a capacity of 20,036,558 gallons. Depth, 20 feet. The banks are 20 feet wide, and slope 1½ to 1 inside and out. The bottom and banks are lined with puddle 2 feet thick. Upon the slopes is a layer of 3 inches of concrete over the puddle, and the bottom and slopes are further protected by an 8-inch covering of brick laid in cement. The bottom slopes from all sides toward the outlet into the drain-pipe. The force-main discharges into the bottom of an influent-chamber at one corner of the reservoir, 6 by 14 feet by 12½ feet deep below the top of the embankments. The masonry is 4 feet thick, and the force-main 20 inches diameter. From 5 feet 7 inches above the bottom of the influent-chamber a 30-inch pipe passes out into the inner bank, and, extending downward, just beneath the puddle-facing, passes through the latter near the toe of the slope into the reservoir, supported in the latter passage upon a pier of masonry. This pipe passes out of the influent-chamber into the reservoir at high-water line. A single overflow-pipe, 12 inches diameter, extends from high-water surface in the external wall of the influent-chamber to the street-sewer.



The effluent-chamber, situated at the opposite corner of the reservoir, is about 35 by 50 feet, of masonry 3 feet thick, and forms but a single chamber or dry well. Through it pass a 30-inch supply-pipe, with stop-valve, and a 12 inch drain-pipe, also stopped by a gate. The former passes through the bank through brick walls, to prevent percolation through the banks. In front of the mouth of this pipe, in the toe of the slope, are two screens, in appropriate chamber.

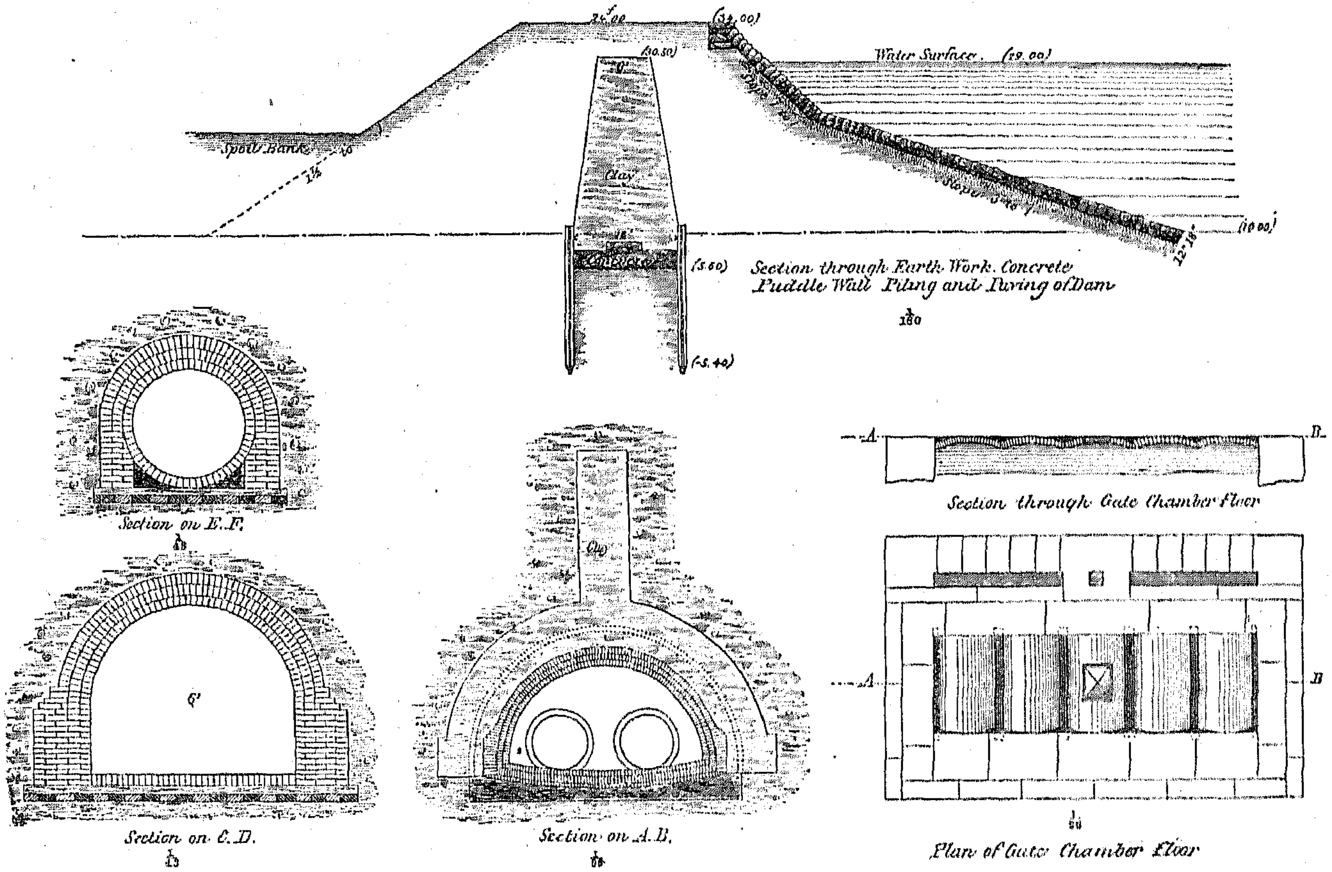
Of the distribution system no pipes over 20 inches diameter are tapped. There are 60,555 taps in the system, which includes Brooklyn city, and Governor's island, in the New York harbor. The consumption averaged in 1880 about 30,745,000 gallons per day, and reached in January nearly 48,000,000 gallons. The result has been at times a scarcity of water in the city.

The supply from Hempstead reservoir and the water-shed from which Brooklyn's supply is derived proving inadequate to the demand, three wells have been dug, at Smith's, Watt's, and Cornell's ponds, and pumps have been placed at the former, delivering into the main conduit, with machinery in readiness for use at the two latter. These wells are each 50 feet in diameter, with a total depth of 20 feet, and depth of water usually 15 feet. They are built of brick, with vertical tie rods through the lining, and sides 2 feet thick. The bottom is sand, and not closed. The curbs upon which the linings were sunk are 4 feet high. These wells are estimated to yield 2,500,000 gallons per day of exceedingly pure water. The soil is entirely white sand. The water pumped from them is forced through 16-inch mains into the conduit. The pumps have a capacity of from 3,500,000 to 5,000,000 gallons per day.

The following table gives details of the meters in service January 1, 1881:

Kind of meter.	$\frac{5}{8}$-inch.	$\frac{3}{4}$-inch.	1-inch.	$1\frac{1}{4}$-inch.	$1\frac{1}{2}$-inch.	2-inch.	3-inch.	4-inch.	6-inch.	Total.
Worthington	210	....	140	....	5	41	11	12	....	428
Gem	265	10	93	....	5	65	9	22	2	471
Crown	156	....	......	1	....	1	....	....	...	158
Ball & Fitts	1	....	......	....	....	......	....	....	....	1
Brooklyn	......	...	2	....	....	6	....	6	....	14
Union	......	....	......	...	....	......	....	....	1	1
Nassau	2	....	4	....	..	1	2	....	....	9
Eagle	3	....	......	....	....	......	....	....	....	3
Total	646	10	239	1	10	114	22	40	3	1,085

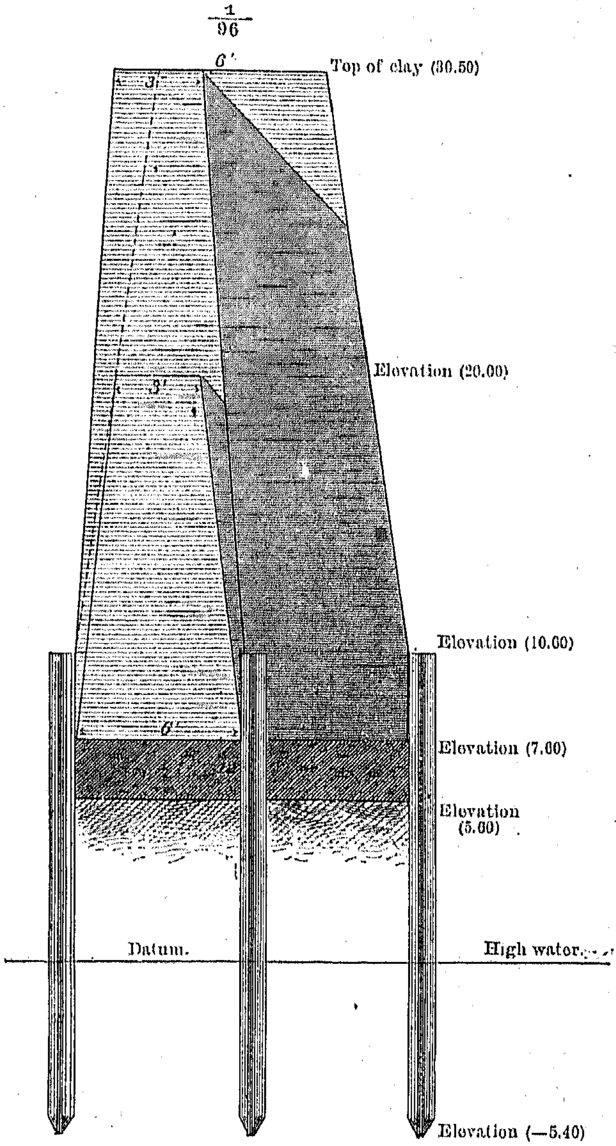
In the distribution mains there are none less than 6 inches diameter, and in the city there are 2,874 fire-hydrants.



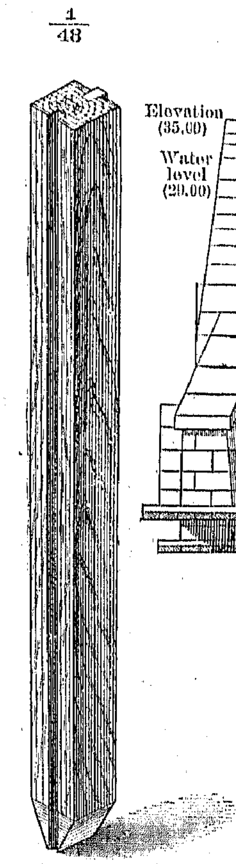
The total cost of the works to date has been $11,379,500, and total receipts $14,231,370, the last yearly receipts being $977,700. The cost of maintenance for the year 1880 was $272,321, itemized as follows:

Salaries:	
Commissioners, registrars, etc	$35,015 26
Distribution and repairs	48,610 87
Ridgewood engine-house	33,796 46
Prospect engine-house	4,940 43
Ponds and conduits	2,776 56
Prospect reservoir	1,940 29
Ridgewood reservoir	1,458 02
Smith's pond	3,064 04
New reservoir	999 97
Supplies:	
Distribution and repairs	15,085 04
Ridgewood engine-house	38,571 76
Prospect engine-house	7,393 30
Ponds and conduits	4,461 45
Prospect reservoir	2,001 61
Ridgewood reservoir	544 45
Smith's pond	2,521 32

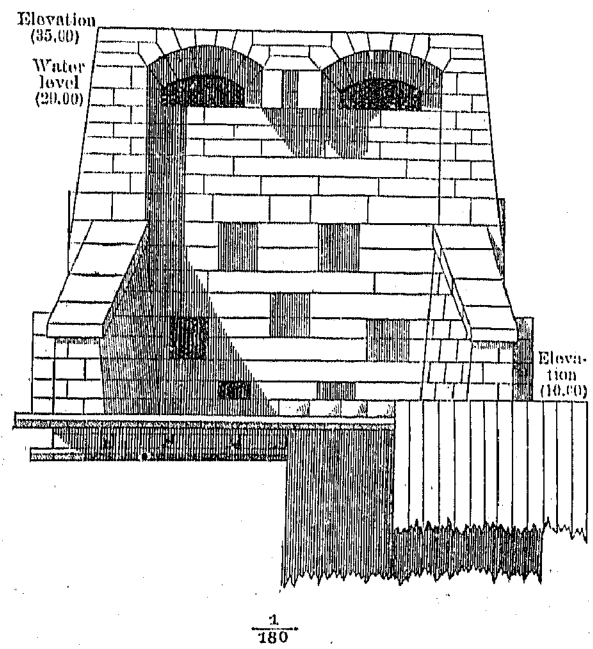
New reservoirs	$1,412 59
Printing and stationery	2,530 98
Taxes	2,061 22
Tapping mains	4,200 60
Office expenses	1,148 13
Contingencies	22 50
Maps, registrars' department	250 00
Resurvey pipe district	2,090 05
Ridgewood reservoir enlargement	110 35
Coal at pumping-stations	54,300 12
Additional water-supply	1,013 00
Pumping engine No. 4	
Cleaning Smith's pond	
Gauging streams beyond Hempstead	
Total	272,321 07



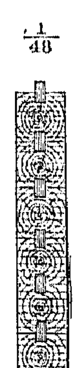
End view of puddle-walls and the sheet piling.



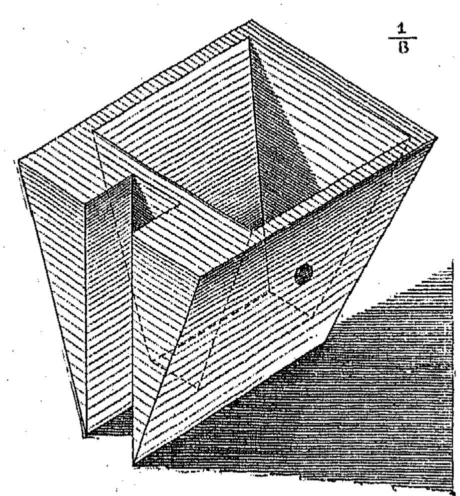
View of sheet pile.



Up-stream side of masonry,



Top view of sheeting.

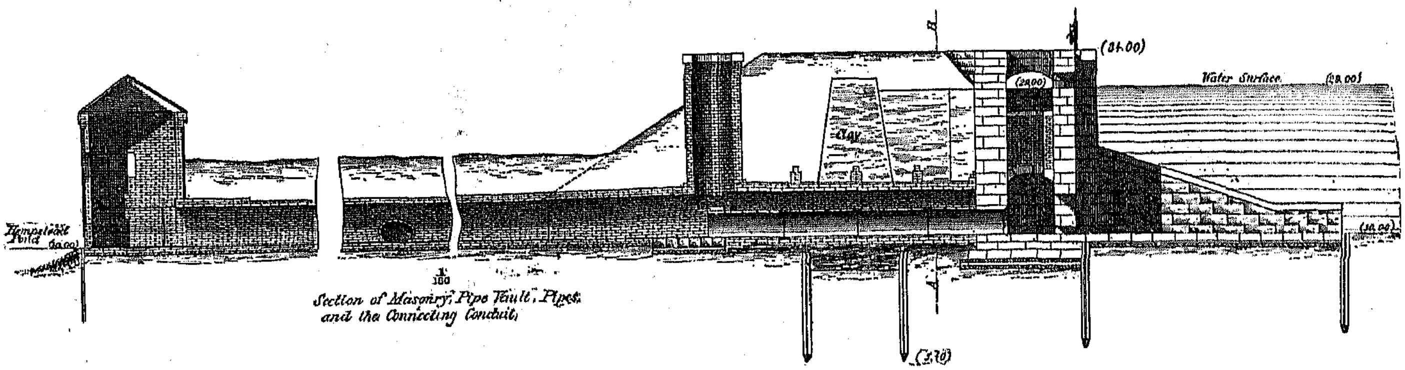


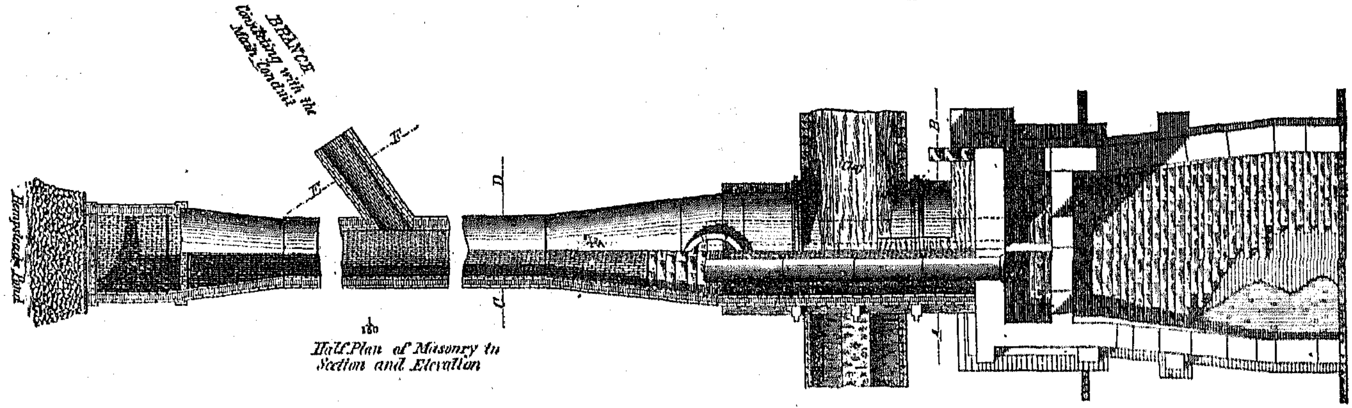
Cast-iron shoe for piling.

The works are under the charge of the department of city works, Mr. Robert Van Buren, chief engineer.

Hempstead reservoir having insufficient storage capacity, a new one is in course of construction and nearly completed. Details of the dam are given in the cuts. It is situated a short distance to the east of the old one, and has a drainage area of 25.78 square miles, with a water-surface of 231 acres, capacity of 1,000,000,000 gallons, and average depth of 15 feet.

Rates for water per meter measurement are 7¾ cents per 100 cubic feet.



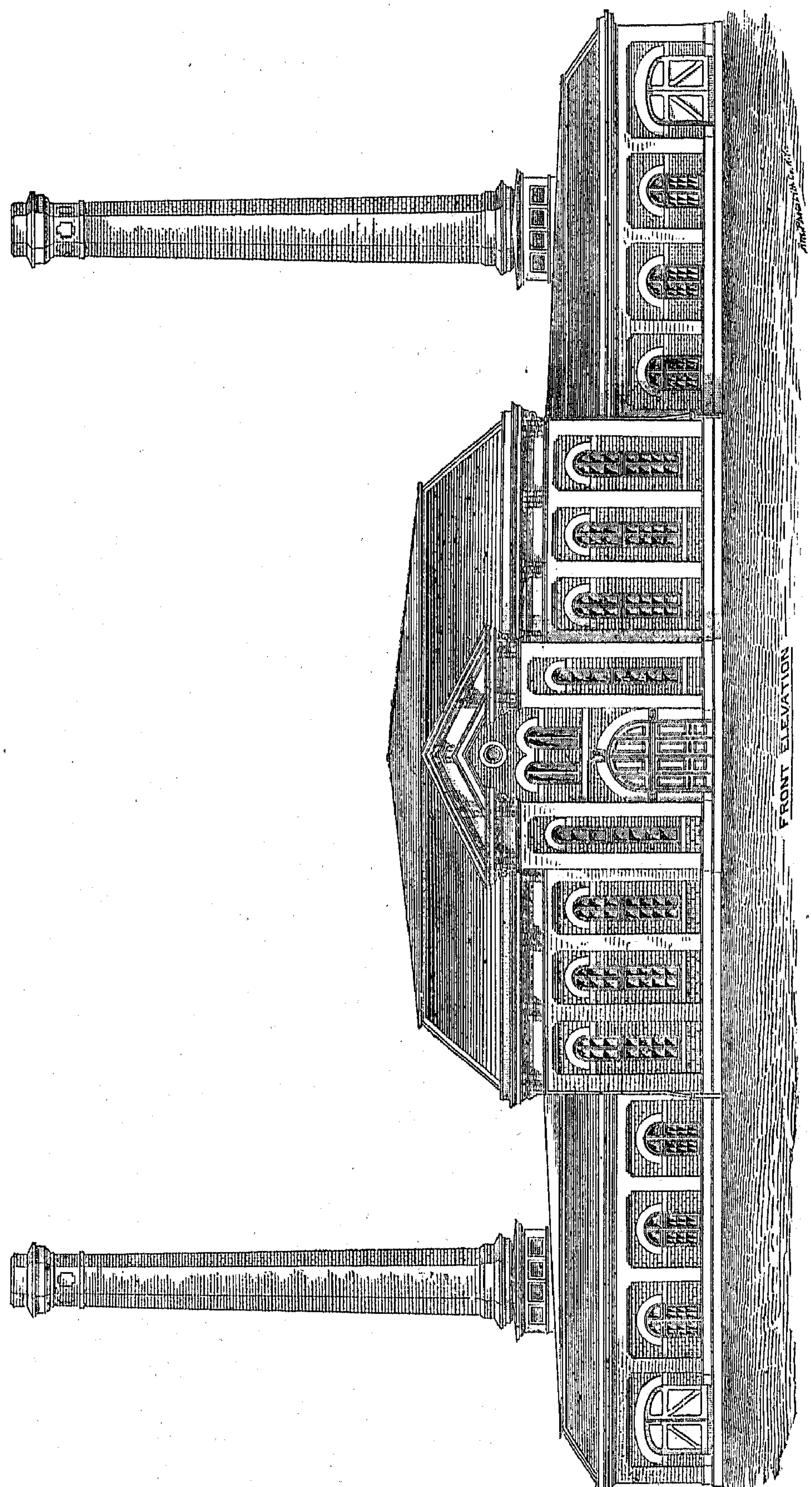


PITTSBURGH, PENNSYLVANIA.

This city, situated at the confluence of the Allegheny and Monongahela rivers, and containing a population of 156,389, introduced a supply of water in 1824, deriving it from the Allegheny river about a mile from its mouth. The city proper is located on a comparatively low-lying strip of land between the two rivers; a part of it on the south side of the Monongahela river rises from 400 to 500 feet above the level. The industries are chiefly manufacturing. The streets, though somewhat irregular, generally intersect each other at right angles. The old water-works are in a bad condition, and will soon be abandoned, a new set of works, begun in 1872 and completed in 1878, having rendered them nearly useless. By the old works the water is pumped into Bedford Avenue reservoir, at which point three engines, drawing their supply from this reservoir, force the water into an upper basin, known as the "old high service".

Water is drawn into the pumps through two cast-iron pipes each 29 inches in diameter. There are two engines in use, built by the Atlas works of Pittsburgh, and both high-pressure; they are operated on an incline, the pumps being submerged. In such poor condition are they that it is ordinarily impossible to see across the engine-house, owing to escape of steam, and the wooden connecting-rods are so rotten that they need constant watching and repair. They are known as the "Hercules" and the "Sampson", and as they are soon to be abandoned, will not be here described.

