NEW YORK CITY AQUEDUCT—ITS ENGINEERING FEATURES AND DESIGN.*

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The capacity of the Croton watershed to furnish a minimum supply of 250,000,000 gallons per day was determined from its meteorological history. The whole question was narrowed down to the selection of plans and means to secure sufficient storage and to conduct the water to the city. The plans for the utilization of the waters of the Croton basin were, therefore, to combine a simplicity of construction, embracing economy in their design, large storage capacity, and a conduit from the Croton River to New York City.

The erection of numerous small reservoirs for storage purposes had been under consideration by the Board of Public Works prior to and during the years 1857 and 1858. Departing from the original plan, it was proposed in place of numerous small dams to build a large one on the Croton River at Quaker Bridge, about four and one-half miles above the mouth of the river, forming a reservoir of 3,635 acres in area, with a storage capacity of about 32,000,000,000 gallons, above the level of the proposed new aqueduct. This dam will receive the entire drainage of the 361 square miles of watershed, including about 23 square miles below the present Croton Lake, not included in any previous plans or calculations. The most economical means for conducting the waters garnered by a system of reservoirs, or a single dam, was by means of a conduit to New York City, constructed of masonry, circular in form, with a capacity to deliver 250,000,000 gallons of water per day, the conduit to be in tunnel wherever possible.

This plan has the advantage of being almost wholly in rock tunnel, securing the greatest possible strength and stability of structure, with the least cost for supervision and maintenance after completion. The prominent features of the entire plan therefore are a large reservoir to receive the entire drainage of the Croton watershed, and capable of holding 32,000,000,000 gallons of water above the level of the aqueduct.

The Croton watershed is located some thirty miles north of New York City, in the jurisdiction of the State of New York, having a catchment equal to an area of 361·8 square miles, with an average yearly rainfall equal to 45·97 inches, an average yearly flow of 135,400,000,000 gallons, or a daily flow of 371,600,000 gallons. This was determined from a meteorological history covering 17 years.

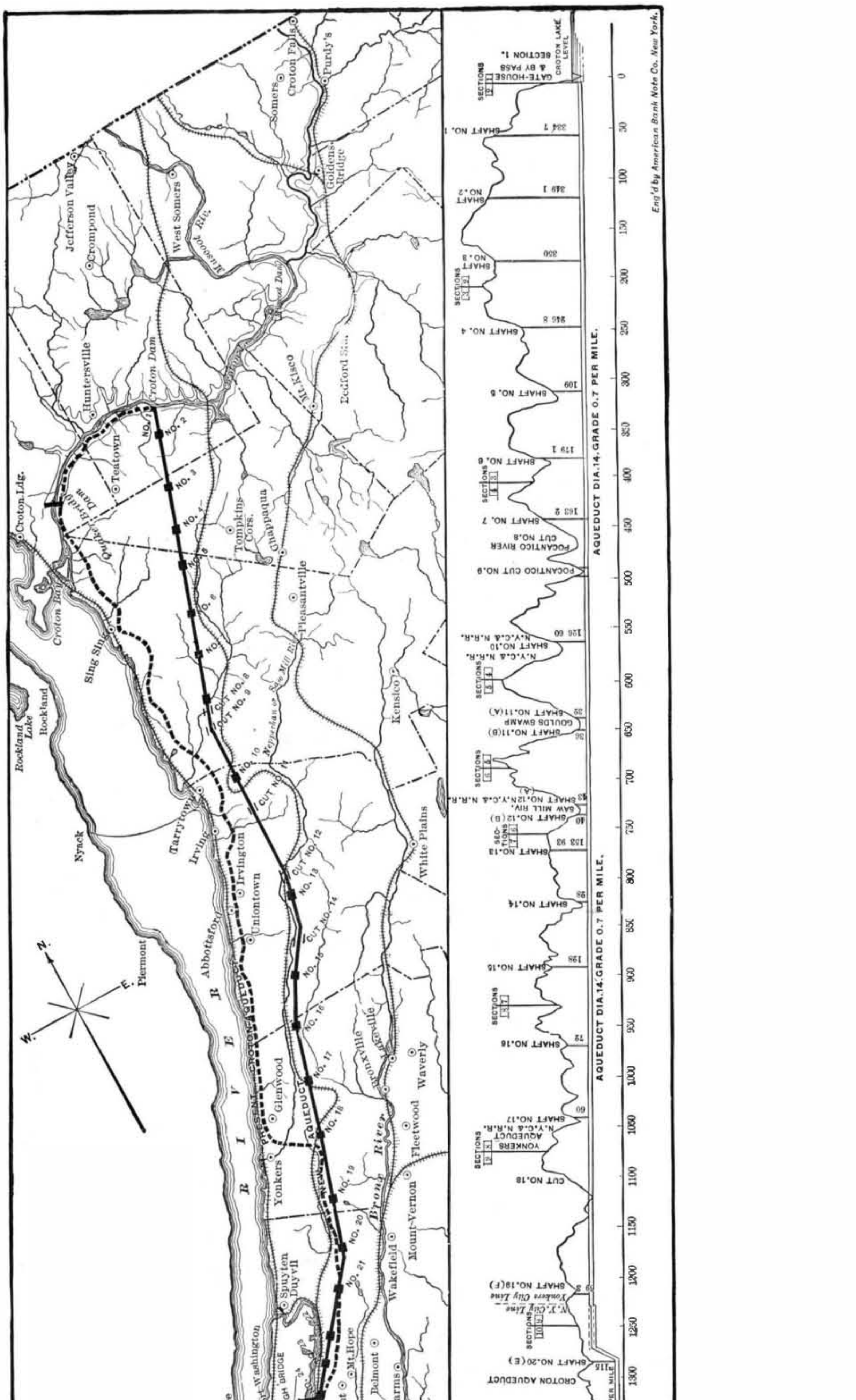
It had long been felt that the capacity and supply of the old system, erected when the population of the city was 350,000, were inadequate for the needs of a population of over 1,500,000, and that steps must be taken to increase the present supply. The Aqueduct Commission was accordingly created by the Legislature of New York in the year 1883, with power to provide an additional water supply.

