NEW YORK WATER SUPPLY.

Department of Public Works.

HUBERT O. THOMPSON, COMMISSIONER.

REPORT

OF

JOHN B. JERVIS

CONSTRUCTOR OF THE CROTON AQUEDUCT.

ON THE PLANS PROPOSED BY

ISAAC NEWTON,

CHIEF ENGINEER OF CROTON AQUEDUCT.

NEW YORK:
MARTIN B. BROWN, PRINTER AND STATIONER,
49 AND 51 PARK PLACE.

1882.

ROME, N. Y., January 11, 1882.

To ISAAC NEWTON, Esq.,
Chief Engineer Croton Aqueduct, New York:

DEAR SIR—I acknowledged your favor of 10th December, 1881, also that of 26th December, 1881. In the mean time I visited your office in New York, and obtained a knowledge of the general features of the plans and estimates of the proposed improvements for the supply of New York City with water. After full consultation with yourself and Mr. E. S. Chesbrough, your Consulting Engineer, I now propose to reply to the questions you have propounded to me.

FIRST QUESTION.—*As to the Necessity of Additional Supply of Water.*

As to this question, it does not appear necessary to go much into detail. For several years, instead of adding to the supply as population increased, the overstrained capacity of the present aqueduct has been the same, and no addition has been practicable to the supply needed for the largely increased population. This situation is alone sufficient to demand an additional channel of supply. A serious failure in the present aqueduct, which has been a source of anxiety for several years, may arrest its functions.

I think it will be found that in all cases where water is freely used for city purposes, under pressure, it will be difficult to avoid considerable waste. There are those general uses for washing streets and sidewalks, and for fountains, which, though they be regarded as luxuries, will no doubt be largely demanded when water can be had within reasonable limits. This, of course, is for the city to decide, whether they will have an abundant or a restricted supply.

So far as I have observed, the recent works for a supply of water in large cities have been contemplated on a scale of much larger per capita allowance than was regarded as necessary forty years ago. No doubt there is a luxury in a free supply of water, although it be attended with considerable waste, and I suppose our present civilization will be willing to pay reasonably for the luxury. New York has a very large shipping interest that needs much water. Since the introduction of the Croton her manufactures have largely increased, and she is reported now as the largest manufacturing city in the United States. These demands must largely increase the per capita supply, and are very important to the interests of the city.

In any view I can take of the situation, it is evident that the present aqueduct is now under demand to its utmost capacity. Now it should not be forgotten that all works of men are subject, not only to unforeseen imperfection, but to the corroding tooth of time, and therefore liable to fail. The present aqueduct has shown some failure, and has demanded attention, though it has for 40 years afforded, without material detention, a supply for the most part much greater than was supposed necessary, but a serious failure may arrest its functions. This would be a calamity that should be guarded against by the most efficient means at command.

The present population is too large to depend for its current supply of water on one aqueduct. Without further discussion of this question, I have no doubt that every consideration of prudent regard to this important interest of the city demands an additional conduit.

SECOND QUESTION.—*Source of Supply.*

I notice by the reports you gave me, that surveys have been made, establishing the practicability of obtaining the supply from the Housatonic river, in Connecticut and Massachusetts. Whatever the feasibility of drawing from this source, or any other, it appears to me to be better that it should be held in reserve until the supply from the Croton valley is exhausted. If the latter was insufficient for a second aqueduct, an auxiliary from the Housatonic might be

necessary, but in my opinion this is not necessary at present. This, I think, will appear from the following remarks:

From gauges made for thirteen successive years, at the Croton dam, the water over the dam has ranged from 146,000,000 per day, in 1880, to 504,000,000 in 1866. It cannot be supposed that these gauges were strictly exact, though they are, no doubt, a reasonable approximation. But we have good means of corroboration.

At an early day in my professional life I had occasion to test this principle of drainage and determine the ratio of rain-fall that could be gathered into a reservoir. For this object I had two streams carefully gauged, one of them about eight months and the other about a year, the rain-fall being gauged at the same time and place.

From these I ascertained that 40 per cent. of the rain-fall was carried by the stream. The reservoirs were built at the same places, and now after 45 years in use the calculation has been fully realized. I applied the same ratio in my report on the Cochituate (Boston) basin, with results equally satisfactory.

Gaugings at Boyd's Corners during 1866 to 1876, inclusive, show a rain-fall of 51.77 inches in 1866, and 40.68 in 1876, when no water passed over the Croton dam for 175 days.