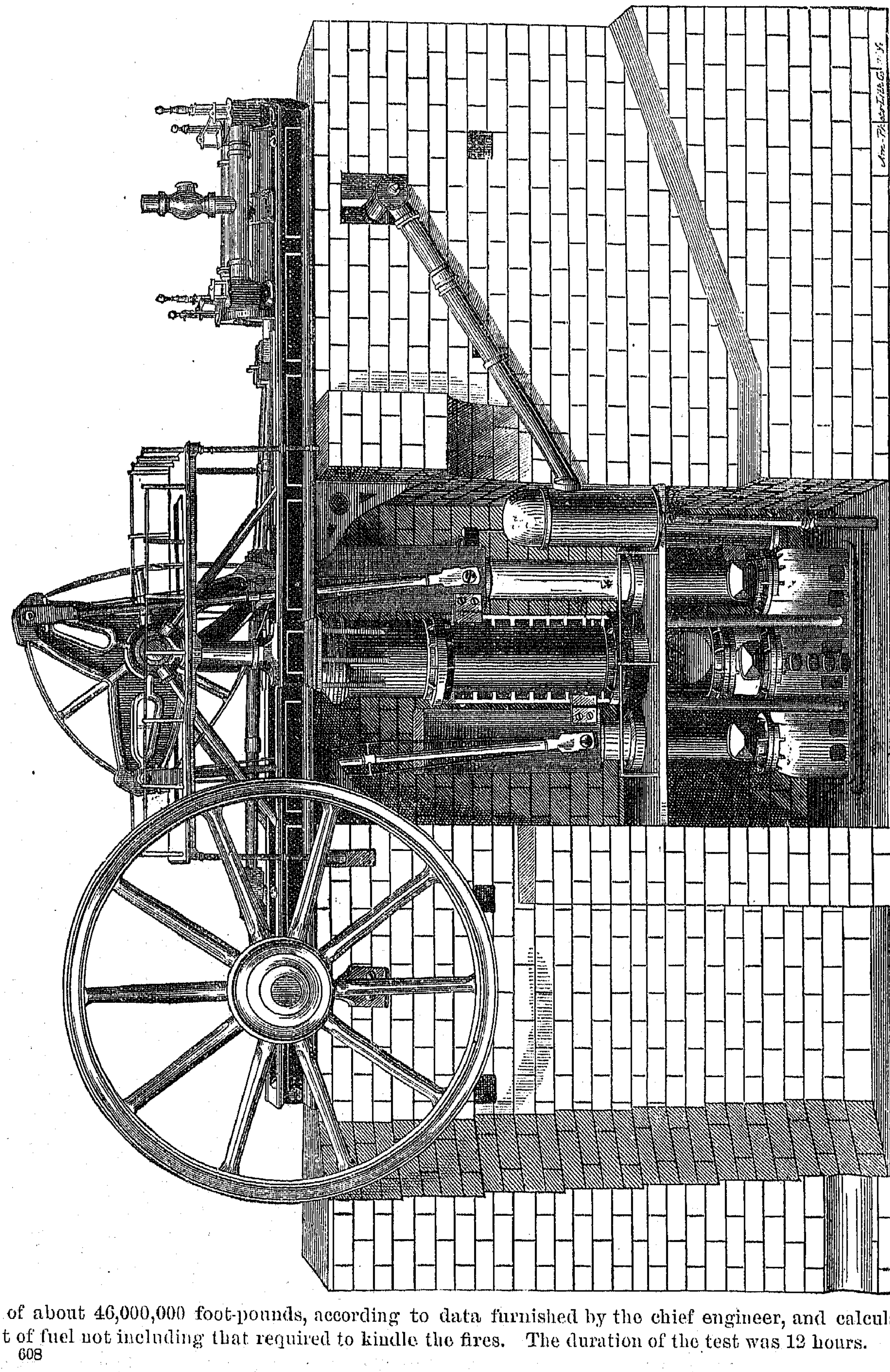
The new works, located at Brilliant station, on the Allegheny, 10 miles above its mouth (the house being shown in the cut on page 91), contain 4 horizontal engines—2 high-pressure and 2 compound condensing—all designed by Joseph P. Lowry, and of the same pattern, the compound engines differing from the others only in having a low-pressure built on the end of the high-pressure cylinder. They are of the following dimensions: Low-pressure cylinders, 106 inches diameter; high-pressure cylinders, 64 inches diameter; pump-cylinders, 44 inches diameter; stroke of steam-piston, 14 feet. They are operated at 9 or 10 double strokes per minute. The pumps are vertical and located in a pit, while the steam piston-rod works horizontally and is connected with the lower arm of a triangular beam. One of the upper arms is coupled with the vertical pump-rods, and the other is connected with a heavy counterbalancing weight. The puppet steam-valves are operated by cams from the main shaft. There are two plain solid-plunger pumps to each engine, with four receiving and four discharge valves to the plunger, each weighing from 200 to 220 pounds, 21 inches diameter, with a lift of 1¾ inch of brass, disk-shaped.



NEW PITTSBURGH WATER-WORKS BUILDING, AT BRILLIANT STATION.

Two engines are generally run at the same time, and from 12 to 24 hours per day, the high-pressure at 7 or 7½ revolutions per minute, with 120 pounds of steam and 165 pounds pressure on the pumps. Jet-condensers, 10 feet

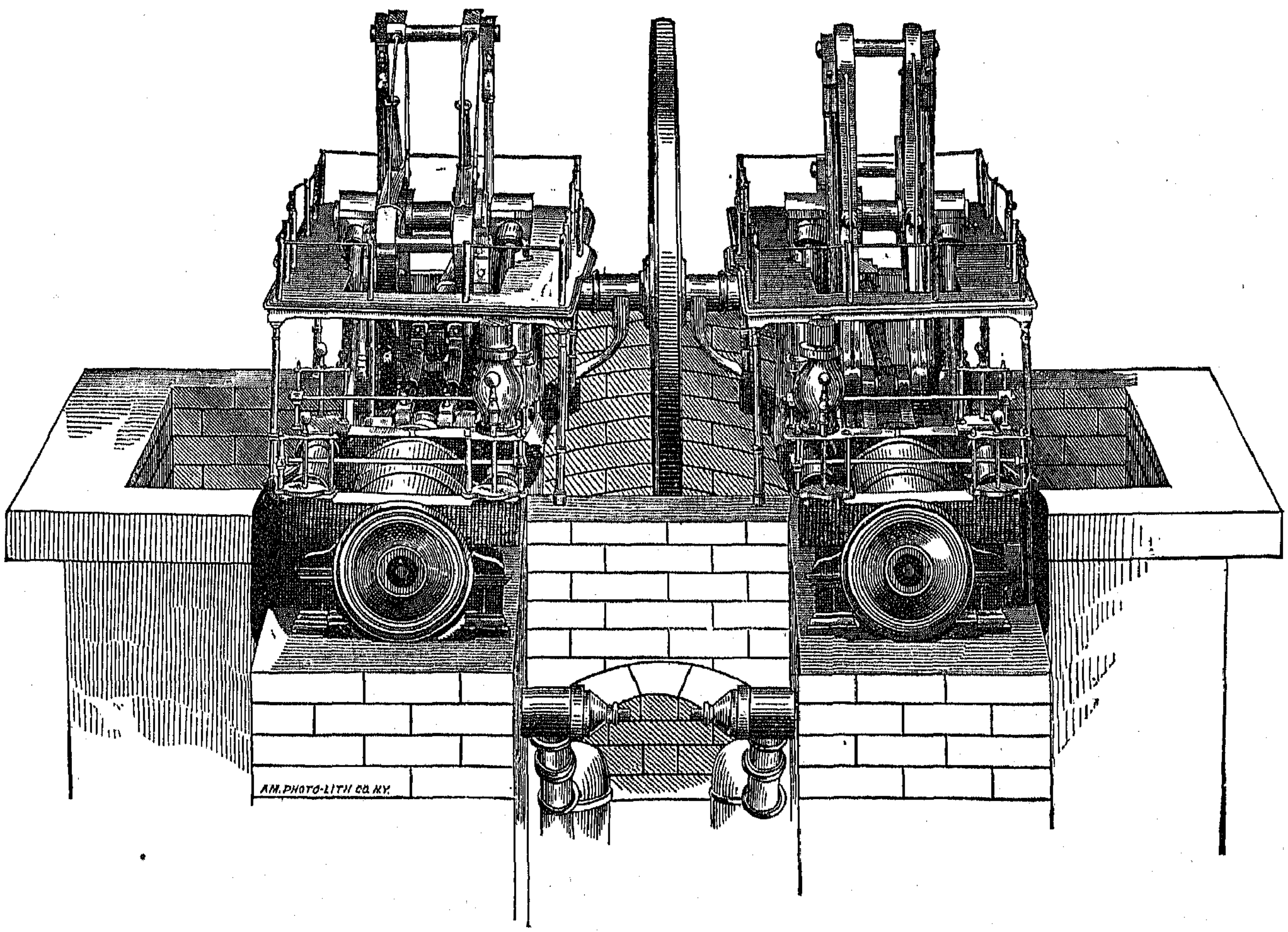
7 inches long by 13 feet 3 inches outside diameter, are used with the compound engines, the air-pumps being 24 inches in diameter by 11 feet stroke. The guaranteed speed was 10 double strokes per minute, which rates the engines at 20,000,000 gallons capacity. No careful duty-trial has ever been made, but an experimental trial showed



a duty of about 46,000,000 foot-pounds, according to data furnished by the chief engineer, and calculated on an amount of fuel not including that required to kindle the fires. The duration of the test was 12 hours.

There are 32 double-flue boilers, each 40 inches diameter by 32 feet long, with flues 14 inches diameter, and burning soft coal. The evaporation has never been computed.

The engines have cost to date about $750,000, and have required expensive repairs. They are the largest horizontal engines used for the purpose in the country. The following cuts show their construction before the addition of the low-pressure cylinders.



From this pumping-station the water is forced through 3,840 feet of 50-inch cast-iron main, under a head of 365 feet, into Hiland reservoir. The pumping-station is shown in the cut on p. 91, and consists of a plain rectangular brick building, with two wings containing the boilers. It is located on the edge of the river, its foundations being much below water-level.

A basin on the hill immediately in front of the pumping-station, and known as the Brilliant reservoir, was begun in 1872, at an elevation of 208 feet above the river, but abandoned before completion.

The Hiland reservoir, containing 117,651,000 gallons, with an area of 19¾ acres at flow-line, is situated 365 feet above the river. It is in excavation and embankment, with slope of 1½ to 1 inside and out, faced on the former with stone riprap 15 inches thick, resting upon 5 inches of broken stone, underlaid by a puddle-facing of 2 feet thickness.

A 20-inch main on Centre avenue, 4,309 feet long, is connected with the 30-inch main from Hiland reservoir. From the former 505 feet of 15-inch pipe conveys the water to the pump-well of the engine-house on Belle avenue. This is Herron Hill pumping-station for high service. The water thus taken from the Hiland main is forced through 1,250 feet of 12-inch main into the Herron Hill reservoir, with a lift of 275 feet.

A pumping-engine, taken from the Bedford Avenue works, has a capacity of 1,500,000 gallons per day. It is operated by a battery of three boilers taken from the Forty-fifth Street works.

Herron Hill reservoir is a rectangular embankment reservoir, 305 by 170 feet on the bottom, 24 feet deep to the level of the top of the banks, with a layer of 5 inches of concrete covering the whole bottom, the banks sloping 1½ to 1 inside and out, having a 2-foot facing of puddle, protected by from 6 inches to 1 foot of broken stone, covered with a riprap of cut stone 15 inches thick. Its capacity is rated at 10,000,000 gallons.

Cast-iron mains to the length of 113 miles, and 4, 6, 8, 10, 12, 15, 20, and 30 inches in diameter, respectively serve to distribute the water to the amount of 16,000,000 gallons per day to the inhabitants, the number of takers being unknown, but the consumption per head being estimated at 100 gallons per day. There are 912 hydrants in use. The works originally cost $110,000, and this amount had been increased in 1872 to $1,627,800. The cost of the new works amounts to about $5,000,000. The expense of maintenance and repairs in 1880 was $130,000. From 1872 to 1879 the expenses were $792,190 and the receipts $2,117,450. Direct-pressure works, erected in 1870 at Forty-fifth street, containing three small engines, are now abandoned, as the new works have rendered them of little use.

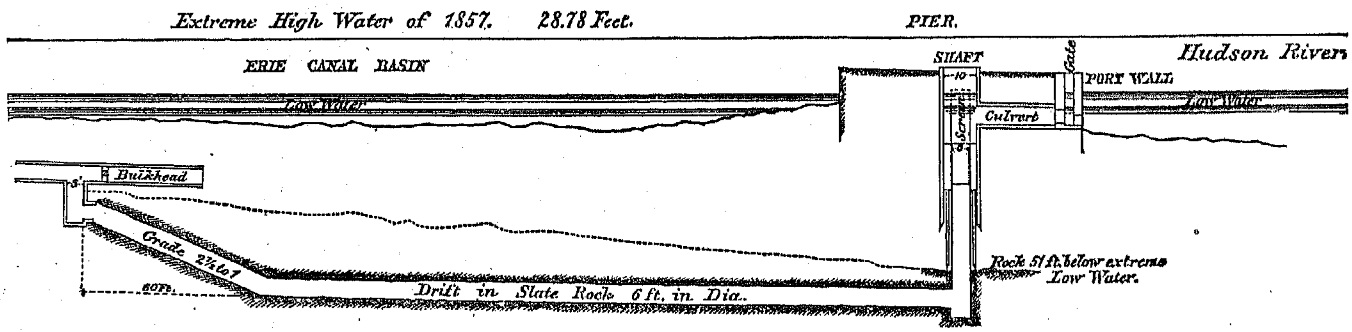
Details of the Bedford Avenue reservoir were not obtainable.

ALBANY, NEW YORK.

This city, situated on the west bank of the Hudson river, 142 miles north of New York, contains 90,758 inhabitants, with interests mainly commercial and lumbering. The ground upon which it is built rises very rapidly and evenly from the river to an elevation of 200 and 300 feet, with the streets rather irregular in plan.

Water was first introduced in 1850 by gravity, and new pumping-works were introduced in 1873. The former being now rarely used, the description will be chiefly confined to the latter. The gravity supply was derived from a number of small ponds or lakes known as Rensselaer and Watervliet lakes, about 3 miles out of the city. The total drainage area is about 8,455 acres, that of the former being estimated at 3,218 acres. From the outlets of these lakes, where the dams were located, a brick conduit about 15,000 feet long conveyed the water to the distributing reservoir located on Bleecker hill, in the westerly part of Albany. In Rensselaer lake the depth at the dam averaged 15 feet, and a puddle-wall extends through the embankment. The region in the vicinity is largely of yellow sand. Total length of dam, 1,400 feet, with no overfall or waste-weir. The top of the dam is 8 feet above the high-water flow-line, and the slope of banks inside and outside is 2 to 1. The puddle-wall is 8 feet thick at top, increasing at the rate of 4 feet for each 10 feet in depth. The area of the lake is stated by McAlpine (Report, page 50) at 39 acres, with an average depth of 16 feet. A gate-house 14 by 18 feet contains the outlet into the conduit, which is oval in section, 4 feet high by 3 feet wide, and built of brick.

The new works, erected and put in operation in 1873, deriving the water-supply from the Hudson river, consist of a pumping-station located 950 feet west of that river, on the corner of Quackenbush and Montgomery streets.



ALBANY WATER-WORKS—SECTION OF TUNNEL AND SHAFT.

On the eastern face of the river pier, 80 feet wide, is a gate-chamber. From this a culvert extends eastward to the shaft in the center of the pier. From the foot of the latter a rock tunnel extends beneath the Erie Canal basin 275 feet, and thence to the engine-house is a brick tunnel 645 feet long. The inlet from the river was built in a caisson, with river opening 18 inches wide by 30 inches long, extending from the top of the pier to a depth of 20 feet, or 7 feet below low water in the river. This opens into a well of the same depth, 4 by 7 feet. From the bottom of this well a culvert, 8 feet in diameter and 42 feet long, extends to the shaft in the center of the pier. This shaft is 10 feet in diameter by 47 feet deep, with a brick wall, 16 inches thick at base, resting on a cast-iron shoe, and was sunk against great pressure. From the 47-foot level another curb, 7½ feet in diameter, was sunk to a total depth of 51 feet below low-water mark. Cast-iron cylinders, 6 feet in diameter and 1½ inches thick, of a total length of 26 feet, secure the curbs from the bottom upward.

At a depth of 6 feet below bed-rock a tunnel, 6 feet in diameter, extends 275 feet to the brick tunnel, the last 60 feet of it rising with a grade of 2½ to 1. In the brick tunnel, near the west side of the Erie Canal basin, a 6-foot shaft, provided with a manhole, is constructed, 40 feet deep, to give access to the interior of the tunnel. The remaining length of tunnel extends beneath Water and Montgomery streets and the Hudson River Railroad tracks to the pump-well beneath the engine-house. The latter is a plain brick building, 52 by 62 feet, in one corner of a plot of ground 105 by 140 feet, nearly the whole of which is covered by the coal-shed, boiler-house, and the remaining buildings.

In this building are located the pumping-engines, two in number, made by Paulding, Kemble & Co. They are condensing beam-engines, connected to the same fly-wheel, each 32 feet diameter; and air vessel, 29½ feet high by 66 inches diameter.

The steam-cylinders are 42 inches diameter by 11 feet stroke, admitting steam essentially after the manner of river-steamboat engines, the steam-valves being operated by cams and plug-rods. The average speed is 12½ revolutions per minute. The pumps have two plain plungers, each with a stroke of 7 feet and diameter of 22 inches. The length of time they are employed and particulars of their working may be seen from the annexed summary of operations during the year 1879:

Number of days' pumping	262.5
Number of hours' pumping	2,906.6
Number of hours pumping per day	11.06
Revolutions per minute	11.957
Revolutions per day	7,944
Total revolutions	2,085,334
Lift in feet	242.492
Velocity in force-main, in feet per second	3.00071
Friction in feet	15.351
Pounds of coal consumed in pumping	3,315,345
Pounds of coal consumed in heating buildings	164,649
Pounds of coke consumed in pumping	117,209
Pounds of coke consumed in heating buildings	6,800
Pounds of ashes, etc	383,701
Ashes, etc., per cent	10.682
Gallons of water pumped into Bleecker reservoir per pound of fuel	335.296
Gallons of water pumped into Bleecker reservoir per day	4,369,271
Total gallons of water pumped into Bleecker reservoir	1,146,933,700
Duty in foot-pounds	71,582,768

The suction- and discharge-valves are of the double-beat Harvey & West type. The capacity of the engines is guaranteed at 10,000,000 gallons, pumped into the Bleecker reservoir (a lift of about 242 feet above low water) in 24 hours, and the duty at 60,000,000 foot-pounds. The condenser is of the jet pattern, 36 inches inside diameter by 5 feet 5 inches high.

The actual duty obtained on an average in 1879 was 71,582,700 foot-pounds; cost of engines, $135,000. The steam is generated by five multitubular return-flue boilers, containing seventy-eight 3½-inch tubes each 10 feet long, with shells 6 feet diameter by 20½ feet long, and consuming 1 pound of coal to pump 268 gallons to the reservoir. Evaporative power unknown. From the pumping-station the water is raised 243 feet through 9,723 feet of 30-inch diameter cast-iron main—1⅜ inch thick to sustain pressures of 250 feet head and over; 1¼ inch thick for from 200 to 250 feet; 1 inch thick for from 150 to 200 feet, and the remainder ⅞ inch thick. This force-main delivers the water into Bleecker reservoir, from whence the lower portions of the town are supplied direct. The upper parts derive their supply from Prospect Hill reservoir, which is supplied from Bleecker hill by the high-service pumps.

The Bleecker is an earth-embankment reservoir, rectangular in plan, 660 feet long by 340 feet wide on the bottom, 720 feet by 400 feet at top of banks, with a capacity of 28,475,000 United States gallons. The banks are of earth, with a puddle-wall through the center, and the faces slope 1½ to 1. The inner face is riprapped part way up the slope with brick, and the remainder with stone, both laid in cement. Depth of reservoir, 15 feet to high-water level. The gate-house measures 10 by 16 feet.

From the northern corner of Bleecker reservoir a 24-inch main 1,390 feet long extends to the well of the high-service engines, located on New York Central avenue, corner of Third street. From here the engines force the water into Prospect Hill reservoir adjoining.

The pumping-works consist of the pump-house, boiler-house, coal-shed, chimney, and engineer's dwelling. The engine-house contains two compound beam-engines, designed by F. Rumpf, and built by the Quintard Iron Works, of New York, in 1877, of a daily capacity of 5,000,000 gallons each, and to do a duty of 75,000,000 foot-pounds at a cost of $30,000. They are both connected to one fly-wheel, as in the case of the low-service, 18 feet in diameter, weighing 18,800 pounds. Beams 18½ feet long between centers and 18 feet above floor. Steam-cylinders: high pressure, 11½ inches diameter; low pressure, 20¼ inches diameter; stroke of high-pressure pistons, 4 feet 10 inches; low-pressure pistons, 6 feet.

The steam is admitted through double-beat valves, operated by plug-rods and cams geared to the main crank-shaft. The condensers are of the jet pattern, 10 by 17 inches, and connected with air-pumps 12 inches diameter by 24 inches stroke. Actual trial has developed a duty in these engines of over 81,000,000 foot-pounds.

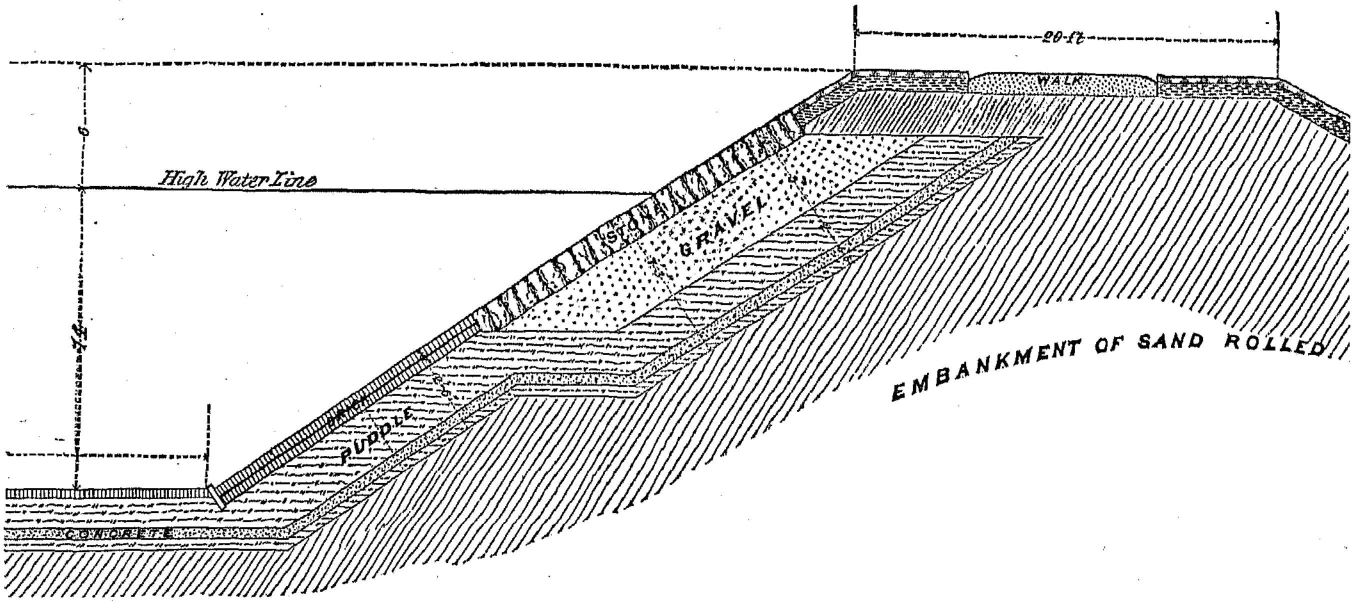
Each engine operates a bucket-and-plunger pump, with pump-cylinders 21¼ inches diameter, plungers 15 inches, and a stroke of 4½ feet. Each contains a butterfly foot- and discharge-valve hinged at the two sides and opening on a center line, with a lift of 4 inches and a diameter equal to that of the pump-cylinder and rubber seats.