Plans and specifications were presented by the Board of Public Works, specifying dams and reservoirs to be located at Quaker Bridge, in the Croton River basin, with a dam at Muscoot Mountain, in the upper Croton basin, together with a dam at Sodom, known as the West Branch Reservoir. After many public hearings and discussions the commission decided that the new aqueduct should be constructed with a conduit having an inside clear area equal to that of a circle of the internal diameter of fourteen feet, locating its northern terminus at Croton Lake, and afterward its southern terminus at Manhattan Valley.

The 9th of April, 1884, the plans relating to a conduit or tunnel thirty and three-fourths miles in length were adopted from gate house at One Hundred and Thirty-fifth Street to Croton Lake. The water was to be conducted to the reservoir in Central Park from the One Hundred and Thirty-fifth Street gate house, by means of pipes, a distance of two and three-eighths miles, making the total length of aqueduct thirty-three and one-eighth miles. The entire aqueduct is practically finished and ready for the introduction of water, its use being debarred only by some minor details. The water will enter the tunnel through a gate house located near the present Croton dam, this being constructed so as to receive water at an elevation of 140 feet above tide at the invert. Two other entrances are provided, one at elevation 166 and one at 184, discharging in Central Park Reservoir. The elevation of the flow line of Quaker Bridge Reservoir will be 200 feet above tide. The maximum elevation of the receiving reservoir in Central Park is 113 feet, the bottom 79 feet. The elevation of point of discharge is 104 feet; the hydraulic grade line at Central Park 113 feet, the total fall from water level of greatest flow in the aqueduct at Croton dam to high water in Central Park Reservoir being 33·8 feet, the distance being thirty-three and one-eighth miles.

The cross section of the tunnel is in the shape of a horseshoe, this modification from a circular cross section having been made with a view to economy in blasting out the rock, the natural inclination of which was to assume a square shape rather than a circular one; the hydraulic area of cross section remains the same as that

* Abstract of a paper read before the Franklin Institute, Philadelphia, Pa.



adopted by the commission, and extends without change twenty-five miles south of Croton Lake, with a hydraulic slope of 0·7 of a foot per mile, giving a velocity of four feet per second, and not being under flow pressure.