We see 40.68 is the lowest fall for 11 years, and if we reduce this to a fall of 38 inches, we have on an area of 340 square miles of drainage, a daily supply of 259,000,000 gallons.

The flow over the waste of the Croton dam, 146,000,000, added to that drawn by the aqueduct, 100,000,000, is equal to 246,000,000 per day. This is 13,000,000 less than by the ratio above stated. The Croton valley is a good district for drainage, and I should estimate it as entitled to a higher ratio than that given above. I therefore conclude we have corroboration of the gauge taken at the dam as before stated, that is quite sufficient to justify its use as the basis of computation.

I have not noticed any record of rain-fall at Boyd's Corners for 1880. It may have been less than for 1876, but probably not materially different. It is possible there may be a lighter rain-fall than that of 1876. This is a question for which there can be no data. An equalization to some extent will, no doubt, be secured by ample storage, as we do not often have two years in succession of light rain-fall, and an average year will leave over in the reservoirs the portion not used in the current supply, and this will aid a light year of rain that may follow. I am therefore of the opinion the Croton basin may be reasonably relied on to furnish 240,000,000 gallons per day for the whole year.

The natural flow of the Croton, beyond which storage should be provided, I think may be taken at 60,000,000 gallons per day. Of course I cannot be exact in this, but regard it as a sufficient approximation.

For a supply of 240,000,000 daily, 65,700,000,000 during the year must come from storage. I have not the data, nor do I know that specific observations have been had to determine this with accuracy, but suppose it an approximate and safe estimate. We may assume in round numbers 66,000,000,000 from storage. It will not be necessary to have reservoirs fully equal to this extent, as they will, to some extent, be refilled or raised by rains that fall during the summer months.

The value of this can only be estimated. On the other hand it should be observed that it is not good for the purity of the water to draw so as to leave a large surface of the bottom of the reservoir exposed. The reservoirs will, no doubt, be constructed gradually, and there will be experience to settle this question definitely before they are all needed, and any error in present estimate may be corrected in time. What is now material is to look at ultimate capacity.

At this time it appears to me a storage capacity of 60,000,000,000 of gallons will be quite sufficient to look forward to for future wants. I shall therefore take this figure as a basis of this question, though I think it rather large.

The facilities for the construction of these reservoirs must be considered. On this point I remark, for the purity of the water, reservoirs to store for city use should be large. This gives the least proportion of shallow border; as far as practicable, a situation that gives the largest proportion of bold and rocky shore should be preferred. Of the reservoirs now in use (excepting the Boyd's Corners and Middle Branch), there are 14, of capacity ranging from 25,000,000 to 575,000,000. I know not what the local situation of these are. They are mostly natural lakes and ponds. The whole 14 contain about 2,300,000,000. I have no doubt many of these will be dispensed with, as more suitable storage is secured. Of course they must be used until so superseded. I consider the large relative proportion of shallow margin a serious objection.

The total storage proposed is	62,000,000,000
Deduct Boyd Corners and Middle Branch, as given in this table, is....	8,230,000,000
To be built	54,770,000,000

This provides for more, say 4,000,000 of storage, than previously estimated, as necessary.

On this table I must make some criticism. The total drainage from the Croton valley is given at 339 square miles. This is stated at the bottom of the table. This table contained the area of drainage for each reservoir.

Reservoirs C and F have a drainage of 26 square miles, and a storage of 12,700,000,000. In these cases the drainage is quite inadequate for the storage. Others have barely drainage to fill them in a fair average season. H, I, and K have largely more drainage than the reservoirs can hold. The sum of areas given in the table is 482 square miles, or about 140 square miles more than the whole as stated at foot of table. Yet the whole drainage of this 140 square miles is deficient in provision for storage.

I have noticed the location of the proposed reservoirs in the topographic map and the drainage gathered into them. As before noticed, some of these reservoirs have not sufficient drainage to fill them, and others cannot store all the drainage that falls into them.

I have looked over the drainage indicated by the topographic map, and do not see how this can be equalized so as to make them efficient, as stated in the table. It is possible the location may show some method of relief; but of this I cannot speak.

From the lines of drainage on the said map, there appears a considerable proportion of drainage that has no storage in the proposed reservoir, which is quite inadequate. There is a considerable area of drainage southeast that falls into Croton lake, and has only the inadequate storage of the lake. On the northerly side of the Croton lake, the Muscoot branch empties into the Croton a short distance above the lake, this leaves very little of its drainage provided for. This is quite an important branch of the Croton. I cannot judge from the map as to the facilities for a reservoir to secure this drainage. I find several other places, where considerable districts of drainage are not gathered into any reservoir.