The speed of the pumps averages twenty-five revolutions per minute. The accompanying record will show the work performed, etc., by the two engines during the year 1879:

Number of days' pumping	255
Number of hours' and minutes' pumping	2,867^{h} 54^{m}
Average time per day, in hours	11.23
Revolutions of engines per minute	23.968
Revolutions of engines per day	16,173.5
Revolutions of engines per month	4,124,342
Lift in feet	58.532

Pounds of coal consumed for pumping	332,826
Pounds of coal consumed for heating buildings	86,640
Total pounds of ashes, etc	63,117
Pounds of ashes, etc., per cent	15.04
Gallons of water pumped into Prospect Hill reservoir per pound of coal	1,439.755
Gallons of water pumped into Prospect Hill reservoir per day	1,312,844
Gallons of water pumped into Prospect Hill reservoir per month	479,188,160
Duty in foot-pounds	75,111,727

These engines derive their steam from a battery of four horizontal multitubular boilers, each $3\frac{1}{2}$ feet diameter by 10 feet long, containing thirty-eight 3-inch tubes, consuming 1 pound of anthracite coal to pump 1,500 gallons into the reservoir, a lift of 55 feet.



Prospect Hill reservoir, which supplies the highest portions of the city under a total head of about 297 feet above high tide, is a rectangle in plan, with the four corners cut off, 360 by $161\frac{1}{2}$ feet on bottom line, 20 feet deep, 420 by 220 feet at level of banks; slope, $1\frac{1}{2}$ to 1 inside and 2 to 1 outside; capacity at high-water line (15 feet), 7,312,203 gallons, with an area of water-surface $1\frac{3}{4}$ acre; width of top of banks, 20 feet.

The construction of the embankments may be seen from the drawing. A 6-inch layer of puddle over the whole bottom, and extending up the face with one offset, is again covered with a 6-inch layer of concrete. Above this is a layer of puddle 18 inches thick on the bottom and 30 inches thick on the face of the bank. The offset begins at about half way up the slope and extends to the top. In this a depth of 36 inches of gravel overlies the last layer of puddle, and a riprap facing of stone 15 inches thick laid in cement. The bottom, and the slope for a distance of 8 feet up to the toe of the granite paving, are covered with brick on edge laid in cement.

The gate-chamber is 10 feet 6 inches by 6 feet 10 inches, situated on the westerly corner of the reservoir, and contains three pipes, one 12-inch drain-pipe 12 inches below the bottom of the reservoir, and two 24-inch pipes, both of which are used as supply-pipes. The drain-pipe is now used for the same purpose. A bridge connects the house with the top of the bank. The inlet- or force-main is 20 inches diameter, and conveys the water from the pumping-engines through about 325 feet of main, under a head of 55 feet over the top of the embankment at the eastern corner of the reservoir, whence it extends downward between the facing of stone and the underlying clay until it reaches the bench at the foot of the gravel, at which point it emerges through the brick riprap, and runs down along the face of the same out upon a stone apron 20 by 8 feet on the bottom of the reservoir. A 20-inch pipe around the foot of the outer slope connects the force- and supply-mains, and is controlled by a valve.

From both Prospect Hill and Bleecker reservoirs a system of supply-mains of cast iron $77\frac{1}{2}$ miles long supplies the population of the city through mains of 20, 16, 12, 10, 8, 6, 4, and 3 inches, respectively, in diameter, with about 4,500,000 gallons per day. Tivoli lakes are said to supply about 2,000,000 gallons. The maximum head of water in the low service is 244 feet, and in the high service 55 feet.

The cost of the Prospect Hill reservoir and pumps and the whole system of water-works to 1880 was estimated at $800,000, and the cost of maintenance and repairs for 1879 at $57,350.

Of hydrants on the distribution mains there are 493. An analysis of the water from the gravity supply was made by Julius G. Pohle, M. D., of New York, in 1865, who found it to contain saline constituents, etc., in the proportion of $5\frac{8}{10}$ grains to the gallon. These consist mainly of the following: Chloride of sodium, carbonate of soda, chloride of calcium, chloride of magnesium, vegetable organic matter, sulphate of lime, silicic acid, carbonate of lime, and carbonate of iron.

The works are at present controlled by Mr. George W. Carpenter, superintendent.

NEW HAVEN, CONNECTICUT.

New Haven contains a population of 62,882 inhabitants, and is situated upon New Haven bay. It is largely a city of residences, with mercantile and manufacturing pursuits. Topographically the city is rather flat, but it is surrounded on the north and west by hills of considerable size. The strata composing the bed and adjoining hills are largely of Triassic formation, with outcroppings of trap-rock. The streets are laid out more or less regularly on the rectangular plan, many being heavily shaded by large elms.

The water-supply, introduced in 1862 by the New Haven Water Company, is derived from four sources, chief among which is a small stream known as Mill river. Several artificial reservoirs west of the city, known as Wintergreen lake and Maltby ponds, furnish the remainder.

Mill river discharges into the sound. At a point about 3 miles north of the city the hills between which it flows approach to within about 400 feet of each other, and here the dam has been placed. The bed of the river is rocky and somewhat shelving. The drainage area of the stream is about 56 square miles, while the total water-shed of the ponds mentioned amounts to about 5 square miles. The dam mentioned has backed the water of Mill river for a distance of about 2½ miles, and the sheet thus formed is known as lake Whitney. The maximum flow of the river is estimated at about 12,000,000 gallons daily, and the quantity constantly stored is calculated at 500,000,000 gallons, with an average depth of 20 feet. The consumption, according to indicators, averages 5,000,000 gallons per day.

The dam is constructed of cement masonry, and is 500 feet in total length, with an inner core of concrete from the foundation to the water-line, 8 inches thick. The upstream face is protected still further by a gravel bank. The thickness of the dam at top varies somewhat at different points. At the overflow the length is 150 feet; height, 38 feet 8 inches; thickness at top, 11.62 feet; at base, 34.12 feet; batter of face, 2 to 12; of back, 7 to 12. In the eastern end the height is 36 feet; thickness at top, 8.58 feet; at base, 34.83; batter of face, 2 to 12; of back, 7 to 12. On the main dam, part first, height, 38.5 feet; thickness at top, 3.25 feet; at base, 25.70 feet; batter on face, 3 to 12; on back, 4 in 12. Part second, height, 38.5 feet; thickness at top, 6 feet; at base, 25.70; batter of face, 3 to 12; on back, 4 to 12. West wing, height, 5 feet; thickness at top, 3 feet; at base, 6 feet. The gates, screens, and pipe from reservoir to pump-house are located in the gate-chamber of masonry in the west wing. The gate is 4 feet square, opening into a wrought-iron pipe 4 feet diameter, at a height of 17 feet above the base of the dam. This pipe furnishes motive-power for the armory and manufactory of the Whitney Arms Company, immediately adjoining the dam; this company formerly owned the water-rights. The water stands in the lake at a depth of 17 feet above this pipe. The waste-weir and overfall are located in the eastern end of the dam, the gate of the waste-pipe below it at a depth sufficient to drain the lake.

The bed of the lake is composed largely of rocky and gravelly soil, no great amount of mold having been present, and the water is of remarkable purity, as will be seen by reference to the appended analysis.

A deficiency of supply sometimes occurs in mid-summer, owing to lack of capacity in the main supply-pipe.

The mean annual rainfall of the district is about 45 inches, and the source of supply is practically unfailing. The system of supply to the city is a combination of gravity and pumping. The latter is accomplished partly by a couple of overshot water-wheels located in the old pump-house, and driving two horizontal pumps, and partly by pumping machinery erected in 1870 and consisting of a horizontal engine driving two horizontal double-acting pumps, located in a separate stone building about 45 by 50 by 20 feet in size, situated between the lake and the distributing reservoir, with boiler-house 35 by 40 feet. The old pump-house and pumps are thus described by the former engineer: The house is a brick building 60 by 40 feet by 25 feet high. Two wheel-pits excavated in rock are each 35 feet by 6 feet 6 inches by 17 feet deep, connected by a water-way 30 feet 6 inches by 9 feet 6 inches by 17 feet deep. The tail-water passes under the foundation-wall into an arched culvert 8 feet high by 8 feet wide by 50 feet long, and thence through an open race into the river below the dam. The water from the lake, after leaving the screens in the pipe-chamber of the dam, passes through the 4-foot iron pipe surrounded by an arched brick culvert into two cast-iron tanks containing a series of gates. Cast-iron pipes connect these tanks with two cast-iron forebays as well as with the rear valve-boxes of the pumps. The forebays conduct the water through gates at various points to the wheels. The two wheels built in 1861 by the Farrell Foundery and Machine Company of Ansonia, Connecticut, are wood and iron back-pitch overshot, 30 feet in diameter. The buckets are of wrought iron, 6 feet long. The power is transmitted through a 100-cog driving-wheel 7 feet 11¼ inches diameter, and a pinion of 43 cogs and 6 feet diameter to the pump-piston. The two crank-shafts are so arranged that either pump can be operated by either wheel, or one pump by both.

The two pumps are each single-cylinder horizontal with a diameter of 16 inches and stroke 5 feet, connected with two air-vessels 7 by 3 feet each. Each pump has a capacity of 52¼ gallons, and is driven at 12 to 12½ double strokes per minute. The wheels are run under a head of 34 feet 8 inches, and are calculated to raise 1 gallon of water 115 feet high to the reservoir with the expenditure of 5 gallons of water.

The water from these pumps is raised through 3,100 feet of cast-iron 16-inch main, with two check-valves, to the Sachem Hill distributing reservoir.

The steam-pumping machinery, built in 1870 by the Yale Iron Works of New Hampshire, was intended to assist the foregoing in particularly dry seasons, and is occasionally used in winter, and to a considerable extent in summer. The engine is a horizontal fly-wheel single-cylinder condensing engine of 26 inches diameter and 4 feet stroke. When pumping, it is run at 55 revolutions per minute, and is calculated to pump 320 gallons of water 115 feet high with 1 pound of anthracite coal. It was erected to supply 6,000,000 gallons, and has frequently reached 6,125,000 gallons per 24 hours, using 4 tons of coal for the purpose. The valve and cut-off motion is given by eccentric rods from the main shaft, and the old-fashioned slide-valve is employed.

A battery of three return tubular boilers, of Boston make, furnishing steam under a pressure of 40 pounds, are 20 feet long, with thirty-three 4-inch tubes in each. To this engine, by gear-wheels, are connected two sets of double-acting piston-pumps, one on each side. They are geared down to run at a velocity of 12½ double strokes to 55 revolutions of the fly-wheel.

The pump-pistons are plain, 21½ inches diameter and 5 feet stroke, operating a pair of flap-valves at each end of the cylinder at every stroke, one suction and one discharge, with a lift of 6 inches. They discharge into a force-main 24 inches in diameter, of wrought iron and cement, extending uphill to the Sachem Hill reservoir, a distance of 1,800 feet, under a head of 95 feet. Air-vessels are connected with the pumps at the engine-house and a siphon-condenser 24 inches in diameter. The duty of the engine has never been ascertained. This engine-and-boiler house is of the rudest character within and without.

The Sachem Hill reservoir is situated on the summit of Sachem hill at an elevation of 129 feet above high water, and a short distance from the steam pump-house (exact distance unknown). It is elliptical in plan, and divided into two compartments.

The sides are partly earth embankment and partly excavation. The inner slopes are puddle-faced, 18 inches thick, and a layer of same thickness covers the bottom. Concrete 4 inches thick is laid upon this, and the slopes are covered with a 12-inch riprap of stone in cement. The total depth is 23 feet, and the water-line is maintained at 19 feet. Dimensions on the water-line, 488 by 244 feet; inner slope 1 to 1, and outer 1½ to 1; width of banks at top, 10 feet; capacity, 10,000,000 gallons. The influent-chamber is located at the east end of the partition-wall of the reservoir; it is divided into two compartments, so that the force-main empties into the first, and the water passes thence directly into either or both divisions of the reservoir by means of 12-inch iron pipes laid through the other compartment on which the valves and gates are situated, or it can pass through a 16 inch cement-lined wrought-iron pipe laid in the partition-wall of the reservoir directly to the effluent-chamber.

The dimensions of the effluent-chamber are: foundation, 28 by 24 feet by 3 feet deep; walls, 6 feet thick at bottom, and 2 feet 6 inches at top; division-wall forming the two chambers, 10 by 6 feet by 18 feet 7 inches deep.

The effluent-chamber has a depth of 20 feet 1½ inch, and is otherwise a duplicate of the influent, with similar screens, etc.

From the water-works to the city there is laid one 16-inch cast-iron main, 1½ mile long, three 16-inch wrought-iron and cement pipes of 3 miles total length, and 9 miles of 12-inch pipe of same material. The distribution is accomplished through 102 miles of pipes 4, 6, 8, 10, 12, and 16 inches, respectively, in diameter, and mostly cement-lined wrought iron.

Considerable lengths of a patent pipe made by D. G. Phipps, the present engineer, are used, and seem to give entire satisfaction. There are in the city of New Haven some remarkable cases of interior corrosion, 16-inch pipes reduced to an effective diameter of 12 inches, and 12 to 9 inches.

Nine hundred and four cement-lined gates are used.

The number of service-pipes is about 6,500, and average consumption 5,000,000 gallons per day.

The first cost of the works was $357,000. The cost to date is not known. Cost of maintenance and repairs for 1879, not including interest, was about $35,000. The hydrants used are made by Bigelow, of New Haven, and about 700 are in use.

Appended will be found a statement of original costs relating to construction in 1862:

Approximate estimate of work done and materials delivered, up to and including December 31, 1862.

Flowage	$6,000 00
Roads	5,000 00
Bridges	20,000 00
Dam	46,840 00
Pump-house	9,959 10
Wheels and pumps	18,000 00
Reservoir	45,160 00
Distribution	119,975 00
Total	270,934 10
Less 10 per cent. reserved	27,093 41
Total	243,840 69
Lands, water-rights, etc	75,000 00
Total amount of estimate	318,840 69

Brought forward		$318,840 69
Work remaining to be done to complete the contract:		
Dam	$3,160 00	
Pump-house	40 90	
Reservoir	840 00	
Distribution	25 00	
		4,065 90
Total		322,906 59
Add reserve percentage		27,093 41
Total		350,000 00
Paid engineer account		7,000 00
Total		357,000 00

Five analyses of the water of lake Whitney give the following results:

Constituents.	Analysis.				
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Organic matter, grains per gallon	1.0	6.0	1.0	8.0	7.0
Inorganic matter, grains per gallon	4.3	3.6	3.7	3.2	3.3

The present engineer is D. Goffe Phipps, esq.

SALEM, MASSACHUSETTS.

Salem contains a population of 27,563. Located on a sandy strip of land between the North and South rivers, two inlets from the Atlantic ocean, it is quite level, with streets laid out at right angles. Its interests are maritime and manufacturing.

The city was one of the earliest in this country to utilize a general water-supply. This water-supply was introduced in 1797 by a number of private citizens, and was brought in 3-inch pipes made of saplings, the head being but a few feet, and the reservoir from which they started consisting of a large cask sunk in the edge of a small pond.

From 1797 the works continued to enlarge and extend under the proprietorship of corporations until January, 1866, when the city began the construction of water-works of much greater capacity. The cost of the old works had reached the sum of over $250,000.

The system as now existing is pumping to a distributing reservoir or to a stand-pipe at will, the water being obtained from Wenham lake, 4½ miles from the city. This lake is situated partly in the town of Beverly and partly in the town of Wenham, with an area of 320 acres and average depth of 53 feet. Its elevation is 31 feet above high tide, and yields an estimated minimum of 2,000,000 gallons per day. It is supposed to derive its water from springs in its bed of sand. Its water-shed is 1,716 acres. A swamp, known as Wenham swamp, a short distance to the northwest, is separated from it by a porous strata, and, owing to an elevation above the lake of a few feet, may furnish much of the supply. The storage supply is practically unlimited.

The water is drawn from the southerly end of the lake by means of a cast-iron pipe 36 inches in diameter and 175 feet long. Its open end projects 32 feet into the lake, and the other enters a stone gate-chamber 10 by 8 feet by 13 feet deep beneath the engine-house.

The well-chamber is divided by a vertical wall of masonry, with four gates, each 2 by 3 feet, one above the other, and regulated by a set of hoisting machinery. Double screens of ⅛-inch mesh copper wire are also used in the chamber opposite these openings. The lake end of the pipe is bell-mouthed and slightly turned upward (with a grating) to facilitate inspection from above. Leaving the well-chamber, the water passes through a brick conduit 26 feet long by 7 feet wide into the pump-well. The latter, as described in the report of the commissioners for 1869, is of masonry lined with brick, 1 foot thick, and 31 feet long by 16 feet wide by 14 feet deep. The bottom is built upon quicksand, and consists of a paving of brick laid upon a flooring or foundation of 2 feet of concrete resting upon a platform of timber. The capacity of the pump-well and brick conduit is 45,000 gallons.

The rainfall at the pumping station was 60.94 inches in 1878, and 39.69 inches in 1879, an average of 50.315 inches for each of the years named.

The engine-house is a plain brick building, 87 by 57 feet by 27 feet high. The engine-room is 53 by 50 feet by 21 feet high, and the boiler-room is 53 by 33 feet by 25 feet high, containing two Worthington duplex compound pumping-engines of 5,000,000 gallons capacity each in 24 hours. The diameter of suction-pipe is 24 inches; of water-piston, 22 inches; the stroke is 48 inches; diameter of low-pressure steam-cylinders, 36⅝ inches; of high-pressure, 21 inches.

Each pump-cylinder contains 64 rubber valves, each 8 inches in diameter. The average speed is 48 strokes per minute. The pumps are run a month at a time, alternately, during about 11 hours per day, five days in the week.

The water is forced through 5,600 feet of 30-inch cast-iron main, under a pressure of 114 feet head, into the distributing reservoir on Chipman's hill, in the town of Beverly. The thickness of the pipe varies from 1¼ inch at the pumps to $\frac{3}{4}$ inch at the reservoir. The space occupied by each pumping-engine on the floor-line is 30 by $9\frac{1}{2}$ by $9\frac{1}{2}$ feet. The ratio of expansion of the steam in the compound-cylinders is as 3 to 1.

The air-pumps, four to each engine, are each 14 inches stroke and 2 feet diameter; the jet-condensers, 24 inches diameter by 4 feet. A battery of two multitubular boilers furnishes the necessary steam. They are each horizontal, 13 feet long by 63 inches diameter of shell, with eighty 3-inch tubes in each. A new battery, just completed, contains two boilers, each 66 inches diameter by 14 feet long, with ninety 3-inch tubes in each. The evaporative power of the old battery is $9\frac{1}{2}$ pounds of water to 1 pound of anthracite coal; of the new, $10\frac{1}{2}$ pounds of water to 1 pound of coal. The record of these engines for 1879 may be seen from the appended statement from the last report.

The actual duty of the engines is 55,000,000 foot-pounds, and 75,000,000 have been obtained. The guaranteed duty was 60,000,000 foot-pounds.

Time of pumping, hours	2,918.9
Coal consumed, pounds	1,286,270
Water raised to reservoir, gallons	707,552,450

The reservoir, situated on Chipman's hill, is an earthwork 400 feet square and 23 feet deep, and contains 20,000,000 gallons. The elevation of the top surface is 145 feet above high tide. The width of the top of the banks is 15 feet. The interior and exterior slopes are $1\frac{1}{2}$ to 1. A wall of puddle is built through the center of the banks for their entire length, and for a height of $12\frac{1}{2}$ feet above the reservoir bottom it is 10 feet thick, with a thickness of 5 feet for the rest of its height. These puddle-walls are connected with a layer of puddle under the whole bottom of the reservoir from 2 to 4 feet thick. Upon this bottom layer is a bed of gravel, 1 foot thick, upon which a cobble paving of stone is laid. Around the inlet-pipe this paving becomes cement masonry, to prevent damage by the inflow of the water, and is about 50 feet square. The face of the banks is covered with 1 foot of gravel and 15 inches of quarried granite, except at the inlet, where 9 inches of concrete replaces the gravel, and the whole paving is laid in cement. The two effluent-pipes from the reservoir are of 20 inches diameter, one from each of the corners on the south side, and join, a short distance beyond, into one 20-inch main supply-pipe to the city. They take the water from screen-boxes, with copper $\frac{1}{8}$-inch mesh-wire screens, at a point 2 feet from the bottom of the reservoir. Brick piers support these pipes as well as a 12-inch iron waste-pipe, as they pass through the banks.

The force- and supply-mains, on opposite sides of the reservoirs are directly connected by a branch pipe, 30 inches in diameter, passing outside the foot of the western bank; and at a point 510 feet from where it joins the supply-main a small stand-pipe has been erected. The latter is of wrought iron, 30 inches diameter, from $\frac{5}{16}$ to $\frac{1}{4}$ inch thick, and 55 feet high, the top being 25 feet higher than the reservoir. In this arrangement the water may be supplied direct to the city around the reservoir.

The main supply-pipe is 20 inches in diameter, 21,453 feet long, and of cast iron. Where it crosses the river it takes the form of an inverted siphon for a distance of 53 feet, and extends below low water to a depth of $14\frac{1}{2}$ feet. The siphon is 30 inches in diameter.

The distribution is carried out in wrought-iron cement-lined pipes, 12, 10, 8, 6, and 4 inches, respectively, in diameter, the total length of the system being 86 miles, 43 of which are in the town of Beverly.

There are in use (1880) 343 fire-hydrants of the Lowry make, and about 480 Coffin patent gates, made by the Boston Machine Company.

The total consumption averages from 2,000,000 to 2,500,000 gallons per 24 hours, with 4,550 service-pipes or connections.

The first cost of the works may be seen from the accompanying list:

	Actual cost.		Actual cost.
Pumping-engine	$35,117 75	Siphon and bridge	$33,881 00
Engine-house	103,243 29	Contingencies and engineering, 5 per cent	55,805 78
Mains and stand-pipe	321,278 59		
Distribution pipes	253,607 97	Total	930,586 66
Reservoir	127,652 28		

The total cost to December 1, 1879, was $1,388,155, and the annual cost of maintenance for 1879 was $21,114, exclusive of interest.