The remaining five miles being under flow pressure, by reason of a change in elevation, the diameter was reduced to twelve feet three inches. The hydraulic grade being raised increased the static head, and the capacity to deliver the amount of water required permitted a decreased diameter. The tunnel approached the surface four times in the total distance, enabling the work to be prosecuted by means of open cuts. Headings were driven in the rock north and south of thirty-eight shafts together with the portals in open cuts.

	Feet.
The greatest depth of shaft from surface	350
The least depth of shaft from surface	28
Aggregate depth of shafts excavated	4,491
Average depth of tunnel underground	170

The work of excavating the tunnel proper was begun March 7, 1885, and finished July 7, 1888, the time being three years and four months. The remarkably short time occupied in excavating the tunnel was due to the advance in mechanical appliances for drilling and excavating rock.

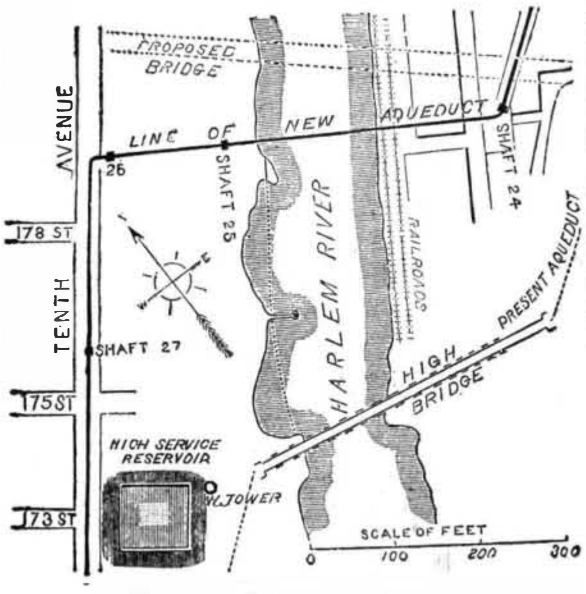
In passing under Gould Swamp the tunnel was driven on an incline with a hydraulic slope of fifteen per cent to a depth of sixty feet below the main tunnel, then carried for a distance of 716 feet under and beneath the swamp, rising again by a vertical shaft to the level of main tunnel. A pumping house was erected at this shaft, No. 11 "B," for the purpose of clearing the siphon of water when the tunnel is to be emptied for examination. The diameter of this siphon is the same as that of the tunnel, the change of elevation in main tunnel, which occurs about twenty-five miles from Croton Lake, descending by an incline with a hydraulic slope of ten per cent to a depth of sixty feet be ow the main tunnel. From this point the flow line is under pressure the remaining distance and the diameter is reduced to twelve feet three inches, the flow due to the increased velocity being about the same. Shaft No. 21, which is located near Jerome Race Course, twenty-five and one-fourth miles from Croton Lake, was designed with a view to the location of a reservoir at this point, discharging the water through this shaft.

The total capacity of the tunnel not under flow pressure being 310,000,000 gallons per day, will admit of storage of the surplus water at this point, the elevation of the surface at shaft 21 being at hydraulic grade line.