I do not consider it necessary for me to pursue this examination of drainage and reservoir in further detail. This should be done by some competent engineer in a thorough revision of the subject. I remark as to the existing state of this question, that there is not a full provision of storage in the reservoirs to provide for the whole flow above Croton dam. I cannot say how much drainage is lost in the two points involved, namely: the inadequate storage in some of the reservoirs proposed, to provide for their own drainage, and the drainage that cannot flow to any of the reservoirs proposed. Roughly estimating from the topographical map, I think from 50 to 100 square miles of drainage is still to be provided for. If you desire to secure all the drainage of the Croton valley, it will be necessary to carefully consider the facilities that the location may afford.

So far as I can judge from the map, it appears to me doubtful if you can obtain storage above the Croton lake for more than 100,000,000 per day, in addition to the flow of 100,000,000 by the present aqueduct.

If the Sawmill river route is adopted, I think you must be content, especially in seasons of light rain-fall, with 100,000,000 per day. It is possible you may find facilities to improve this, but I am not able from the topographical map to discover them.

THIRD QUESTION.—*Position of Reservoir for Storage—Importance of having them Large and well down the Stream.*

I have in part answered this in the previous question. No doubt large reservoirs are to be preferred, and the nearer the lower end of the valley, the more effectual will they be to secure the whole drainage of the basin. A large reservoir at the lower end will secure the flow that passes reservoirs higher up in the valley. In this case, it will naturally embrace all the drainage below the Croton dam, and a large part of that which now passes into the inadequate storage of the Croton lake. I am not able to be exact as to the extent to which you may secure by this means this extra drainage, but I think it reasonable to assume it will be equal at least to 50 square miles. It will afford opportunity to make the reservoirs that will still be necessary in the valley above, by selecting the most eligible sites for large capacity. The securing of large reservoir sites, instead of several small ones, is decidedly important in securing pure water. Then it is proper to consider that there may be seasons of less rain-fall than those recorded, and the city may need all those margins that must be unavailable by any other plan than the dam near the mouth of the river. This plan certainly provides for the most efficient method of securing the entire drainage of the Croton valley. By the plan proposed, you will take water into the aqueduct not less than 50 feet below the surface, in the purest condition.

I am well acquainted with the situation of the district for this reservoir, excepting a small part at the head. The shores, for the most part, will be bold and favorable, and for nine miles it will have very deep water. No doubt there will be shallow water at the head. This cannot be avoided in any location, but it will be as much less in proportion as its area and depth are larger. This brings me to the consideration of the next (fourth) question, a very grave and important one.

Fourth Question.—*Practicability of a High Stone Dam—Its Safety—Precautions to be Observed—Means of passing Flood Water during Construction of the Foundation—Height of Dam above Flow-line—Length of Waste-weir and Height of Water to be permitted above Flow-line during and after greatest Storms.*

As to general practicability, I have no doubt. But it will be a high dam; so far as can now be judged, about 230 feet above the rock bed, or 180 feet above the surface of the ground. You may require to go lower to secure a rock foundation for the highest part. Your soundings not being complete, I do not think it probable you will have to go materially lower than now appears probable, as above stated. It is not expected you will think to make it with dressed stone closely bedded. There will be no difficulty in making a wall of hydraulic masonry, sufficient to sustain it against the power of the water above from overthrowing it. The main question will be the power of the materials to resist the crushing force of the weight.

The materials will not weigh over 150 pounds per cubic foot, 230x150 34,500 pounds. Compact limestone will sustain about five times this weight.

I think you will have no difficulty in obtaining stone in the vicinity of the location that will sustain this pressure. Good brick will bear near four times the weight without crushing.

I propose the structure to be made of large, well shaped quarry stone, laid close together in full hydraulic mortar on their broadest beds; the vertical joints to be so trimmed up as to offer no obstruction to a thorough filling up of the vertical joints, which are to be filled with mortar or fine concrete as the opening may require; then the whole course leveled off with cement preparatory for the next course. Now the question is, will the cement sustain the pressure? Hydraulic mortar must intervene between the creases of stone and must be submitted to the same pressure.

During the building of the aqueduct I had occasion to take up, in the spring, about 30 feet that had been put down late in the fall previous, and had laid open uncovered during the winter. I was

rather surprised on breaking up to notice the fractures made no distinction, passing through cement or brick irrespectively, showing the strength of the cement was about equal to the brick.

Not a brick was saved whole in the 30 feet taken down.