The following meters are in use:

Kind of meters.	3-inch.	2-inch.	$1\frac{1}{2}$-inch.	1-inch.	$\frac{3}{4}$-inch.	$\frac{5}{8}$-inch.	$\frac{1}{2}$-inch.	Total.
Worthington	....	2	4	51	....	15	....	72
Union rotary	...	1	2	4	4	16	....	27
Ball & Fitts	....	....	....	1	....	1	...	2
Gem	1	....	....	5	....	....	....	6
Crown	....	....	....	....	....	....	1	1
Weir's motor	....	....	....	7	....	....	....	7
Indicators	....	....	....	2	....	....	....	2
Total	1	3	6	70	4	32	1	117

An analysis of the water of Wenham lake, by Dr. Jackson, February 17, 1864, shows that one imperial gallon of this water, equal to 10 pounds avoirdupois, yields:

	Grains.
Organic (vegetable) matter	1.12
Chloride of sodium (sea-salt)	0.40
Sulphate of lime	0.38
Oxide (originally crenate) of iron	0.20
Insoluble siliceous matter	0.12
Total impurity	2.22

The present superintendent is James W. Lyon, esq.

CINCINNATI, OHIO.

Cincinnati contains a population of 255,139, and is situated on the northern bank of the Ohio river, 501 miles above its mouth. Its interests are commercial and manufacturing. The site of the city is a semi-circular basin, rising in two distinct terraces 50 and 108 feet, respectively, above the river, and bordered on the east, north, and west by bluffs 400 feet high, of limestone, belonging to the Hudson River epoch of the Trenton period in the Lower Silurian. The streets are very regular.

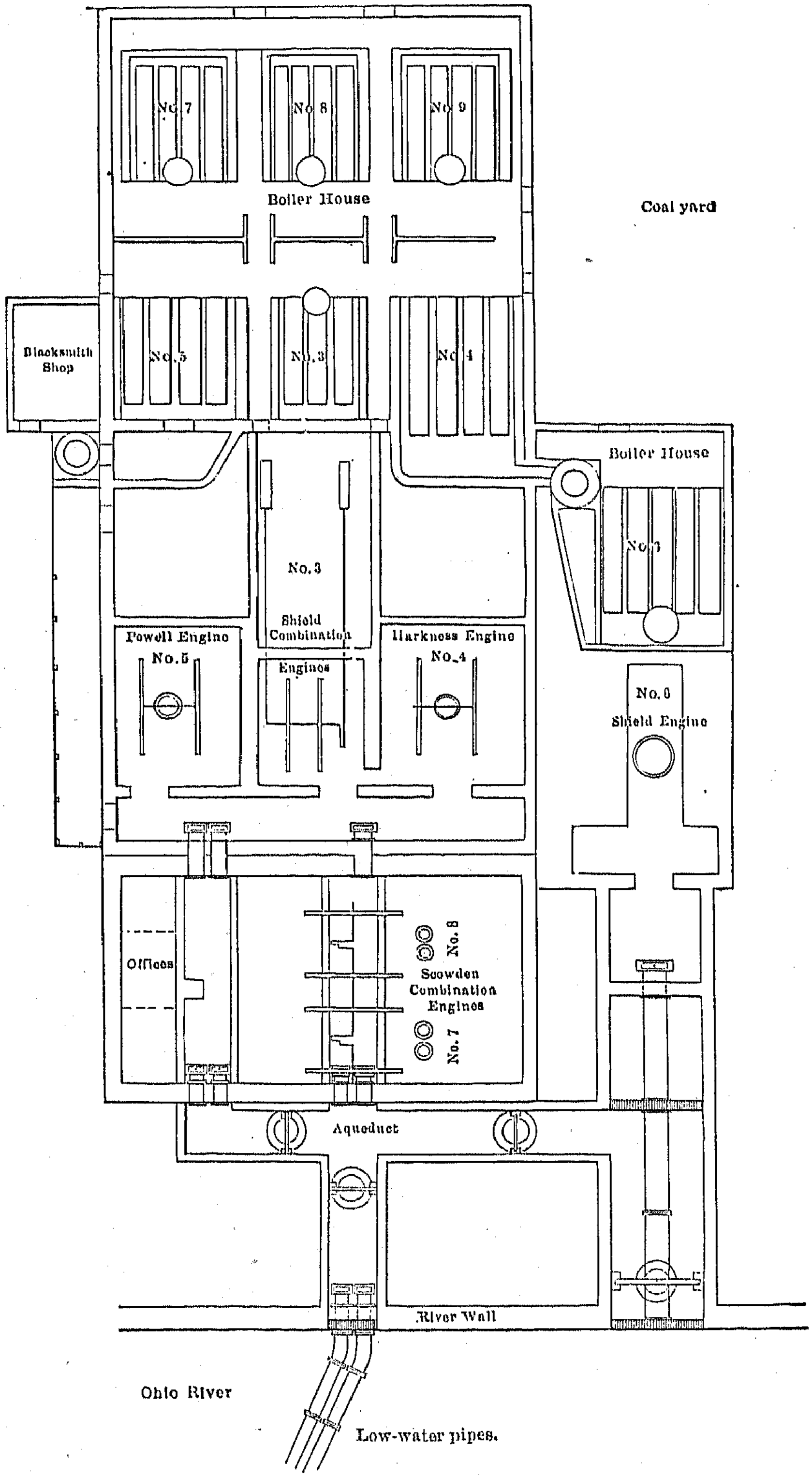
In 1826 a supply of water, introduced into the city by a private company, was pumped from the Ohio river. In 1839 the works were purchased by the city, and are now managed by a board of city commissioners. The water is taken from the river at a point nearly opposite the center of the city, about 5 miles below its upper limit, through inlets of masonry and iron pipe. A kind of wall is constructed near the river channel, and forms the face in which the mouths of the inlets are situated. These inlets consist of two stone aqueducts, one 10 feet wide by 21 feet, and 134 feet long from the south end of the pump-house. On the river-end a further extension is made by two 40-inch pipes, resting on the river-bed and extending to the channel. The other aqueduct or conduit is 20 feet wide by 19 feet, and 134 feet long, as before, with a 60-inch iron pipe on the inside, extending a few feet in front of the conduit mouth for an independent supply to pumping-engine No. 6. This, however, has fallen into disuse, the river deposit having completely stopped it up. All these conduits are cleaned out once a year.

The dimensions of the engine-house, and the number and locations of the pumping-engines, may be seen from the accompanying plan of the present main works.

The oldest of the engines in use at present is known as the "No. 3 combination", a sketch of which is shown in the cut on p. 103. Owing to the tremendous rise and fall of 60 feet to which the river is liable, the pumps of each set of engines are located in the bottom of pits from 50 to 60 feet below the floor of the engine-house, upon which their respective cylinders rest.

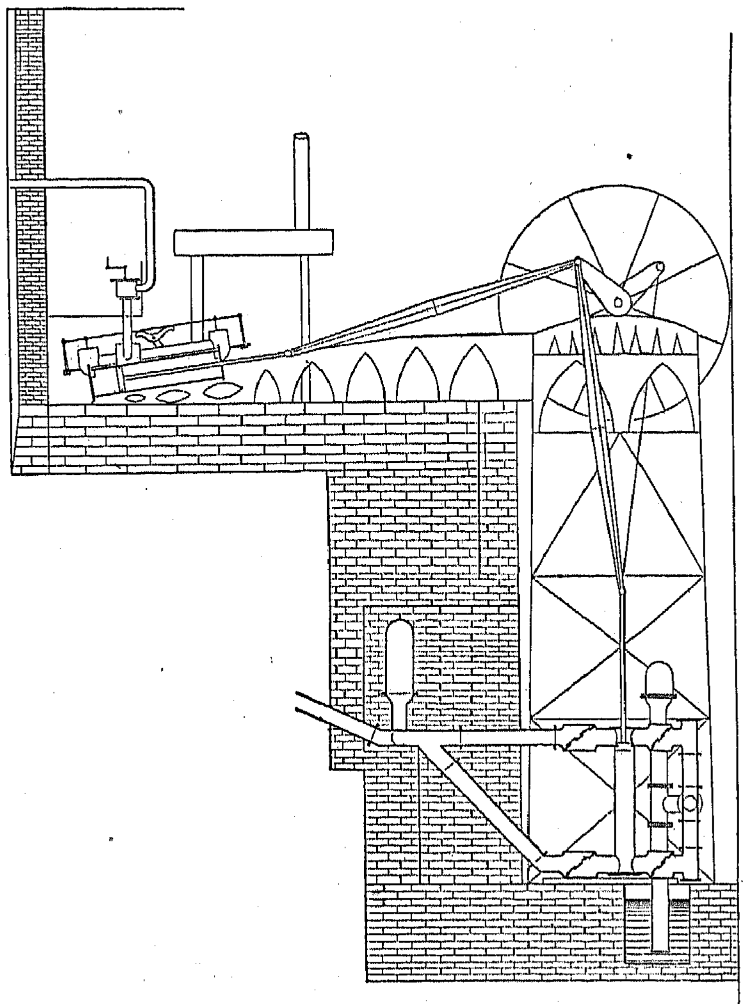
The No. 3 combination, built in 1845 by Shield & Yeatman, of Cincinnati, consists of two horizontal steam-cylinders driving a pair of fly-wheels on the same shaft, and, by connections with the same crank-pins, vertically acting pump-rods operate the two pumps in the pit below. These pumps are non-condensing, with steam-cylinders 23 inches in diameter; pump-pistons, double-acting, 14 inches in diameter; stroke of both, 10 feet. The steam is distributed by puppet-valves, operated by a cam lifting the valve-levers, as shown. There are two brass hinge-valves in each suction- and delivery-chamber, 8 by 10 inches, with a free lift. The speed of the engine averages 12 or 14 revolutions per minute. During 1879 the pumps were in almost continual operation 24 hours per day for 241½ days. Their duty is small, showing only 43,566,178 foot-pounds of work when tested in 1872, although given at 48,000,000 in 1880. The cost of the "Combination" is given at $85,000 originally, but much has since been spent in repairs and alterations. The work done in 1880 can be seen from the table of operation for all engines, given on page 104. The pump-main is 750 feet long by 17 inches in diameter, with a maximum pressure on the pumps of 224 feet when supplying the middle service. Capacity, 5,000,000 gallons per day, approximately. A battery of three horizontal boilers, each 48 inches in diameter by 26 feet long, of the Cornish type, with eight flues 8 inches in diameter, furnishes steam for the combination. These boilers have 44 square feet of grate-surface and an evaporation of 8½ pounds of water per pound of coal.

As the second engine, known as "No. 4", is almost exactly like No. 5, the third, a description of the one will answer for both. A sketch of it is shown on p. 105. It is a condensing-engine, with double-acting piston-pumps, the same as in No. 3, and with a capacity of 4,500,000 gallons per day. The steam-cylinder is 45 inches in diameter. Pump-piston of No. 4, 18½ inches; of No. 5, 19½ inches diameter, and stroke of all, 8 feet. Double-beat puppet steam-valves are operated by cams and plug-rods. The pump-valves are of same design and size as in No. 3. Average speed of engines per minute equal to 16 revolutions. No. 4 pumped during 320$\frac{3}{10}$ days of 24 hours in 1879, and 262¾ days in 1880, through 750 feet of 20 inch force-main against a static head of 165 feet. The jet-condenser connected with it is 4 by 4 feet, with an air-pump 3 feet diameter by 3 feet stroke. The duty-trial made at same time as last showed 37,789,990 foot-pounds, and in 1880, 38,014,283 foot-pounds. The two engines, Nos. 4 and 5, are used only for the low-service. The cost of the former was $30,000, and it was built by Harkness & Son, of Cincinnati, in 1850; the latter by Powell & Son, of Cincinnati, in 1854, for $35,000, and both after designs by T. R. Scowden, C. E. Two batteries of 4 boilers each, and similar to those last described, furnish steam for the two engines, No. 4 being 30 feet long by 72 inches diameter, with three flues 17 inches, and two 21 inches diameter, and No. 5 battery being 30 feet long by 54 inches diameter, with eight 8-inch flues and external furnaces. Those for No. 4 have grate-surface of 133 square feet and evaporation of 8 to 1, and for No. 5 grate-surface of 64½ square feet, evaporating 8½ pounds of water to 1 pound of coal.



PLAN OF MAIN PUMPING-WORKS.

Engine No. 6, which is used as auxiliary to the others in the works, was built in 1865 by the water-works, after designs by George Shield, at a cost of $200,000, and is of theoretical capacity of 20,000,000 gallons, but actual available capacity of only 12,000,000 gallons per day. It is a condensing vertical-acting Bull-pump, the pump-cylinder being directly beneath and the plunger operated by an extension of the piston-rod. The steam-cylinder is 100 inches in diameter and the stroke 12 feet. The steam-valves are balanced puppet, with buffet on the plug-rods. The condenser is of jet pattern, 6 feet diameter by 3½ feet deep, with an air-pump 32 inches diameter by 12 feet stroke, located immediately beneath the steam-cylinder, and having its piston operated by the rod of the steam-piston. The vacuum obtained is equivalent to but 14 inches. The duty of the engine averages from 21,500,000 to 29,750,000 foot-pounds, and it is used for both low and middle service against lifts of 179¼ feet and 247$\frac{33}{100}$ feet,



SKETCH OF "NO. 3 COMBINATION" PUMPING-ENGINE.

respectively, including friction. On the trial-test in 1872 the duty developed was 23,580,687 foot-pounds. The water-cylinder contains one double-acting piston-plunger, 46 inches diameter, with 12 feet stroke. There are two valve-chambers at each end of the cylinder, which contain 7 rubber-faced iron puppet-valves each. They are 14 inches diameter, with a lift of 2½ inches. The velocity of the engine averages 12 double strokes per minute when in operation. There is a battery of five boilers, with external furnaces, each boiler being 28 feet long by 72 inches diameter, and containing each five flues—three of 17 inches and two of 21 inches diameter. They have a surface of 133¾ square feet, and evaporation of 10.12 pounds of water per pound of coal supplies the steam to operate it. The coal used is first-quality bituminous for all the boilers in the works.

Engine No. 6 is connected by a 50-inch main 750 feet long, to the old or Third Street reservoir, and also with the Eden Park basin by 3,300 feet of 46-inch main, enabling water to be forced into either by simply operating a valve.

Engines Nos. 7 and 8, duplicates of each other, were built in 1874 by the Cincinnati Engine & Hydraulic Works, after designs by T. R. Scowden, at a cost of $204,000. They are duplex non-condensing engines, with steam-cylinders 28 inches diameter; pump-cylinders, 23½ inches; plungers, 16½ inches by 8 feet stroke, the pumps being of the Thames-Ditton variety. The average speed when in operation is 14 revolutions per minute, and in 1880 they were operated, No. 7 about 283½ and No. 8 about 267 days of 24 hours. The steam double-beat valves are operated by rocking-cams and plug-rods. Their duty averaged in 1880 about 39,000,000 foot-pounds. In the pump-chambers there are 7 receiving and 6 discharge brass puppet-valves, the former being 10 inches and the latter 12½ inches diameter. In the eduction main are 7 check-valves of same dimensions as the receiving valves. The force-mains from the pumps to the reservoir in Eden park is 24 inches diameter by 3,690 feet long. The capacity of the two engines is 15,000,000 gallons per day, pumped into the reservoir against a static head of 220 feet. The steam is derived from three batteries of four boilers each, with shells 48 inches diameter by 26 feet long, each containing five flues—two of 11 inches, two of 12 inches, and one of 16 inches diameter.

Operation of the Cincinnati pumping-works for the year 1880, showing the performance of each service and engine.

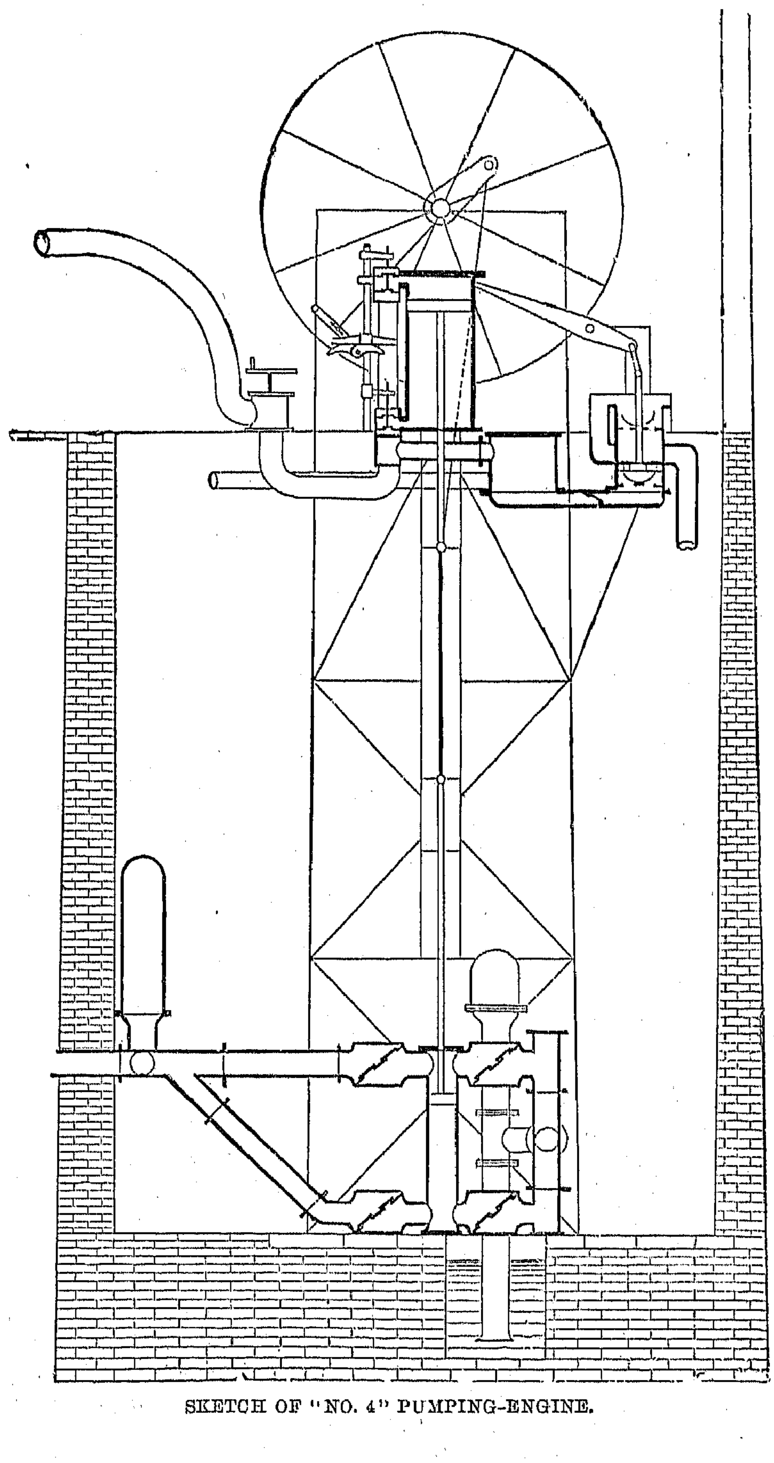
	Running time.		Revolutions made.		Gallons of water delivered into reservoirs.	Gallons of water per revolution.	Percentage of total amount of water pumped.	Coal consumption.			
	In days of 24 hours each.	In hours and minutes.	Total.	Average per minute.				Raising steam and banking—pounds.	For pumping—pounds.	Total pounds.	Daily average in tons.
Low service:		H. M.									
No. 3, Combination engine	37.71	905 5	662,899	12.21	198,869,700	300.00	2.7	68,013	710,628	770,641	....
No. 4, Harkness engine	262.79	6,306 50	5,925,002	15.66	1,203,863,575	203.18	16.5	} 126,412	7,837,736	7,964,148	....
No. 5, Powell engine	200.25	4,805 35	4,273,735	14.82	919,009,185	215.04	12.6				
No. 6, Shield engine	0.46	11	2,294	3.47	4,129,200	1,800.00	0.1	15,078	13,414	28,492	....
Total for Front street, 1880	501.21	12,028 30	10,863,930	....	2,325,871,660	....	31.9	210,403	8,561,778	8,772,181	12.00
Total for Front street, 1879	525.96	12,826 20	11,140,401	....	2,612,706,830	....	40.6	348,425	9,924,224	10,272,649	14.07
Middle service:											
No. 3, Combination engine	162.88	3,909 5	2,742,331	11.69	823,060,520	300.13	11.3	116,612	3,617,291	3,733,903	....
No. 6, Shield engine	43.92	1,054 5	281,834	4.46	507,301,200	1,800.00	7.0	50,935	3,453,919	3,504,854	....
No. 7, Scowden engine	283.63	6,807 25	5,376,688	13.16	1,874,687,055	348.66	25.7	} 246,932	18,789,624	19,036,556	....
No. 8, Scowden engine	266.83	6,404 15	5,038,570	13.11	1,754,451,160	348.20	24.1				
Total for Garden of Eden, 1880	757.26	18,174 50	13,439,423	....	4,959,499,935	....	68.1	414,479	25,860,834	26,275,313	35.99
Total for Garden of Eden, 1879	633.59	15,206 15	11,694,292	....	3,844,990,342	....	59.4	319,486	18,351,935	18,671,421	25.58
Total for both (main works), 1880	1,258.47	30,203 20	24,303,353	....	7,285,371,595	....	....	624,882	34,422,612	35,047,494	47.99
Total for both (main works), 1879	1,159.55	27,832 35	22,834,783	....	6,457,697,172	....	....	667,911	28,276,159	28,944,070	39.65
Total Mount Auburn high service, No. 1 old power, 1880.	196.79	4,723	4,022,020	14.19	563,082,800	140.00	......	378,000	2,620,588	2,998,588	4.10
Total Mount Auburn high service, 1879.	230.64	5,562 45	6,812,792	....	567,796,271	....	......	393,000	3,090,710	3,483,710	4.77

	No. gallons water pumped with 1 pound coal.		Lift with friction, in feet.	Duty performed in foot-pounds per 100 pounds coal, with frictional resistance and total coal used.		Stores used.				Lubricants.	
	Into reservoir.	Raised 100 feet high.		For 1879.	For 1880. (*a*)	Oil, gallons.	Tallow, grease, pounds.	Cotton waste, pounds.	Packing, pounds.	Cost.	Cost per 1,000,000 gallons.
Low service:											
No. 3, Combination engine	255.11	446.01	174.83	42,474,029	37,197,321	21	23	42	10¼	$24 71	$12 42
No. 4, Harkness engine	} 266.55	455.80	171.00	39,218,632	38,014,283 }	32½	57	95	97½	41 45	3 44
No. 5, Powell engine						33½	40½	95	82	41 55	4 52
No. 6, Shield engine	144.92	259.77	179.25	26,251,775	21,605,474	1¾	....	6	14	1 58	39 50
Total for Front street, 1880	265.14	453.39	171.00	....	....	88¾	120½	238	182¾	109 29	4 70
Total for Front street, 1879	254.33	453.80	174.50	....	....	114¼	98	246½	110½	137 50	5 26
Middle service:											
No. 3, Combination engine	220.43	531.24	241.00	45,417,212	44,304,907	88¾	78½	107	77	95 01	11 65
No. 6, Shield engine	144.74	357.90	247.33	....	29,850,494	32¾	15	30	125	32 90	6 37
No. 7, Scowden engine	} 190.64	407.07	245.00	40,744,354	38,053,517 }	231¾	83	200	45½	200 26	10 68
No. 8, Scowden engine						221¼	103½	187½	148⅝	194 40	11 08
Total for Garden of Eden, 1880	188.70	402.46	245.00	....	....	574½	280	524½	396⅛	522 96	10 54
Total for Garden of Eden, 1879	205.93	509.32	247.33	....	....	454½	227¾	623	350½	466 80	12 14
Total for both (main works), 1880	207.87	463.55	223.00	....	....	663¼	400½	762½	579	602 25	8 08
Total for both (main works), 1879	223.11	496.60	218.10	....	....	568¾	325¾	869½	460¾	604 30	9 37
Total Mount Auburn high service, No. 1 old power, 1880.	187.78	550.20	293.00	41,312,709	45,886,944	48¾	....	188	207	36 30	6 43
Total Mount Auburn high service, 1879.	171.62	502.84	293.00	....	....	57	....	171½	167½	42 10	7 04

a Inferior coal used during part of year.