The hydraulic slope of the tunnel from the point at which the diameter changes to twelve feet three inches, as far as the north bank of the Harlem River, is 0·7 of a foot per mile. At this point a vertical descent of 169 feet is made in order to pass beneath the Harlem River. [See illustrations on first page.] The tunnel under the Harlem for a distance of 965 feet, being under flow pressure, was reduced to a diameter of ten feet six inches, which was found to be all that was required. In this part the hydraulic slope is 1 foot in 100 feet. The water is delivered to the tunnel through shaft No. 25, rising 321 feet, to an elevation 9 feet above high water mark, the tunnel being designed from this point to deliver the water at a gate house located at One Hundred and Thirty-fifth Street, with a rising slope of 0·065 per 100 feet, in order to drain that portion of the tunnel south of the Harlem into the Harlem River by an adit emptying into the river at shaft 25, situated on the south bank of the Harlem. Shafts 24 and 25 were constructed for the purpose of draining the tunnel under flow pressure north and south of the Harlem River, shaft 25 also serving as a pumping station to free the siphon under the river. The tunnel ends at the gate house located at One Hundred and Thirty-fifth Street, and the water is then conducted to the reservoir in Central Park by twelve lines of iron pipe, three feet in diameter. Four waste weir gate houses are located on the line, one at Pocantico River, near Tarrytown, nine and one half miles south of Croton Lake; the second at Saw Mill River, six and one-fourth miles further south, near Ardsley; the third at Tibbets Brook, five and one-half miles further; and the fourth at the Harlem River, seven miles below. Three gate houses serve to control and regulate the water supply through the aqueduct; the largest at Croton dam, the entrance; the second at the south end of the tunnel, One Hundred and Thirty-fifth Street, where the pipe line begins; and the third at the final terminus, in Central Park. The character of the rock varied considerably; hard, granitic, and syenitic gneiss rock was encountered, also lime rock, a soft laminated, micaceous gneiss and mica schist appeared in stretches. Disintegrated talcose rock occurred at shaft 18 south, and crushed in the strongest timbering. At shaft 30 south, some 300 feet of the tunnel were lined with iron in the form of rings bolted together, surrounded with brick and backed with rubble masonry. This was found necessary in such bad ground. Nearly every variety of tunnel experience was met with in this work.

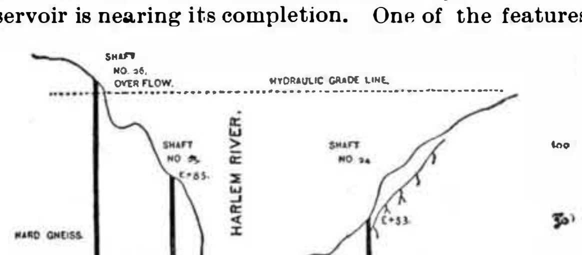
The entire tunnel is lined with brick from end to end, forming a wall sixteen to twenty-four inches thick, and filled in from brick lining to rock face with rubble masonry. In order to obtain room for this lining, the tunnel had to be excavated to a clear diameter equal to eighteen feet along the section, with an internal diameter of fourteen feet, and to fifteen feet in that part twelve feet three inches in diameter.

By far the greatest feature of the system designed for an additional water supply is the erection of Quaker Bridge dam and reservoir. Its utility and necessity are conceded, though its construction has not been finished. Its successful and permanent construction will undoubtedly become an established fact, in view of the real design and intention for which the new aqueduct has been constructed. The total height at center will be 265 feet; the width or thickness at base will be 216 feet; width at top, 20 feet; its length at top, 1,500 feet; elevation of base, —52 feet; elevation of flow line, + 200 feet; elevation of flood line, + 206 feet; elevation of top of rail, + 213 feet. This dam has been designed as a straight dam, and has met with difference of opinion in regard to this feature from numerous engineers.



THE HARLEM RIVER TUNNEL.

In connection with Quaker Bridge reservoir, the erection of a dam and reservoir at Muscoot Mountain, six miles above Croton Dam, is contemplated as a necessary auxiliary to Quaker Bridge reservoir. The dam would cover this territory with its back water, and would serve a sanitary purpose. In case the reservoir were drawn down at any time, the surrounding country would not be laid bare to the sun's rays, the consequences of which would be the serious contamination of the water. In order to acquire an increased storage of water above the present supply, pending the final determination and erection of the Quaker Bridge reservoir, a selection of a site on the west branch of the Croton River, near Sodom, was resolved upon. The reservoir is nearing its completion. One of the features



THE HARLEM RIVER TUNNEL.

of the Sodom dams and reservoirs is a double dam, two distinct drainage areas having two dams connected by a tunnel, so that the water can pass freely from one to the other.

The capacity of the Sodom or east branch reservoirs is about 10,000,000,000 gallons. The erection of this dam about doubles the existing storage in reservoirs and lakes located in the Croton watershed.

The Sodom or west branch reservoirs are impounded by small dams, one of them being of masonry 500 feet long, and the other an earth dam with masonry core. The Department of Public Works is erecting a reservoir on the Amawalk River, a small tributary, near the site selected for the Muscoot dam, with a capacity of 7,000,000,000 gallons. This, together with existing reservoirs and lakes, and the west branch reservoirs now building, will give a total storage of 26,000,000,000.