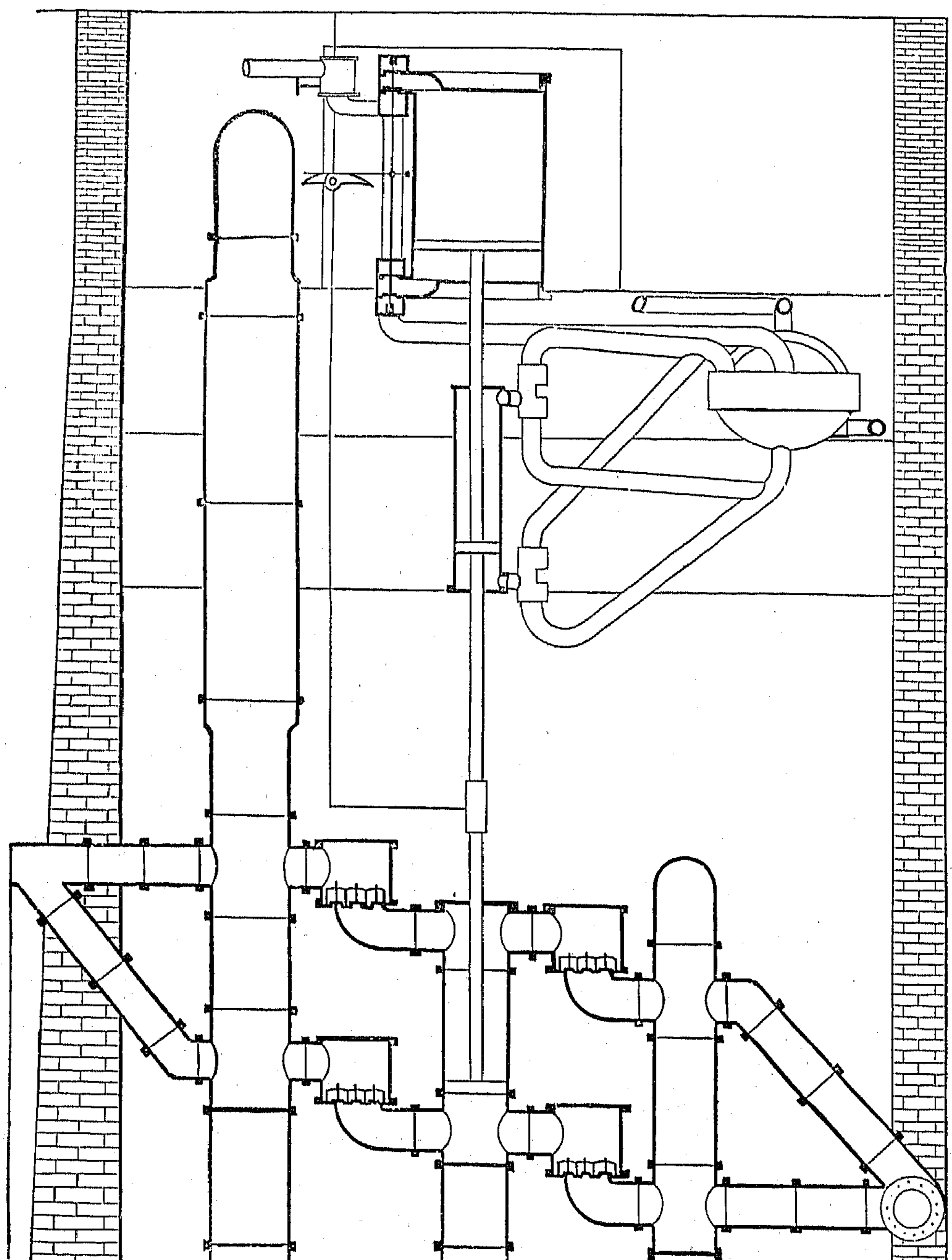
Grand total of all the services.

Services.	1876.	1877.	1878.	1879.	1880.
Water pumped from river (low and middle services), in million gallons	6,321	6,005	6,274	6,457	7,285
Water pumped by high service, second lift, in million gallons	520	502	500	508	563
Coal consumed during the year for pumping purposes, in tons	18,495	16,395	16,306	16,213	19,023
Daily average consumption of coal, in tons	50.9	44.9	44.7	44.3	51.97
Pounds of coal for each million gallons of water pumped	5,399	4,970	4,745	4,597	4,848
Current pumping expense for the year	$104,972 25	$93,641 44	$94,496 88	$102,505 59	$114,923 32
Daily average pumping expense	$286 80	$256 55	$258 89	$280 84	$314 00
Cost of pumping one million gallons into reservoir (water pumped by high service not considered).	$16 60	$15 59	$15 06	$15 88	$15 77
Average price of coal per ton	$2 77	$2 38	$2 43½	$2.58½	$2 86



SKETCH OF "NO. 4" PUMPING-ENGINE.

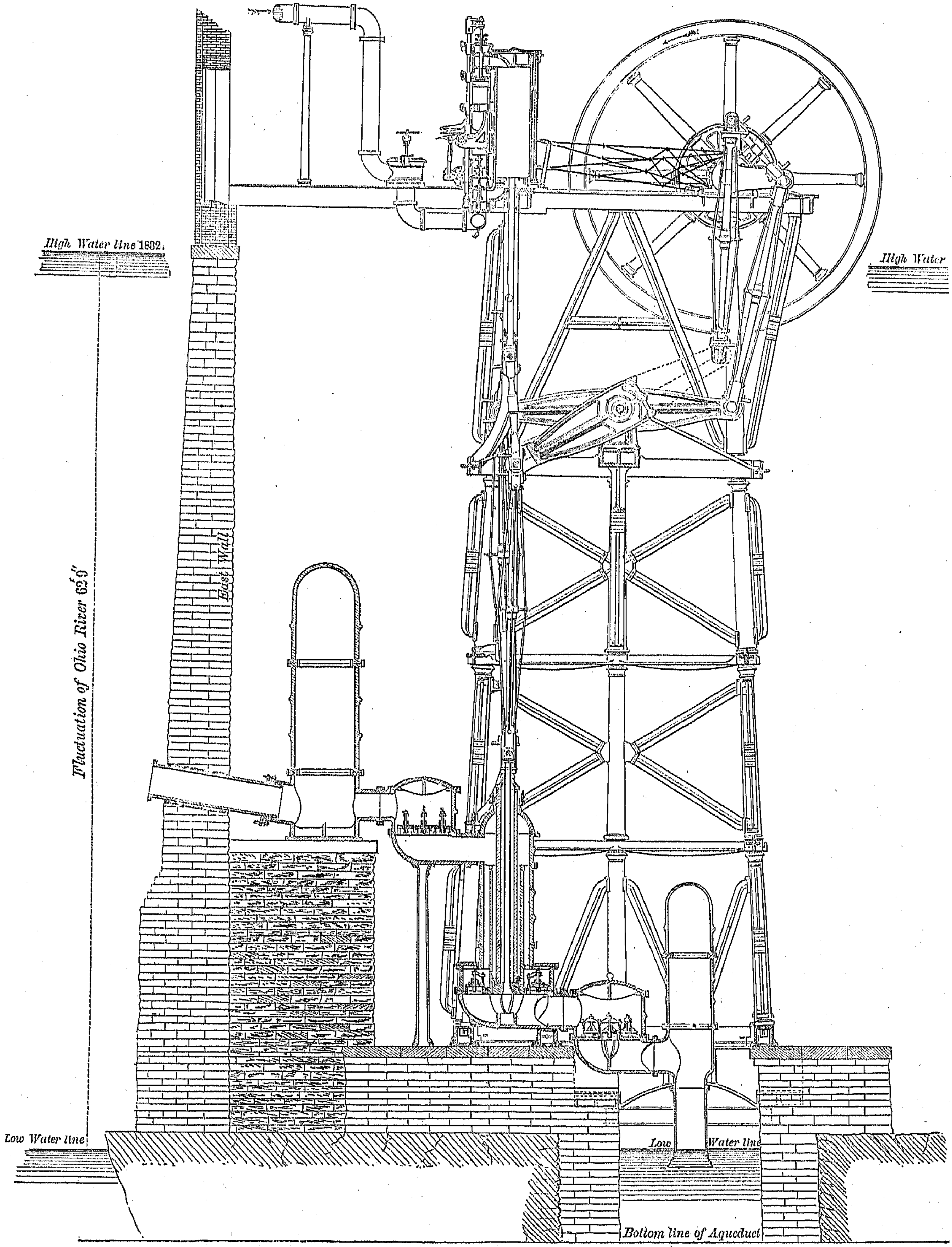
There are in use two reservoirs, one of which is known as the old Third Street and the other as the Eden Park basin. The former is rectangular in plan, divided by a wall into two compartments. One of the latter is at the bottom, 172½ by 108½ feet, and the other 158 by 108½ feet, with interior slope of about 1 to 6. The dimensions at level of banks are, respectively, 180¾ by 116¾ and 163½ by 116¾ feet. The capacity of the former, at 22 feet depth, is 3,249,628 gallons, and of the latter, 2,961,024 gallons. Total depth, 24 feet. The reservoir is at an altitude of 165 feet above the pumping-works, and is entirely above level. The walls have a hollow space between them, and are 7½ feet thick at top by 10 feet at base, and are tied together at intervals. This basin serves for the low service, and is the recipient of water pumped by engines Nos. 3, 4, 5, and 6.



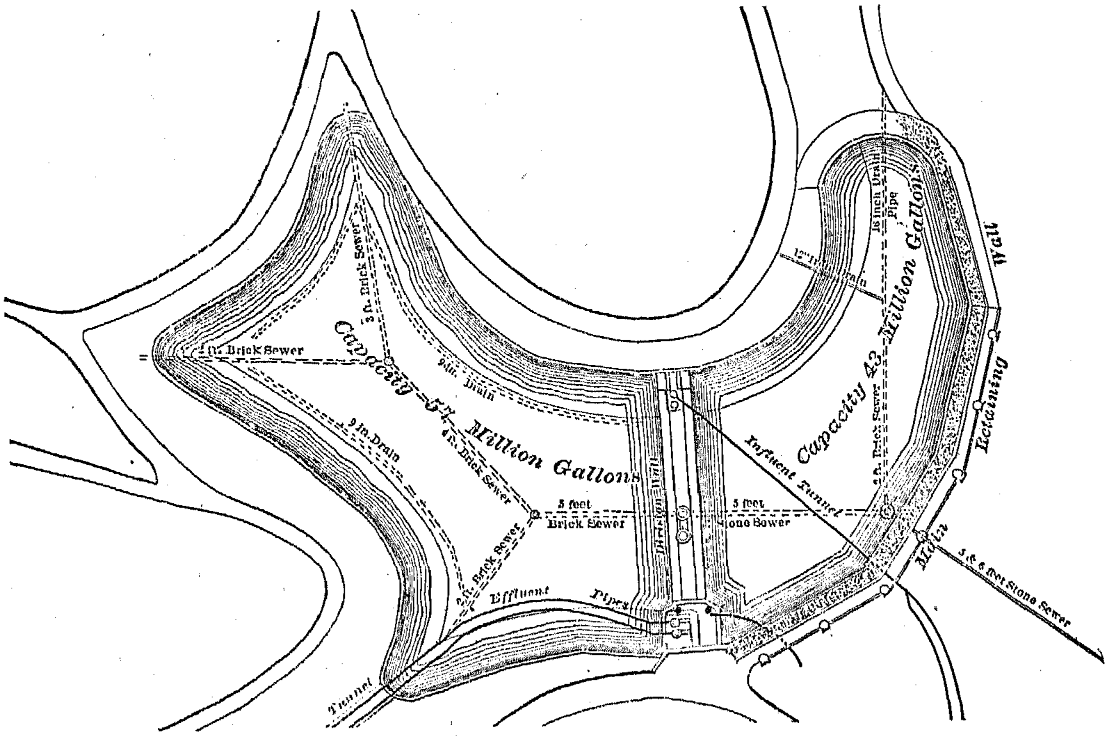
SKETCH OF "NO. 6" PUMPING-ENGINE.

The Eden Park basin is shown in plan in the cut on p. 108. It is very irregular in outline, and is separated by a masonry division-wall into two compartments. A heavy retaining-wall at one end is 1,251 feet long, and is shown in section in the cut, which gives the dimensions. The top of the wall, being used as a roadway, is supported by eight elliptical arches, 55 feet span by 8 feet rise. The division-wall is 400 feet long, 30 feet thick at base by 10 feet at top, and has an effluent-chamber at the western end and an influent-chamber at the eastern end. A tunnel under the hill to the north, 12 feet in diameter and 1,100 feet long, of brick, conducts the effluent-pipes to the supply-pipes.

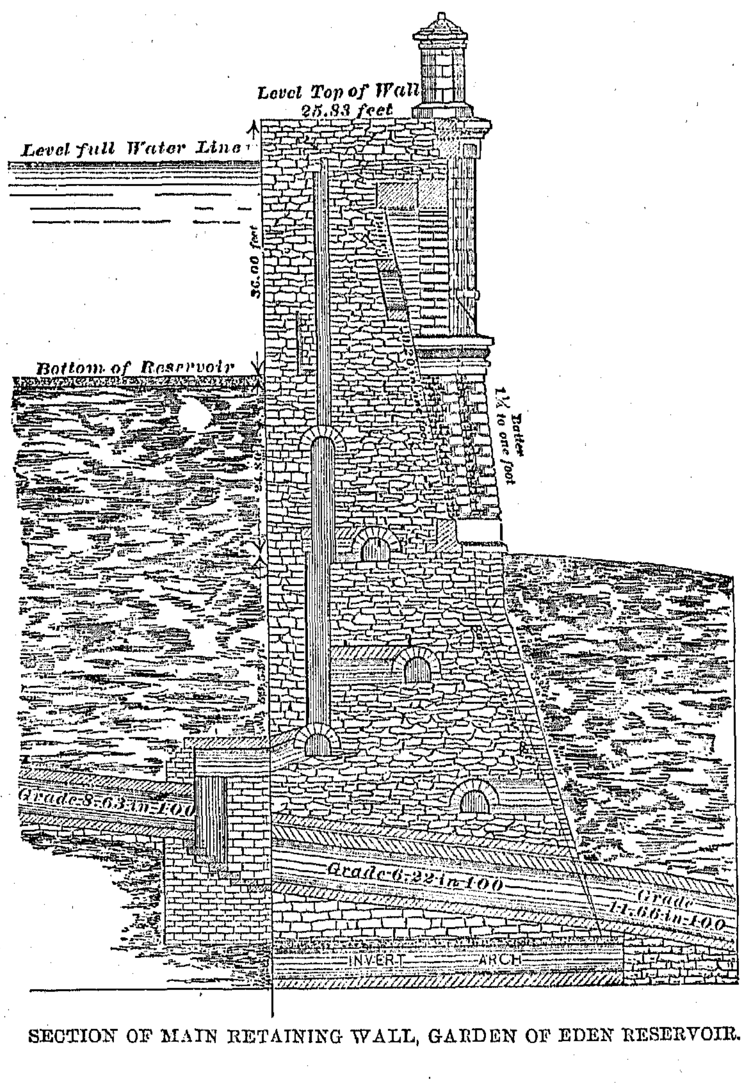
The depth of water in front of the main retaining-wall is usually only about 29 feet. Total area of high-water surface is 7 acres, and capacity 100,000,000 gallons. The division- and retaining-wall are both of rubble masonry.



VERTICAL SECTION OF DIRECT-ACTION PUMPING-ENGINE FOR THE CINCINNATI WATER-WORKS.



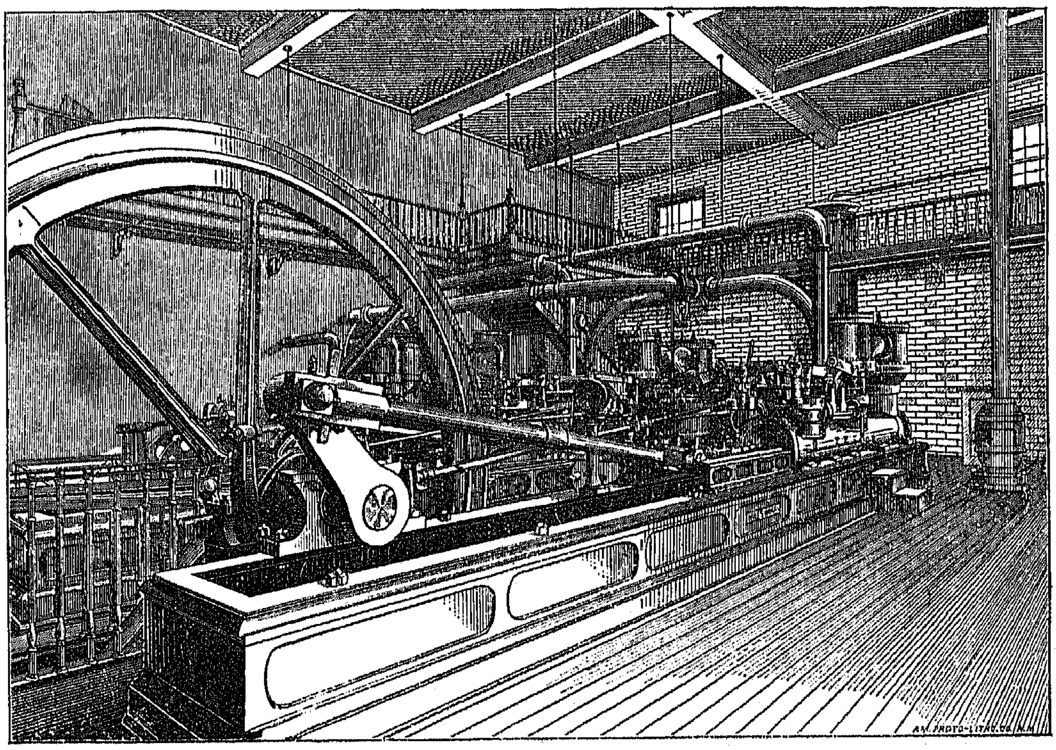
PLAN OF EDEN PARK RESERVOIR.
Built, 1866-1876; cost, $1,660,000.



SECTION OF MAIN RETAINING WALL, GARDEN OF EDEN RESERVOIR.

The total cost of the basin was $1,660,000, $1,000,000 of which was spent upon the retaining-wall. The water can be made to cascade over the division-wall, which is $67\frac{1}{2}$ feet high, but the depth is usually maintained at 29 feet. The effluent-chamber is made pentagonal in shape, with two compartments, one a dry well. The oval water-ways are controlled by valves. From the wet well two 35-inch iron distributing mains pass along under the bottom of the lower basin and enter the tunnel already mentioned. The reservoir, being surrounded by hills on all sides but one, is mostly in excavation around its sides, the slope of the upper basin being 2 to 1, puddled with blue clay and imbedded with concrete. The whole bottom is also concreted from 12 to 18 inches in depth.

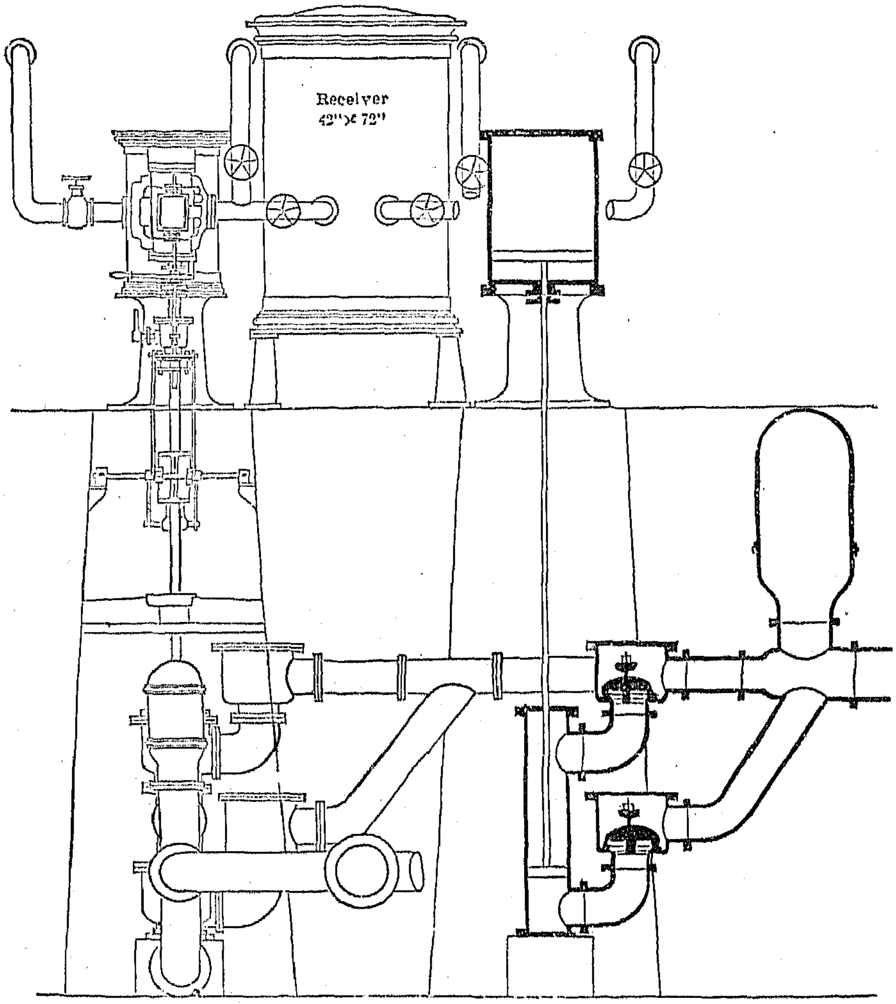
The middle and low service, supplied under heads of 172 and 110 feet, respectively, by the Eden and the Third Street basins, is supplemented by high-service works on Hunt street for the supply of the residents on the bluffs. These works consist of a rectangular brick engine-house, with boiler-house attached. It contains one duplex non-condensing horizontal-engine, built by the Niles Works, of Cincinnati, and a vertical compound engine, built by the city water-works. These engines take their supply from the Eden reservoir supply-mains, under a head of 60 feet, and force it into a couple of tanks on mount Auburn, under a head, including friction, of 340 feet.



DUPLEX NON-CONDENSING NILES ENGINE.

The Niles engine shown in the cut, was designed by Arthur G. Moore, the present superintendent, and built by the Niles works in 1869. It is non-condensing, with steam-cylinder 18 inches in diameter by 5 feet stroke, and the pump-rod is a prolongation of the piston-rod. The pump-cylinder is $13\frac{3}{4}$ inches diameter, and the friction-head against which it pumps is 290 feet, through a main 20 inches diameter for 2,705 feet, and 16 inches by 4,501 feet long, for the remaining distance. The capacity of the pumps is 4,000,000 gallons per day. Average speed per minute, 18 revolutions, working 12 hours per day. There are four inlet- and four outlet-valves at each end of the pump-cylinder, and the pump is double-acting. These valves are brass puppet-valves, 7 inches diameter by $\frac{5}{8}$-inch lift. The steam-valves are puppet relief-valves, operated by straight levers raised by a rocking-cam. The duty shown in its operation in 1880, during $196\frac{3}{4}$ days' running time, was 45,886,944 foot-pounds per 100 pounds of coal of an inferior grade. Steam is derived from two batteries of two boilers each, with 48 inches diameter and 24 feet length of shell. They each contain two 10-inch and four 8-inch flues, and the pressure is maintained at 125 pounds. Their evaporative power with the poor grade of coal in use is given at from 9 to 11 pounds water per 1 pound of coal. Cost of engine erected, $15,000.

The other high-service engine, built by the water-works, after the design of Americus Warden, in 1879, at a cost of $8,600, is a vertical compound engine, with high-pressure cylinder 14 inches diameter; low-pressure, $22\frac{1}{2}$ inches diameter. Stroke of both, $2\frac{1}{2}$ feet. Pump-cylinders, 10 inches diameter; stroke of plunger, $2\frac{1}{2}$ feet, and double-acting. The high-pressure cylinder exhausts into the receiver between it and the low-pressure, and the latter draws it thence and exhausts into a heater for the feed-water. The steam-valves are D-slides operated by the Cope & Maxwell isochronal cataract gear. The cylinders and their pumps connected can be operated at high pressure separately. The pumps have a single suction- and delivery-valve in each end of the cylinder. They are hemispherical rubber discs on brass seats, with spindle. The area of opening is $40\frac{3}{8}$ square inches. The receiver is 42 inches diameter by 72 inches high, with 4-inch connecting pipes. The cylinders derive steam from one of the batteries last described.



WARDEN VERTICAL COMPOUND ENGINE.

The reservoirs into which the high-service engines pump are situated on mount Auburn, and consist of two tanks of wrought iron, one built in 1869 and one in 1871. They are situated at McMillan and Auburn streets, and are each 60 feet diameter by 38 feet deep, with its bottom of $\frac{1}{4}$-inch plate resting upon a bed of sand. The plates are 50 by 140 inches each, and vary in thickness from $\frac{11}{64}$ to $\frac{7}{16}$ inch. The cost of each was $15,000. The vertical seams are lap-welded and double-riveted. The force-mains supplying these tanks being tapped, they serve merely as stand-pipes to maintain the pressure.

The total length of distribution mains January 1, 1881, was 188.86 miles, of the sizes, etc., shown in the subjoined summary:

	Feet.
3-inch	55,933
4-inch	486,027½
5-inch	2,040
6-inch	133,805
8-inch	47,663
10-inch	145,394
12-inch	193
14-inch	603
16-inch	21,346
20-inch	78,029½
24-inch	5,607
30-inch	582
35-inch	7,337
36-inch	4,783
40-inch	3,782
46-inch	3,294
50-inch	803

Total number feet of cast- and wrought-iron water-pipe of all sizes in use in the city of Cincinnati December 31, 1880, 997,222 feet=188.86 miles, with 2,334 valves.

There were laid in the city up to 1838 about 118,000 feet of 2½-inch bored logs, most of which are discarded, and none laid since that time. Two 35-inch mains from Eden reservoir and two 20-inch pipes from the Third Street basin are all the supply-pipes in use. There are in use 789 hydrants, mostly manufactured by Cummings & Son, of Cincinnati.

There are 23,000 water-takers recorded, and the consumption in 1880 averaged 19,476,000 gallons per day, of which 32 per cent. is supplied to the low, 67 per cent. to the middle, and 1 per cent. to the high service.

The city, in 1839, when it purchased the works, paid $300,000 for them. With the extension of them the total cost to January, 1881, amounted to $6,727,838. The annual cost of maintenance and repair for 1880 amounts to $200,000, and the total revenue for the same period has been $523,100.

Of meters there are in use January 1, 1881, 545, as follows:

Kind of meter.	½-inch.	⅝-inch.	1-inch.	1½-inch.	2-inch.	3-inch.	4-inch.	Total.
Worthington	....	104	247	61	55	24	8	499
Union	...	28	......	6	....	....	....	34
Gem	8	......	......	...	....	....	....	8
Marsland	....	......	1	...	....	....	....	1
Ball & Fitts	....	1	......	...	....	....	....	1
Crown	2	......	......	...	....	....	....	2
Total	10	133	248	67	55	24	8	545

In addition to these there are 318 hydraulic elevators.

It is proposed to erect new works on the river, outside of the city limits, at a point farther up, known as Markley's farm, where settling basins are to be used.

Analyses, made by Mr. Stuntz, of the water at different points in the Ohio river and of the works show the following results:

Parts by weight in 100,000 of water. Hardness: Grains of $CaCO_3$ in United States gallons.

Locality.	Date.	Ammonia.		Residues dried at 212° F.			Chlorine.	Hardness.	Temp. deg. F.	
		Free ammonia.	Albuminoid ammonia.	Inorganic solids.	Organic and volatile.	Total solids.			Water.	Air.
	1880.									
Bonte's well, Dayton, Kentucky	September 17	......	......	......	......	......	......	30.1	......	......
Bellevue well, Brickyard	September 17	......	......	......	......	......	......	32.5	......	......
Pumping-works	September 17	0.0047	0.0218	6.96	2.82	9.78	0.62	6.3	67	74
Eden reservoir	September 17	0.0045	0.0214	11.22	3.16	14.38	0.75	6.8	74	76
Storrs	September 17	0.0132	0.0150	9.16	3.96	13.12	0.70	5.8	64	74
Markley farm	September 18	0.0010	0.0121	8.20	2.94	11.14	0.22	5.3	67	82
Sand beach	September 28	0.0083	0.0099	7.76	2.58	10.34	0.27	7.4	68	71
Sand beach	October 4	0.0090	0.0087	8.96	4.04	13.00	0.22	7.4	68	70
Storrs	October 16	0.0118	0.0236	9.16	3.96	13.12	0.77	5.7	67	74
Sand beach	November 1	0.0054	0.0075	9.32	2.60	11.92	0.25	7.3	56	47
Pumping-works	November 1	0.0050	0.0156	11.14	4.66	15.80	1.33	8.3	50	49
Storrs	November 1	0.0180	0.0198	11.10	2.70	13.80	1.16	8.5	50	40
Eden reservoir	November 1	0.0231	0.0200	11.68	2.18	13.86	0.91	9.2	50	49
Markley farm	November 3	0.0015	0.0024	13.16	2.54	15.70	0.39	8.2	50	50
Sand beach	November 9	0.0040	0.0244	7.82	1.70	9.52	0.30	7.0	56	54
Markley farm	November 9	0.0042	0.0628	12.44	3.32	15.76	0.83	6.0	43	54
Pumping-works	December 3	0.0076	0.1366	11.06	6.80	17.86	0.44	6.8	45	35
Storrs	December 4	0.0262	0.1200	13.84	4.02	17.86	0.34	4.7	36	40
Eden reservoir	December 4	0.0209	0.0728	10.38	3.20	13.58	0.64	7.4	35	39
Markley farm	December 4	0.0080	0.0420	16.38	2.72	19.10	0.43	4.6	35	45
Sand beach	December 14	0.0031	0.0170	11.00	2.38	13.38	0.41	7.9	56	44

The works are now managed by Mr. Arthur G. Moore as superintendent and chief-engineer, appointed by the board of public works.

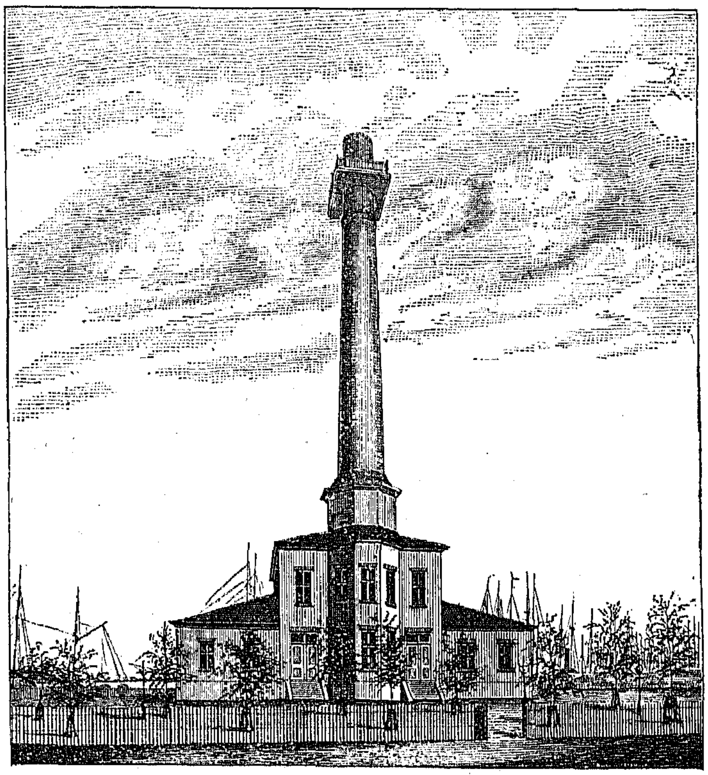
The water is sold under a special tariff of water-rates.

CLEVELAND, OHIO.

Cleveland, with a population of 160,146, and situated on the shores of lake Erie at the mouth of the Cuyahoga river, is an extensive manufacturing city. Its streets intersect each other at right angles, and most of them are on a plain elevated from 80 to 100 feet above the surface of the lake and that of the river, whose banks rise to about the same height on either side.

Water was introduced in 1856, under municipal control, and is derived by pumping from lake Erie. For this purpose a crib is built in the lake at a distance of 6,661 feet from the shore. It was completed in 1874, and many of the following details were derived from the reports of the trustees for that year.

The protection crib is built of 12-inch square pine timber, 61 feet high, of pentagonal form, each side measuring 54 feet on the exterior and 19 feet on the inner or well wall. Between the two walls is an additional wall. The space between the inner and the outer wall is 24 feet, and the walls are tied together and braced, the face of each being of 2-inch oak plank. The spaces between are filled with stone to a level 12 feet above lake surface. A filling of concrete 5 feet deep, below low-water line, is placed between the outer and middle walls to form a foundation for the stone superstructure which was built thereon in 1878. Stone is piled up against the outside of the crib as a protection against the wash of storms, and the outer side of the crib is also plated for a distance of 5 feet below high water with $\frac{1}{2}$-inch iron as a protection against ice. From this crib, which is surmounted by a government light, a tunnel under the lake extends, in a nearly straight line, 6,661 feet. It is $5\frac{1}{6}$ by 5 feet in diameter, and connects with the crib through a vertical shaft 8 feet in diameter, the bottom of which is $90\frac{1}{6}$ feet below lake surface.



ENGINE-HOUSE, CLEVELAND, OHIO.

At the shore the shaft depth is only $67\frac{1}{2}$ feet, and diameter 8 feet. The construction occupied nearly five years, and, owing to the nature of the ground excavated, was a peculiarly difficult operation. There were 20 feet strata of quicksand in the shafts, and numerous irruptions of water, gas, and clay. The total depth of the crib had to be increased from 44 to 61 feet. The inlet-shaft extends from a short distance below the floor of this crib to the top of the tunnel, and 46 feet of the lower portion is of cast iron 2 inches thick, the rest being $\frac{5}{8}$-inch boiler iron. The top of the shaft is 9 feet below water surface.

From the shore-shaft to the engine-house well a conduit of brick is constructed, oval in section, 4 by 5 feet, and 3,500 feet long. There are two engine-houses, one having been recently built. The former and older contains a pair of regular Cornish engines, erected in 1856, by the Allaire Works, of New York, coupled together, and each of 4,500,000 gallons capacity. The cost complete, with boilers, was $83,000. These engines are 72 inches diameter of steam-cylinder, 30 inches diameter of pump-plunger, 10 feet stroke of steam-piston, 8 feet 9 inches stroke of pump-piston, and run at from 7 to 11 revolutions per minute. One was operated during 116 and the other during 193 days in 1880. They have plain plungers; one suction- and one discharge-valve in each pump, 36 inches in diameter, of double-beat type. The steam-valves are operated by an eccentric from the main shaft. A spray-condenser is used in connection with each engine, and is 2 feet 8 inches by 4 feet $10\frac{1}{2}$ inches, the air-pump for it being 36 inches diameter by 5 feet 2 inches stroke. The duty has amounted to about 52,000,000 foot-pounds.

To supply steam for these two engines there are two batteries of three Cornish boilers each 6 feet diameter by 30 feet long, with a single 40-inch flue, and evaporating $7\frac{1}{2}$ or 8 pounds water per pound of coal at a pressure of 20 pounds, the fuel being bituminous-coal slack. From this engine-well the water is forced through 2,300 feet of 24-inch main under a head (including friction) of 150 feet into the distributing reservoir. At the engine-house a stand-pipe is erected on this main, as shown in the cut. It is 148 feet high by 36 inches diameter, of boiler iron, encased in brick.

The new pumping-station is directly across the street from the old station, and contains three pairs of pumping-engines, No. 2 being a Henderson duplex compound, similar to a Worthington in appearance, each pump having a capacity of 5,000,000 gallons. It was built by the Cuyahoga Works, of Cleveland, in 1874. The steam-cylinder of each is of peculiar construction, having an annular space 4 inches wide around the piston; this space is cut off from the rest of the interior of the cylinder behind the opposite ends of the piston by a flange which fits the interior of the cylinder, thus separating the steam-space at the ends of the piston from the annular space already described. The cylinder, which is 8 feet long, is divided midway by an annular flange 4 inches high cast on its inside, through which the main body of the piston works steam-tight, thus forming two annular spaces between the opposite ends of the piston, each 4 feet long, in which the steam acts at high pressure. It is admitted at low pressure behind the ends. The steam-cylinder is 56 inches in diameter and the stroke 4 feet, operating a single pump-piston, as in a Worthington, 31 inches diameter by 4 feet stroke. There are 16 suction- and 16 delivery-valves, each 4 by 16 inches, and rising $\frac{3}{4}$ of a inch in guides. The engines without the boilers cost $52,750. The duty has only reached as high as 37,000,000 foot-pounds, and economically they are considered of no great value as used in these works. They were operated 70 days during 1880, running at a speed of about ten double strokes per minute, and showing a duty of about 29,500,000 foot-pounds. A jet-condenser 3 feet 2 inches by 6 feet is used in connection with two air-pumps in each engine, 28 inches in diameter by 2 feet stroke.

There are two batteries of boilers, one containing four marine and the other two tubular boilers; the former are $8\frac{1}{2}$ feet in diameter by 20 feet long, and contain one hundred and four 4-inch tubes in each. The pressure averages 35 pounds, and the evaporation is $8\frac{3}{4}$ pounds of water per 1 pound of coal. The tubular boilers, with the same evaporation and pressure, are 6 feet in diameter by 16 feet long, and contain seventy-two 4-inch tubes each.

Engines Nos. 3 and 4 are Worthington duplex, the former having been erected in 1876, and the other being just completed. No. 3 cost $47,500, and No. 4, $38,500. They are each of the following dimensions:

High-pressure cylinder, $33\frac{3}{4}$ inches diameter; low-pressure cylinder, $58\frac{1}{4}$ inches diameter; pump-plunger, 31 inches diameter; stroke, 4 feet; number of double strokes per minute, 12; capacity, 10,000,000 gallons.

No. 3 was in operation 304 days in 1880, and the duty somewhat exceeded 42,000,000 foot-pounds.

There are, as usual, two air-pumps to each engine, one set being 27 inches diameter, the other $23\frac{3}{4}$ inches diameter, and all 24-inch stroke.

The four engines in the new pump-house force the water through 1,600 feet of 36-inch main into the reservoir, under a head of 150 feet (including friction).

The reservoir is a rectangular embankment structure 225 feet long by 95 feet wide on the bottom, 300 feet by 175 feet wide at top, depth 21 feet, width of bank 16 feet, with a division-wall of earth 12 feet high faced with brick and puddled. The banks are of earth with a puddled face 2 feet thick, and riprapped with brick laid in cement and 4 inches thick; slope of the inner face, $1\frac{1}{2}$ to 1; outer face, $1\frac{3}{4}$ to 1; capacity, 6,000,000 gallons. The whole structure is in embankment. The force-main enters through the top of the division-wall. The distribution to 11,563 takers is carried out through $125\frac{3145}{5280}$ miles of cast-iron pipe 36, 30, 24, 20, 16, 12, 10, 8, 6, and 4 inches in diameter. There are 1,000 Matthews hydrants in use. The consumption in 1880 averaged 10,179,461 gallons.

Two hundred and ninety-nine water-meters are in use, and 25 hydraulic elevators; the former are mostly Worthington and Ball & Fitts patents.

The original cost of the works was $550,000, and the cost up to 1881 was $2,630,829. The annual cost of maintenance and repairs was $55,652 for the year 1880.

A quantity of the water taken for analysis from the lake about 3,500 feet from the shore gave, on analysis by Dr. J. L. Cassels, of Cleveland, the following results:

Potassium chloride	grains per gallon..	0.086	Magnesium carbonate	grains per gallon..	0.488
Potassium sulphate	do	0.090	Peroxide of iron	do	0.038
Sodium chloride	do	0.190	Alumina	do	0.058
Sodium sulphate	do	0.185	Silica	do	0.030
Calcium sulphate	do	2.470	Organic matter	do	0.640
Calcium carbonate	do	1.165			

The presence of lime is due to the fact that the city is built upon a limestone formation.

The repairs to the Henderson engines are expensive every year, it is claimed, and the Cornish engines are old, though still in fair condition.

LOWELL, MASSACHUSETTS.

Lowell is situated upon the Concord and Merrimack rivers, at their confluence, and has a population of 59,475 inhabitants. It is almost entirely a manufacturing city, the chief products being woolen and cotton goods, carpets, stockings, dyed and printed cloth, machinery, and shawls.

The water was introduced in 1872 under the auspices of the city authorities, and is derived from the Merrimack river by pumping, at a point about 1¾ mile above the center of the city. It enters a filtering gallery, located 1,500 feet above Pawtucket bridge, through an inlet-pipe of cast iron, 30 inches in diameter and 220 feet long, with its river-end 45 feet from the river-bank, and built upon a grillage, surrounded by masonry, and fastened by iron bands to a row of piles. This was constructed to be used only when the amount of water passing through the gravel-bank intervening between the filtering gallery and the river was insufficient to supply the demand for water. As some details concerning this method of filtration, which is rare, are of much value, they are given here as derived from personal inquiry of the water-works authorities, and the reports of the commissioners for different years. The distance between the gallery and the river is 100 feet, in which the material is gravel and sand. The gallery is on the north shore of the Merrimack river, and is 1,300 feet long by 8 feet wide and 8 feet high. The intrados of the crown is on a level with the top of Pawtucket dam. Its walls are 2¾ feet thick, of stone in cement, and 5 feet high. The crown is semi-circular, of brick, 1 foot thick, and laid in cement. Stone braces 1 foot square and 10 feet apart are placed on the bottom and bear against the foot of the side-walls. Upon the bottom, coarse gravel 1 foot thick is laid, and all water enters the gallery from below. From 1872 to 1874 this gallery served the purposes of the city satisfactorily, but in August, 1874, after constant pumping for thirty-one days, the water was exhausted, and it was found that about 940,000 gallons per day were being pumped.

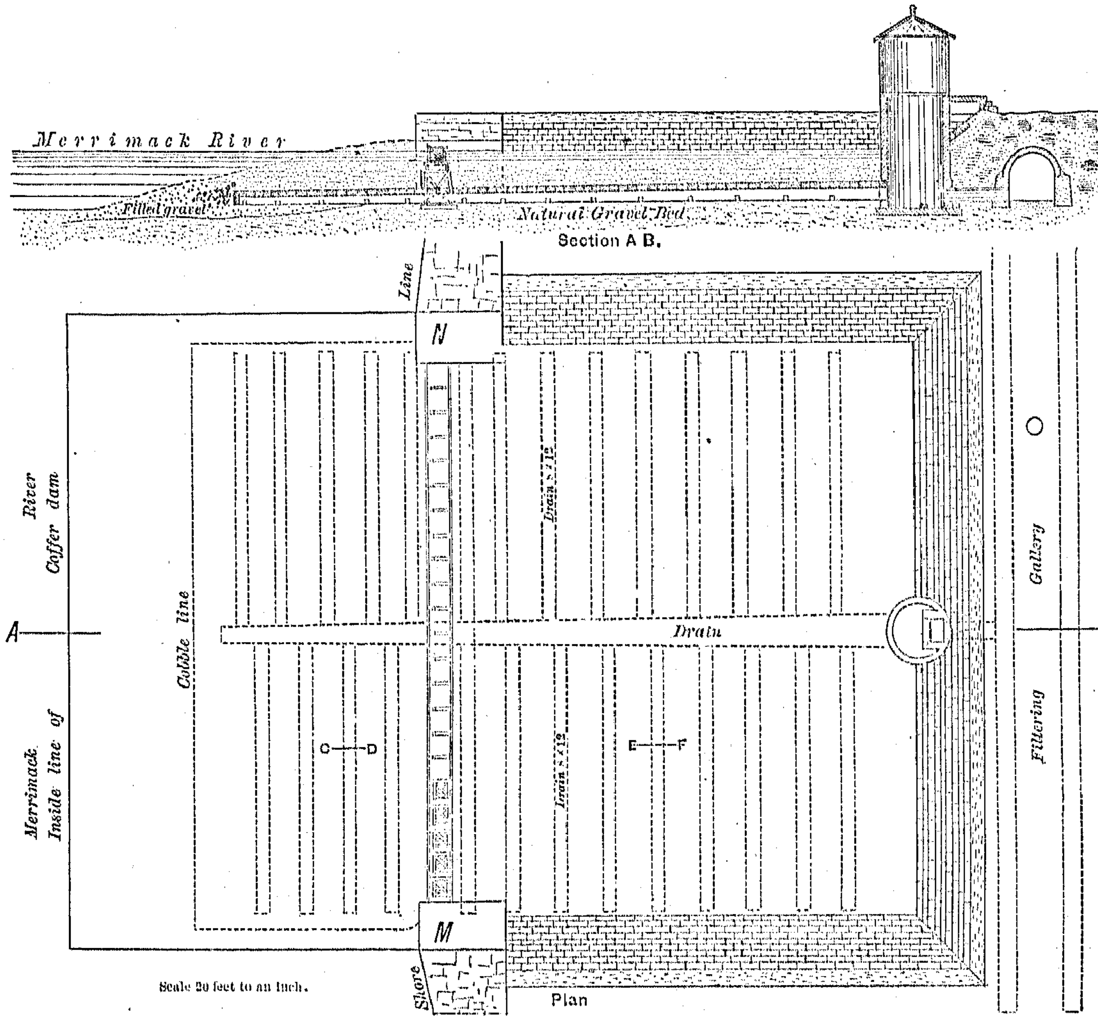
On May 10, 1875, the supply again ran short after pumping twenty-one days, the yield being 960,000 gallons per day. At the latter time the water in the river was somewhat higher than during the former trial, which would probably account for the slight difference in the quantity furnished. Taking the area of infiltration surface to be equal to 10,400 square feet, the area of the bottom, the latter quantity would give 92.3 gallons per square foot per 24 hours.