All the water in the Croton watershed will, in a few years, be stored up for use.

ESTIMATE OF FUTURE CONSUMPTION OF WATER IN NEW YORK CITY BY PROLONGING THE MEAN CURVE OF PAST CONSUMPTION.

Year.	Million Gallons.	Increase Million Gallons.	Year.	Million Gallons.	Increase Million Gallons.
1876	98·0	....	1889	168·0	7·0
1877	102·0	4·0	1890	176·0	8·0
1878	106·0	4·0	1891	184·0	8·0
1879	110·5	4·5	1892	193·0	9·0
1880	115·0	4·5	1893	202·0	9·0
1881	120·0	5·0	1894	212·0	10·0
1882	125·0	5·0	1895	222·0	10·0
1883	130·5	5·5	1896	234·0	12·0
1884	136·0	5·5	1897	246·0	12·0
1885	142·0	6·0	1898	258·0	12·0
1886	148·0	6·0	1899	272·5	14·5
1887	154·0	6·0	1900	290·0	17·5
1888	161·0	7·0			

The evidence of this record is that the Croton must be supplemented from some other source within a few years. The total capacity of the two aqueducts—the old and the new one—together being 350,000,000 gallons of water per day, their supply will answer all purposes for some time to come.

THE OLD CROTON AQUEDUCT.

Although the aqueduct which has for many years served New York City so well will undoubtedly be thus styled hereafter, it should not be forgotten that it still stands as one of the finest engineering works of its kind in the world, and will still be able to supply the city fairly well for some time yet in case of any failure in the newer and larger work. The Croton aqueduct was completed in 1842, having been five years in building, under the superintendence of John B. Jervis, chief engineer. The whole expense of the aqueduct, including $1,800,000 for distributing pipes, and amounts paid for right of way and other incidental charges, was $10,375,000, but commission and interest brought the total up to $12,500,000. The capacity of the old aqueduct is about 120,000,000 gallons daily, but of this amount only about 90,000,000 gallons daily reaches the great reservoir in Central Park for general use. This reservoir has for a long time been only a quarter to a third full. Its capacity is 1,030,000,000 gallons and it is the intention of the commissioners at first to use the new aqueduct only to fill up this great reservoir, flushing out the aqueduct for its whole length before letting the water into the reservoir. After the reservoir is full the water will be shut off for sufficient time to make a thorough inspection and repairs, wherever they may be needed. Readers should also in this connection refer to the article in last week's SCIENTIFIC AMERICAN on the Sodom and Bog Brook reservoirs.

Front Door Letter Box Wanted.

It is reported the Postmaster-General, in order to increase the efficiency of the free delivery service, desires to secure a device for a letter box for the doors of dwellings that will be simple in construction, low priced, and capable of adjustment to the interior or exterior of doors without injuring or defacing them. A letterbox that will fill these requirements will save much of the carriers' time, while increasing the security of the mail to the householder. The Postmaster-General has appointed a committee, of which Postmaster Van Cott and the postmasters of St. Louis, Washington, New Orleans, and Boston are members, to invite the public to send to either of the members designs, samples, models, or suggestions for such a box. Designs will be received until October 1 next, and the committee, after examining them, will tell the Postmaster-General which box, in their judgment, is best adapted to the purpose. The Postmaster-General will probably officially adopt the box or recommend it to the public for general use.

PASTEUR might have been the richest man in the world if he had cared for the commercial value of his discoveries and protected them by patents. In addition to his discoveries in the prevention of hydrophobia he discovered the cause of a mysterious disease among silkworms, which threatened to destroy the silkworm industry in France, and applied a remedy. The wine growers of France and Italy complained of their vines being slow to mature and the grapes to turn sour. Pasteur's investigations of the yeast germs taught the grower how these evils could be cured. He discovered the microbe which propagates disease in sheep, and suggested a remedy. These discoveries represent a gain to the community of many millions of dollars, but the great scientist has made no effort to profit personally from any of them.—*N. Y. World.*