As the consumption had, in 1875, amounted to an average of 1,219,225 gallons per day, it was resolved to construct a filter-bed between the gallery and the river. This was completed in the latter part of the year 1876. The accompanying plan (page 115) shows its mode of construction, with the following details by Mr. Evans, the city engineer:

It is rectangular in plan, with a bottom area of 11,400 square feet. The bottom is graded to an elevation of 24 feet, city datum, encountering a gravel stratum. The well-chamber adjoining the gallery, and seen in the drawing, contains a gate to exclude the water of the filter-bed from the gallery, if desirable. It is of brick, 10 feet interior diameter and 19 feet deep, the bottom elevation being 23 feet. The pipe-connection with the gallery is 30 inches diameter and 12 feet long, of cast iron, entering the latter at the floor-level.

The main drain on line A B of the filter-bed is of stone laid dry, 15 inches square at the river-end, 30 inches square at the well, and 110 feet long, connecting with the well. From this drain 27 lateral drains of similar construction, but 8 by 12 inches in size, extend to the foot of the slopes of the banks, and have a total length of 1,350 feet. These drains are covered in layers with cobble-stones, 36 inches deep, varying from 3 to 8 inches in diameter; screened gravel, 1 to 2 inches diameter, 10 inches deep; gravel, ½ to 1 inch diameter, 2 inches deep; gravel, pea-size, 6 inches deep; coarse screened sand 4 inches deep; and, lastly, fine sand, 18 inches deep. This is shown at section E F on the plan. The top of the last layer is 1 foot below the top of Pawtucket dam at an elevation of 31. On the river side of the bulkhead or trestle-work the layers are laid as in section C D of plan. Ninety-two feet of trestle work divides the filter-bed in two parts at N M, the ends being connected to wooden bulkheads, 8 feet 6 inches by 14 feet 6 inches, filled with earth and stones. Stone wing-walls forming the shore-line extend along the whole front of the bed from these. The sides of the latter are faced like a reservoir embankment with a riprap of granite blocks, sloping 1½ to 1, and extending to within 3 feet of the top of the slopes. Pine plank faces the river side of the trestle down to the cobble-stones, and a platform 4 feet 6 inches wide covers the whole top. To this latter flash-boards are hinged, which, in winter, are laid flat upon the platform and fastened to prevent damage by ice. The area of the bed outside of the trestle-work is 2,850 square feet. This bed furnished a constant supply until 1878, when, for forty-three days in all, it furnished an average daily supply of 1,879,810 gallons. For the rest of the year 1878, or 269 days, the inlet-gate had to be partially opened. Owing to the large amount of silt which the river carries, the deposit in the filter-inlet and on the bed is very large, the former requiring to be cleaned as often as three times in a month. With an area, therefore, of 11,400 feet filtering surface, and the yield calculated at 1,800,000 gallons, we have an average of 158 gallons per square foot as the amount obtainable from the filtering bed.

At the lower end of the filtering gallery an inlet-chamber is built for the purpose of connecting the river inlet-pipe, already described, and the gallery with the supply-pipe or conduit to the engine-house well. This chamber is 17½ feet wide by 38½ feet long, with a 15½ by 13½ foot wing. One portion of the chamber, 8 by 10 feet, contains a boat for examining the gallery. The chamber contains self-operating gates, two in number, to regulate the supply to the engines. Water can be drawn into the supply-conduit either from the gallery or the river-pipe,



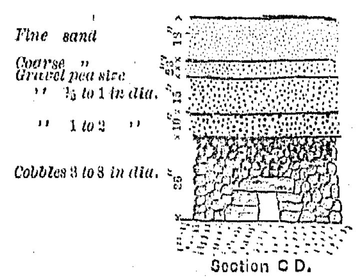
or from both. Screens are placed at the ends of the inlet- and supply-conduit, the latter being double. A brick gate-house covers this inlet-chamber.

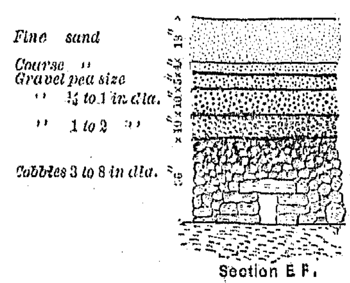
The supply-conduit extends 4,182 feet from the inlet to what is known as the terminal chamber. Part of it is tunneled, and the fall of the whole is 9 inches per 100 feet. It is circular brick masonry 4 feet 3 inches interior diameter and 8 inches thick. Two manholes are built into it 1,100 feet apart. About 1,788 feet of it is tunneled in rock.

At the easterly end of this conduit the terminal chamber is located, the top of which is 15½ by 11 feet, and covered by an octagonal brick gate-house. A sluice-gate, operated by hand, regulates the head of water in the outlet-pipe. The latter, known as the pipe-conduit, extends from this terminal chamber to the pump-well of the engine-house. It is a 30-inch cast-iron pipe 6,655 feet long. A part of it crosses a brook 4 feet below its bed by an inverted siphon. The latter is 100 feet long and about 13 feet below water-surface, with a 6-inch blow-off branch, and a manhole pipe connected with its lowest point.

The engine-house is 56 feet 7 inches by 75 feet, and the boiler-house, 41 feet by 56 feet 3 inches; both are of brick.

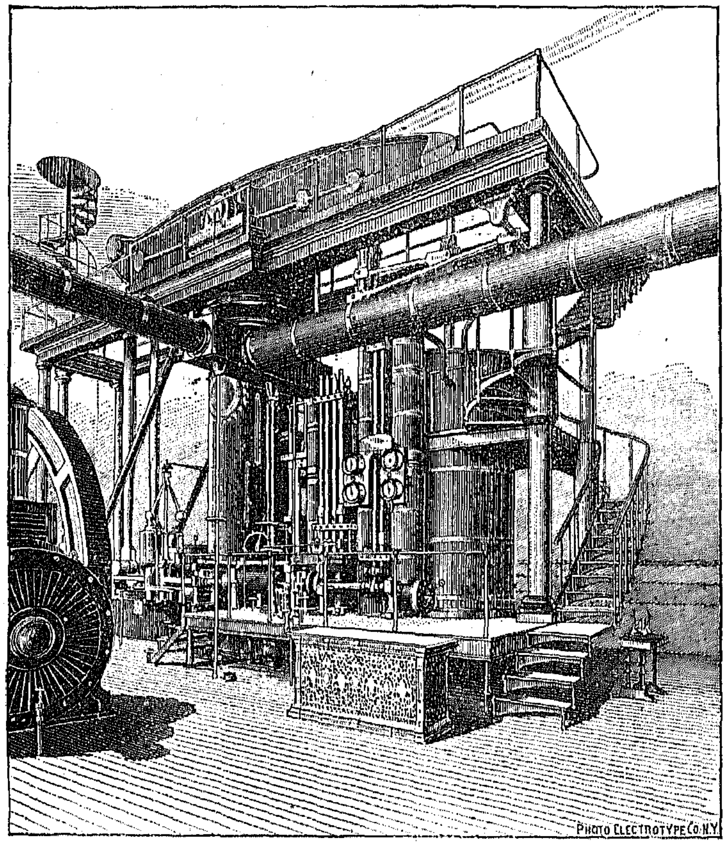
There are two pumping-engines, one made by H. G. Morris, of Philadelphia, and the other by H. R. Worthington, of New York. The former is a beam and fly-wheel compound condensing engine, with bucket-and-plunger pumps attached. The ratio of expansion from high- to low-pressure engine is 1 to 5. High-pressure cylinder, 36 inches diameter by 60 inches stroke; low-pressure cylinder, 57 inches diameter by 96 inches stroke. The illustration on next page gives elevation and plan of the working parts. The steam-valves, of the double-beat puppet class, are operated by a graduated cam-shaft geared to the driving-shaft. The speed varies from 22 to 26 single strokes per minute. The supporting





FILTER BED OF THE LOWELL WATER WORKS.

column of the beam serves as an air-chamber, with a capacity of 360 cubic feet. The air-pump is 25 inches diameter by 36 inches stroke, and is used in connection with a jet-condenser. The fly-wheel is 25 feet in diameter. The pump-cylinder contains seven suction-valves of the double-beat (Harvey & West) pattern, each 17 inches in diameter and 2 inches lift. The delivery valves are similar, but three in number. The pump takes the water during the up stroke only, but delivers it in about equal quantities during the up- and down-strokes. The plunger is 25.45 inches diameter, and the pump 36 inches diameter by 6 feet stroke. The guaranteed duty is 75,000,000 foot-pounds, and the capacity was guaranteed at 5,000,000 gallons per day at 11⅝ revolutions. The actual duty, averaged for each month in 1879, computed from the amount of coal used in pumping only, was 100,073,389 foot-pounds, the duty on the total coal consumed for the same period being 78,512,994 foot-pounds, no deduction being made in either case for ashes or clinkers. It is used during 12 or 13 hours per day.



WORTHINGTON PUMPING ENGINE.

The Worthington engine, erected in 1876, to be used when necessary to repair the Morris engine, is also of a capacity of 5,000,000 gallons per 24 hours. The diameter of the high-pressure cylinders is 25 inches; of the low-pressure cylinders, 43.3 inches; length of stroke, 48 inches; diameters of pump-plungers, 22½ and 22 inches, respectively; diameters of air-pumps, 27 and 30 inches, respectively; stroke, 24 inches; jet-condenser, 35 by 72 inches. The guaranteed duty was 65,000,000 foot-pounds; average speed, 12 revolutions per minute. A trial under the direction of G. E. Evans, city engineer, in 1876, gave 69,000,438 foot-pounds. Its record for 1879 is given below:

Number of days' pumping	41
Average number of hours' pumping per day	10.9
Number of hours' pumping per month	448.25
Number of strokes made per month	280,206
Average number of strokes made per minute	10.42
Average head, including friction, in feet	163.63
Quantity pumped per month, in United States gallons	86,863,860
Average quantity pumped per day, in United States gallons	2,118,631.
Duty in pounds, 1 foot high, with 100 pounds coal, used in pumping only, no deduction for ashes or clinkers.	74,136,672
Duty on total coal consumed, no deduction for ashes or clinkers	59,862,329

The cost of the Worthington engine was $34,250. (For further details of these engines, see report of F. R. Hutton, E. M., "Steam-pumps and pumping-engines," Vol. XXII of Tenth Census.)

The cost of the Morris engine is approximated at $70,000. It is run under 50 pounds of steam; cut-off at one-quarter; evaporation of boilers, 9.61 pounds of water per pound of anthracite coal. The steam to both engines is supplied by a battery of three multitubular boilers, 16 feet long by 6 feet diameter, containing 94 brass 3½-inch tubes in each, and a heating surface of 1,000 feet. Two are used at a time; each has a grate-surface of 25 square feet. One small 10-foot boiler is used to heat the jackets of the Worthington cylinders. These pumps force water from the pump-well through 2,666 feet of cast-iron pipe 24 inches diameter into the distributing reservoir under a head at the pumps of 165½ feet.

The reservoir, located within the city limits, on Sixth street, is partly in excavation and partly in embankment. In shape it is a square with two corners cut off, 520 feet long, 510 feet wide, and 24 feet deep; high-water surface 4 feet below the embankment top and 181½ feet above datum; covers 7 acres; water-surface, when full, 5.2 acres; capacity, 30,000,000 gallons; only one compartment; slopes of the banks, 1½ to 1 inside and 2 to 1 outside; interior slopes puddled 2 feet thick, covered 1 foot thick with broken stone, and a granite riprap laid upon it 15 inches thick. A base course of 1 foot 6 inches forms the foot of the slope-wall. The whole bottom is puddled 1 foot deep. A 12-inch drain-pipe from the southeast embankment serves to empty the reservoir for repairs, etc. The width of the banks on top is 15 feet. From the gate-chamber a 30-inch cast-iron pipe crosses the reservoir to the eastern bank, supported on masonry piers. The gate-chamber is located on the inside of the western embankment; it is divided into two compartments by a wall 3 feet 6 inches forming the influx- and efflux-chambers. The former is divided in two with an adjustable weir to measure the amount of water pumped. From the weir the water passes through the 30-inch pipe above mentioned. Two sluice-gates, each 2½ by 3 feet, protected by screens, are placed in the reservoir-wall of the efflux-chamber, one above the other, for use in drawing the water from different depths. An opening or sluice-gate, 2 feet 6 inches by 3 feet 4 inches, in the main division-wall, between influx- and efflux-compartments, allows water to be pumped direct into the distributing mains through the reservoir. The whole gate-chamber is built of cut granite and is 26 feet square.

The distributing system embraced, in 1879–'80, 320,286 feet of cast-iron and of wrought-iron and cement pipes. Of the latter there are but 4.31 miles. The sizes are 30, 24, 16, 12, 10, 8, 6, and 4 inches.

Water is supplied to 11,427 water-takers. The original cost of the works was $1,266,766, which has been increased to $2,156,032 on January 1, 1880. The annual cost of maintenance and repairs was, for 1879, $21,228. Up to 1880 there were 653 fire-hydrants made by the Boston Machine Company, and 584 meters, divided as follows, and mostly owned by the takers:

Varieties of meters.	⅝-inch.	¾-inch.	1-inch.	1½-inch.	2-inch.	3-inch.	4-inch.		Total.
H. R. Worthington, New York	336	25	48	3	5	2	2	......	421
Union Water Meter Company, Worcester (Ball & Fitts)	30	21	1	1	1	......	......	......	54
Fitts rotary	62	18	7	2	1	......	......	......	90
W. E. Desper & Co., Worcester	13	2	2	......	......	......	......	......	17
"Standard"	1	......	......	......	......	......	......	......	1
Motor register	......	......	......	......	......	......	......	1	1
Total	442	66	58	6	7	2	2	1	584

It is claimed by the engineer that the Morris engine has cost but 22 cents per 1,000,000 gallons for repairs for several years. The consumption for 1879 averaged 2,024,768 gallons per day.

Analyses of the water, by Professor W. R. Nichols, are appended. An examination of them leads one to suppose that some water enters the gallery from the land side, increasing the hardness.

The engineer in charge of the works is Mr. Horace G. Holden.

Locality.	Date.	Ammonia.	"Albuminoid ammonia."	Solid residue of filtered water. (a) Inorganic.	Organic and volatile.	Total.	Chlorine.	Sulphuric acid.	Silica.	Alumina and oxide of iron.	Lime.	Magnesia.	Oxygen, cubic inches to the gallon.
Merrimack river, opposite inlet-chamber (b)	September 2, 1873	0.0027	0.0089	1.03	1.35	2.38	0.08	......	......	......	......	......	......
Do	September 10, 1873	0.0027	0.0000	0.91	0.84	1.75	0.06	0.20	0.29	c 0.18	0.32	Trace.	......
Do (d)	September 10, 1873	0.0026	0.0058	1.05	1.07	2.12	0.07	......	......	......	......	......	e 0.43
Do (f)	January 1, 1874	0.0031	0.0058	1.45	1.17	2.62	0.12	......	......	......	......	......	g 1.82
Inlet-chamber, gallery	September 2, 1873	0.0008	0.0016	2.82	1.05	3.87	0.14	......	0.23	0.12	0.50	Trace.	......
Do	September 10, 1873	0.0008	0.0012	2.71	0.68	3.39	0.12	0.16	0.57	0.08	0.57	Trace	e 0.16
Do	January 2, 1874	0.0038	0.0022	3.04	0.70	3.74	0.15	......	......	......	......	......	g 0.64
Engine-house	September 2, 1873	0.0012	0.0033	3.29	0.84	4.13	0.22	......	......	......	......	......	......
Water as delivered in Lowell	July 10, 1873	0.0012	0.0030	3.06	0.86	3.92	0.18	......	......	......	......	......	......
Do	January 2, 1874	0.0022	0.0020	3.67	0.72	4.39	0.18	......	......	......	......	......	g 1.72

a Filtered through filtering paper.

b Water taken 100 feet from shore, 1½ foot below surface. The unfiltered water contains: inorganic matter, 1.17; organic matter, 1.40; total, 2.57.

c Trace of phosphoric acid.

d Water taken 100 feet from shore, 6 feet below surface.

e These determinations were made on the spot.

f Water taken 100 feet from shore, 7 feet below surface.

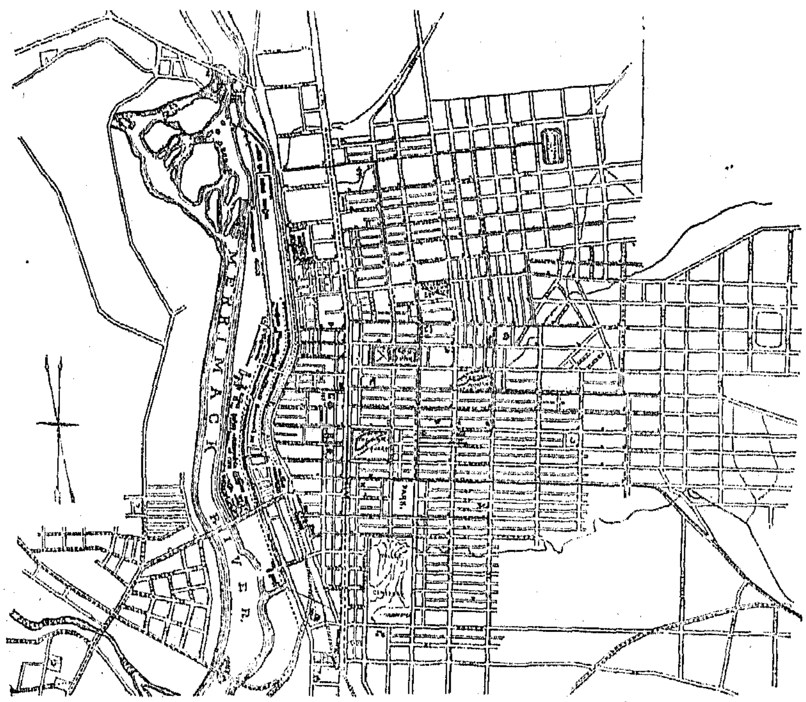
g These determinations were made in the laboratory.

7.—PUMPING BY WATER-POWER.

MANCHESTER, NEW HAMPSHIRE.

Manchester contains a population of 32,630, and is located on the east bank of the Merrimack river near its confluence with the Piscataquog. At this point it has a drainage area of 3,000 square miles. The interests of the town are almost exclusively manufacturing, the chief products being woolen and cotton goods. It is the most important city in the state.

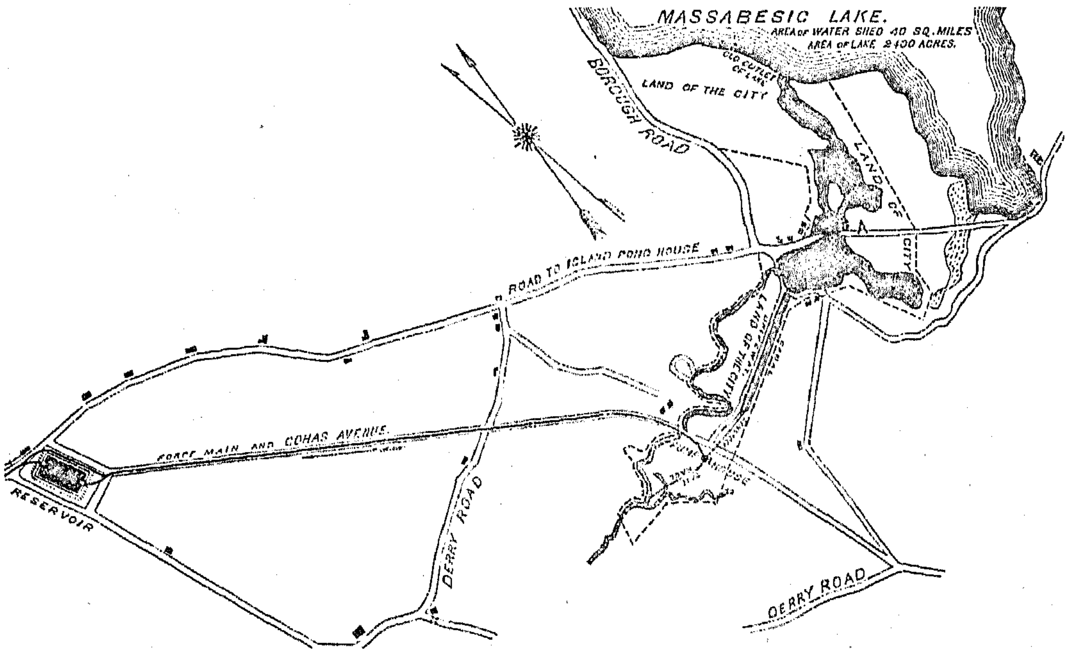
The city is laid out with great regularity, as may be seen from the accompanying map, and is comparatively level.



MAP OF THE CITY OF MANCHESTER.

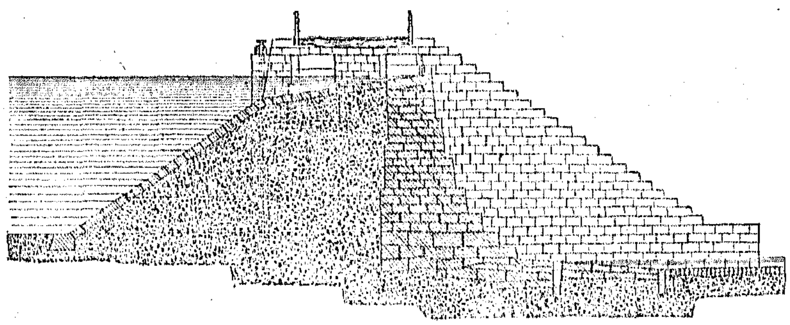
The water-supply introduced in 1874 by the city authorities is derived by pumping from lake Massabesic, situated about 4 miles east of the city. This lake has a water-shed of 45 square miles, and an area of water-surface of 2,350 acres, with a circumference of 20 miles. According to Mr. Fanning, chief engineer, the surface of the adjoining country is hilly, with impervious soils and but little meadow-land in the vicinity, and the shores of the lake are somewhat abrupt. This lake has been utilized for supplying the city with water by damming its outlet with a rough dam, producing a head of water of 24 feet by which to operate a set of turbines driving the pumping machinery. The average daily flow from the lake is 40,000,000 gallons. The head produced by the flash-boards of the lower dam, or the total depth of the lower pond below the main dam which can be drawn upon at present, is about 3 feet. The average yield of the lake for domestic purposes, when utilizing it as power in pumping, is estimated at 8,000,000 gallons per day raised into the reservoir. The 3 feet additional depth produced by the lower dam are equivalent to an increase of storage of 2,345,000,000 gallons.

The main dam is located at A (see diagram on next page), about 3,000 feet below the old outlet of the lake. The dam is shown in section. Its total length is about 225 feet; width of top of banks, 22 feet; total height of dam, 28 feet. The waste-weir or overfall is 42 feet long, of masonry, with a series of 7 steps on the lower side to break the fall of the overflowing water, a fall of $24\frac{1}{2}$ feet. The sides of the overfall are protected by abutments. Beyond these the dam is of earthwork, with a masonry priming-wall $2\frac{1}{2}$ feet thick at top and sloping 1 to 16. A riprap of



MANCHESTER WATER-WORKS.

stone faces the upstream side, and the lower side is grassed, both sloping $1\frac{1}{2}$ to 1. A vertical masonry wall rises from the face 2 feet below high-water mark to a height of 7 feet, making the width of the banks 22 feet, upon which a roadway is constructed. The overfall is spanned by a bridge.



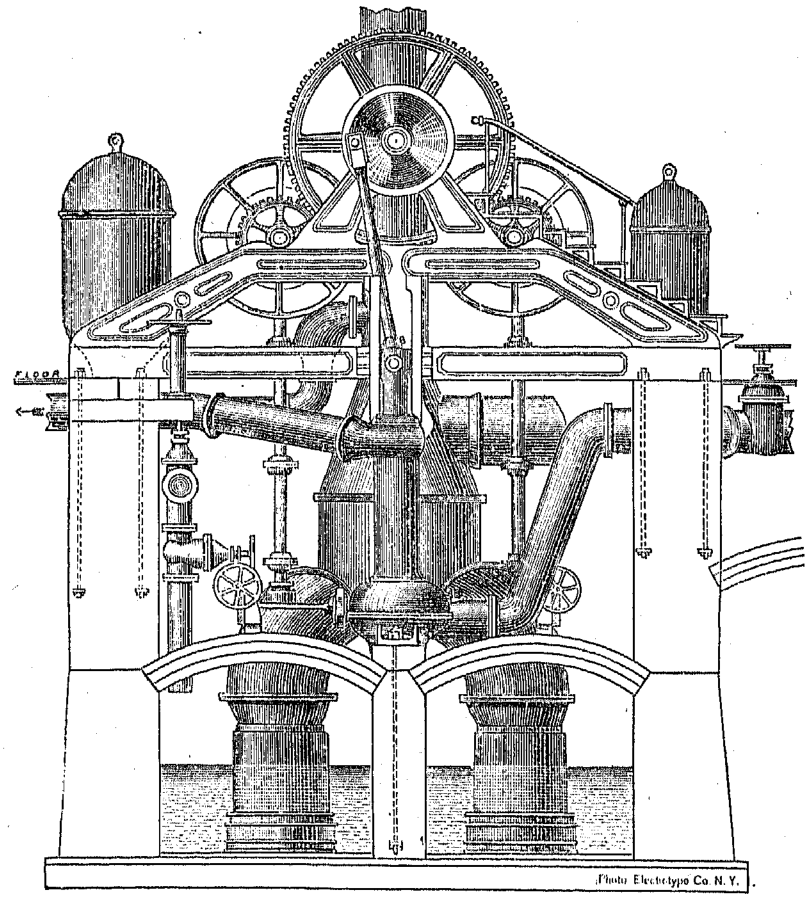
DAM OF THE MANCHESTER WATER-WORKS.

The water, flowing from the above-described dam, extends itself over the lower pond shown in the plan, and at the outlet to this is erected the rough wood-and-stone dam mentioned. From here an open ditch conveys the water about 1,000 feet to the head of an excavated canal, one end of which can be seen in the accompanying sketch. This canal is about 16 feet deep by 1,470 feet long by 35 feet wide at top. From the lower end of it, controlled by gates and protected by screens, the circular wooden penstock extends to the pump-house.

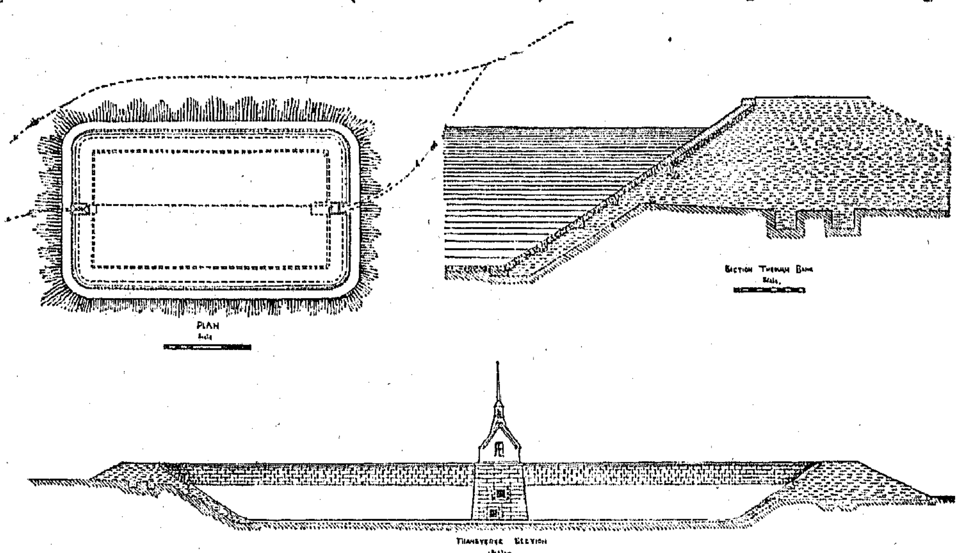
The upper end of the canal has also a set of four gates, 3 by 5 feet each, similar to the lower ones. The sides of the canal are unpaved as yet. The penstock is 6 feet internal diameter, bound with iron hoops, and 716 feet long. At its foot in the pump-house the head of water is 40 feet.

The pump-house is a plain brick building, the left wing being the engineer's dwelling. It contains a set of pumping machinery, shown in plan and elevation on page 120, which is operated by two Geyelin turbines. The whole set of machinery was built by R. D. Wood & Co., of Philadelphia, in 1874. The turbines are 36 inches diameter, under a head of 40 feet, and so connected that either or both pairs of pumps may be run. The pumping machinery contains two pairs of upright pumps of the bucket-and-plunger type, with four 16-inch cylinders, 40 inches stroke, and $11\frac{1}{4}$-inch plungers, each pair having a capacity of 2,500,000 gallons each, and running at an average speed of 18 revolutions per minute. They are run constantly. The pressure on the pumps in lifting to the reservoir is 110 pounds per square inch. The pump-valves are double-beat.

From the pump-house a cement-lined wrought-iron force-main, 20 inches in diameter and 8,170 feet long, leads to the distributing reservoir. This is situated at the "Centre", at an elevation of 152 feet above Elm street at the city hall, making a lift of 113 feet above the high-water level in the lake.



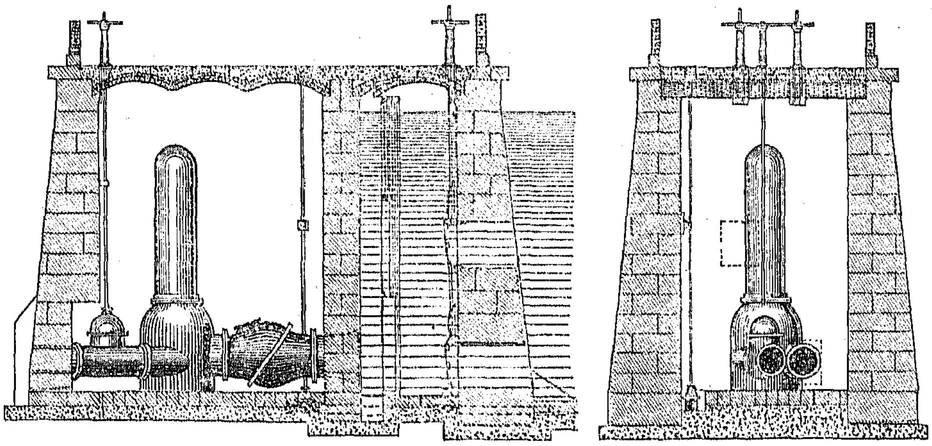
The annexed diagram shows plan and sections of the distributing reservoir. It is in earthwork with concrete face 10 inches thick, laid to within 4 feet in perpendicular depth of the surface. Above this the slope is faced with masonry in cement. It is rectangular in plan, 460 by 265 feet at the top of the banks, which have a width of 18 feet, and slope 1½ to 1 inside by 3 to 1 outside. Area of high-water surface, 2.75 acres; depth, 19 feet; capacity, about 13,500,000 gallons. A concrete bottom (12 inches thick) to the reservoir prevents leakage.



DISTRIBUTING RESERVOIR OF THE MANCHESTER WATER-WORKS.

The force-main enters the inlet-chamber at the southern end of the reservoir. In this is a measuring-weir and inlet-sluice, over which the water may be passed into the reservoir. At the opposite or northern end is the effluent-chamber, shown in the cut on page 121, the arrangement of the gates, etc., being there given.

The force- and supply-mains are directly connected around the reservoir, as shown, a gate being placed in the connection just beyond its junction with the force-main to enable the water to flow into the distribution mains without passing through the reservoir.



DISTRIBUTING RESERVOIR—SECTIONS OF EFFLUENT CHAMBER.

From the reservoir a 20-inch cement-lined wrought-iron pipe, 6,800 feet long, extends to the city mains.

The distribution system, the total length of which is given below, is carried out through cement-lined wrought-iron and a few thousand feet of cast-iron pipes.

Cement-lined pipe.	Feet.	Cast-iron pipe.	Feet.
20-inch	20, 934. 90	20-inch	104. 00
14-inch	6, 825. 00	14-inch	4, 925. 00
12-inch	8, 400. 00	12-inch	6, 002. 00
10-inch	5, 131. 75	10-inch	532. 00
8-inch	12, 644. 00	8-inch	2, 346. 00
6-inch	82, 734. 50	6-inch	14, 949. 00
4-inch	8, 950. 00	4-inch	980. 00
Total	145, 620. 15	Total	29, 847. 00
Equal to $27\frac{3060.15}{5280}$ miles.		Equal to $5\frac{3447}{5280}$ miles.	

Total of cast-iron and cement-lined pipe, $33\frac{1227.15}{5280}$ miles.

Three hundred and five hydrants made by the Boston Machine Company are in use up to date, with 257 gates.

The consumption averages 1,250,000 gallons per day, delivered to 3,950 families through 1,800 service-pipes, at an annual cost for maintenance and repairs of $11,600 for 1879.

The first cost of the works is given at $614,000, the main dam having cost $101,198. This has been increased to $742,128 up to January, 1880, divided as follows:

Land and water-rights	$30, 858 67
Dam, canal, penstock, and race	101, 198 20
Pumping machinery, pump-house, dwelling, etc	88, 493 96
Distributing reservoir and fixtures	71, 542 36
Force- and supply-main	88, 674 02
Distribution pipes	245, 106 51
Fire-hydrants and valves	30, 149 99
Tools and fixtures	10, 649 35
Boarding- and store-houses	919 36
Roads and culverts	2, 084 24
Supplies	550 39
Engineering	22, 176 19
Livery and traveling expenses	2, 856 64
Legal expenses	563 79
Grading and fencing	11, 349 62
Service-pipes	27, 247 49
Meters, boxes, and brass connections	7, 707 72
Total construction account	742, 128 50

The analysis of water from lake Massabesic, as made in 1869 by S. Dana Hayes, state assayer of Massachusetts, shows the following results:

	Grains in 1 U. S. gallon.	Parts in 100,000.
Vegetable organic matter	1. 66	2. 77
Mineral matter	1. 16	1. 93
Total	2. 82	4. 70

Hardness (Clark's scale), 0.84.

The record of the pumping-engines for the year 1879 and cost of pumping is thus stated:

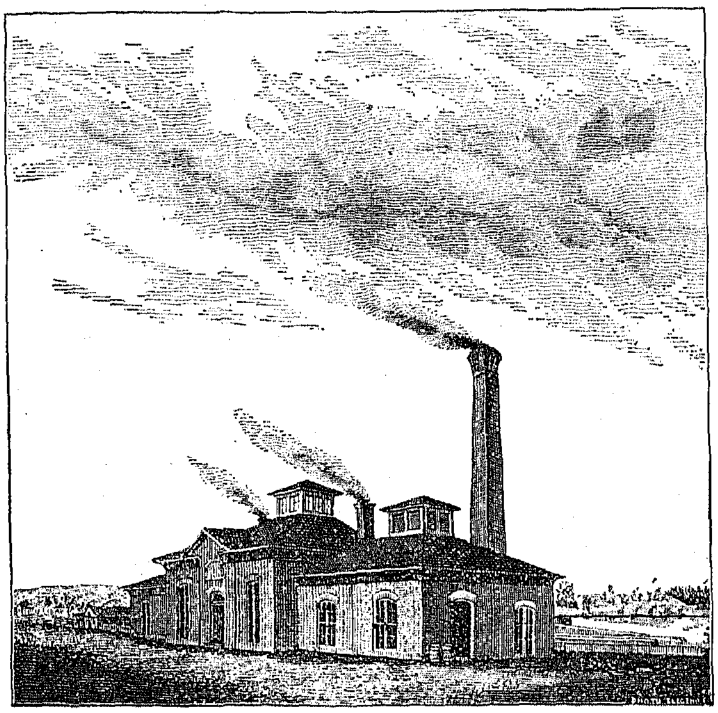
Number hours' work for both pumps	7,586.33
Average strokes per minute	15.83
Total number strokes per month	7,205,364
Total gallons pumped in one month	455,094,062
Daily average gallons pumped	1,246,913

Cost of raising 1,000,000 gallons into reservoir, $2 78.
Cost of raising 1,000,000 gallons 1 foot high, 2.46 cents.

The works are under the direction of Mr. Charles K. Walker, superintendent.

BANGOR, MAINE.

Bangor was first supplied with water in 1876 by the city authorities, the Holly system being adopted. It is a city of 16,856 inhabitants, situated on the west bank of the Penobscot river, from which the supply is derived. It is exceedingly irregular in topography, the principal part of the business streets being in a valley with hills of considerable altitude entirely encompassing it. The streets are more or less regularly laid out, and the industry of the place is shaping or exporting lumber and ship-building.



PUMPING STATION, BANGOR WATER-WORKS.

The pumping-station is located on the west bank of the river, about 1½ mile from the heart of the city, to the north. At this point a wooden dam is built across the river, raising its surface 8 feet. The drainage area of the river above this is estimated at about 7,200 square miles, with a mean annual rainfall of 42 inches.

The power to drive the pumps is derived from the fall of from 6 to 12 feet, driving three American turbine water-wheels, each 7 feet in diameter, using 110 gallons per revolution, and run two at a time. These are geared to an improved Holly pumping-engine of four cylinders. There are two of the latter, 21 inches in diameter and 30 inches stroke, and two of 14 inches in diameter by 24 inches stroke. They are so arranged that two may exhaust into the condenser after using the exhaust-steam from the other two, or all may be used at high-pressure. They are run at 20 revolutions per minute for the ordinary domestic pressure of 110 pounds per square inch during the whole of the year, and can be increased to 120 revolutions.

The pumps are geared to this engine or to the water-wheels at pleasure. There are four plungers, 12 inches in diameter by 27 inches stroke, making from 7½ to 10 double strokes per minute each. The pump-cylinders contain 12 inlet- and 12 outlet-valves each, with a lift of ⅞ inch, 2 inches diameter by 12 inches long, of wood, and cylindrical in form.

The steam-cylinder valves are of the ordinary Holly pattern. A single-acting air-pump, 14 inches in diameter by 14 inches stroke, and a jet-condenser in the shape of a rectangular parallelopiped, 3 by 3 by 1½ feet, are connected with the engine. The cut-off valves are puppet-valves, the main valve being a slide-valve.

Steam is supplied from a battery of two horizontal multitubular boilers, 5 feet in diameter by 15 feet long, under a pressure of 80 pounds per square inch. They contain fifty-six 2-inch tubes each; the fuel used is wood. Steam is used in pumping only when accident or other cause prevents the use of the water-wheels. The Holly system seems to have been adopted here chiefly as a matter of economy. No source of supply exists within a moderate distance of the city from which a sufficient head could be obtained without pumping, and it was considered too expensive to build a reservoir for the distribution. It is one of the few instances in which water-power is available to do the work free of cost.

A Holly rotary pump is held in reserve for use in case repairs are necessary to the main pumps. This is capable of discharging 16 gallons per revolution, and is run at a velocity equal to five times that of the main engine. Diameter of suction and discharge, 12 inches inside.

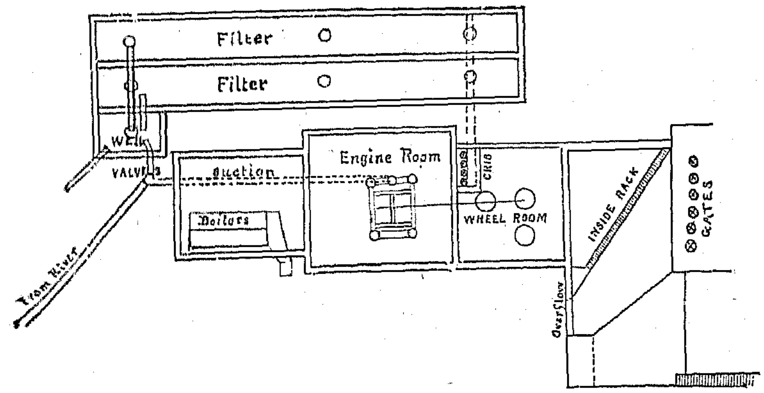
The cost of the engine and pumps was $17,000, and of the water-wheels $13,000. The time spent in repairs is calculated at about five hours per year.

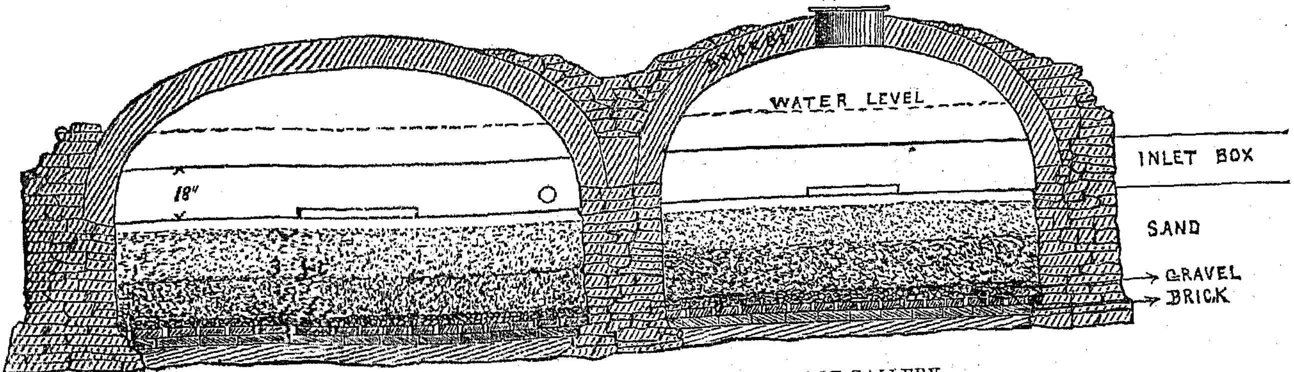
The water from the pumps enters the city through 5,316 feet of cast-iron main, 16 inches in diameter, and there connects with 23 miles of distributing cast-iron mains of 4, 6, 8, and 12 inches diameter. On this latter system there are 155 Holly hydrants for fire purposes, and about 70 stop-gates. The capacity of the pumping-engine is 4,000,000 gallons per 24 hours.

The length and dimensions of the pipe in use are as follows:

	Feet.
16-inch	6,110.6
12-inch	4,347.5
8-inch	19,697.2
6-inch	40,414.9
4-inch	31,000.5
3½-inch	175.0
2-inch	14,592.7
1-inch	205.0
Total	116,543.4

A filtering chamber is employed to purify the water before its entrance into the force-main. Two chambers, side by side, each 153 feet long by 12½ feet wide, end in a well-chamber 14 by 24 feet, from





BANGOR WATER-WORKS—SECTION OF GALLERY.

which the water is taken by the pumps. The gallery is parallel to the pump-house and closely adjoining it. The water enters it from above the dam, through the wheel-pit, at a point midway between its surface and bottom. From the wheel-pit, in one corner of which is a confined crib, the water is conveyed through four gates into a trough of wood, and thence into the filter-chambers, with stop gates so arranged that it can be cut off from either chamber or from both. In the crib is an octagonal revolving screen (one revolution every ten minutes), 12 feet long, of wire-cloth with 35 meshes to the inch. It is attached to the shaft, and, by revolving, is self-cleansing.

The water enters the filter-chamber above the level of the filtering material, flows over its surface, and downward through 3 feet of gravel and sand into drains below, and then passes to the pump-well. The arrangement of pump-house and filter, etc., is shown in the accompanying sketch.

The consumption of water from March 1, 1879, to March 1, 1880, was as follows:

	Gallons.
March	21,886,700
April	23,704,780
May	24,982,320
June	21,326,800
July	14,459,940
August	19,065,310
September	14,129,500
October	13,992,000
November	17,965,310
December	20,022,200
January	24,337,500
February	24,227,500
Total	240,099,860
Average for each day	656,011

The consumption occasionally reaches a little over 1,000,000 gallons, as indicated by registers at the pumps. The filters are cleaned annually of a sediment about $\frac{1}{4}$ inch thick. About 4 feet of water is over the filtering bed at all times.

The original cost of the works was $200,000, which has increased to a total cost at the present time of $487,022, with an average cost of $15,000 per year for maintenance and repairs. Very few meters are used as yet. The water can not be said to be very pure. In quantities, it has a decidedly brownish tinge. At the point where it discharges over the roll-way of the dam this color is darker than any I have elsewhere encountered. It is probably due to the presence of organic matter transported from the upper portion of the river, as it is translucent and unlike the water encountered in rivers such as the Ohio and the Mississippi. It has also a peculiar taste, at times similar to decayed organic and vegetable matter.

The works are under the direction of Mr. W. H. Brown, president of the water board; Mr. W. W. Fellows is the engineer at the works, and Mr. F. E. Sparks the inspector.