This experiment showed very fairly the strength of cement was about equal that of a hard brick. The mortar used was Ulster cement, with clean sand.

The pressure of 230 feet in height will only apply to what may be termed the shaft of the wall, or a section of perhaps 20 feet through the centre. That is, if the wall was the same width from bottom to top.

But this will not be the form; extending unequally on each side of the supposed shaft, the foundation will spread, making a base of upwards of 150 feet, which will be all bonded together in one solid mass, diffusing the pressure of the shaft over this large base.

I have no hesitation in expressing the opinion that the Ulster cement, with clean sand, will make mortar and concrete sufficient for this work. If you can find cement that is stronger, it will be prudent to use it in the lower section of the dam.

The building of the wall should proceed so that the cement and concrete in one course should have proper time to set before another course is laid on it.

No rolling or truck machine should be allowed on the wall.

The materials should be handled with cranes and derricks. The stone lewised for handling so as to set them square and full on their mortar beds.

A dam of stone and cement of the character I have stated, if well constructed, will, in my opinion, be perfectly safe.

I now proceed to the second *item* in this question, namely:

Means of Passing Floods during Construction.

The floods of the river will, no doubt, embarrass the work of construction, and as this will be a work of years, the preparation should be very efficient.

I recommend that a temporary dam be made about 10 feet high at a suitable point above the foundation pit. The water of the river carried from this temporary dam to a point below the foundation in a tight wooden trunk or aqueduct. The trunk to be supported on timber trestles. As the earth under the aqueduct is removed, higher trestle to be substituted. The trunk should have capacity to carry a moderate flood in the river, so as to prevent it from arresting the work. As the work rises the space occupied by this aqueduct must be filled up. In the mean time you must provide at a suitable height in your wall a waste culvert, as a current means to carry off the ordinary stream, including light floods ; you must so arrange this culvert that it may ultimately be filled up with masonry.

Similar culverts in addition will be needed as the work rises. So far as possible, have the discharge of the culverts on rocky beds, otherwise you must make sluices or aprons to carry their water beyond your foundation.

Until your work is up, so as to supersede the wood trunk, it will be necessary to have efficient pumping apparatus to clear the water that may rise and fill the foundation pit. Temporary plank sluices, at low points in the wall, will be very useful, as an aid to the discharge of the culverts. These may be moved as the work rises, and will be an auxiliary that may provide for a rise of water that would otherwise stop work.

As winter approaches, the work should be brought into such a form that all parts exposed to floods should be covered with an apron of timber and plank, over which the water may pass during the winter, with the least injury to the masonry. In view of this, select a place in the masonry of sufficient breadth for the floods, having reference to the safety of the discharge, and leave this at a level that will not allow other parts of the masonry to be flooded.

Such a work cannot be executed without many contingent embarrassments, and you will find occasion for the most vigilant assiduity, and your best professional judgment will be demanded.

Though it is a bold enterprise, I regard it as quite practicable, and with a sound business arrangement, you may go forward with reasonable confidence.

The next item, namely :

The Height of Dam above Flow-line—Length of Waste Weir and Height above Flow-line Floods.

The old dam has a waste weir of 270 feet. In about 40 years since its construction, no flood has been reported, except in one instance, of a rise of 8 feet above the crest of the dam.

It appears this may be taken as an extreme rise.

The establishment of reservoirs will no doubt tend to relieve the floods in the channel of the river. As reservoirs are constructed, they will retain a large portion of the flood waters that now pass off in the stream. When the rise was 8 feet, there was no artificial reservoir, except Croton Lake, and this was a trifle in such case. It is possible there may be greater floods than have been known, and it is best to move on the safe side, and take no account of the influence of the reservoir on floods. I should regard this a very safe course.

A computation of this greatest flood has been sent me, and the result is, it would require a waste of 540 feet in length, with a rise on the crest of the dam of 5 feet, to discharge it. With this state of facts, I advise a waste of 540 feet. If I understand the location, and I have no doubt it was well explained to me, the facilities for a waste weir in the proposed dam are very good. Its position will be in the subsidiary dam that is required north of the main dam, where the waste weir and the channel from it will be in solid rock. You can make such channel in this rock as may be necessary to lead the flood into the river below at a safe distance from the dam.

I suggest that you be particular, as to this channel from the waste, to guard against any danger to the main works; for though it be in solid rock, there will be a powerful volume which should be carefully directed.

The length of weir proposed provides for a rise of 5 feet above the flow-line. A rise of more than one foot above this height, making the total of 6 feet, is the largest that can be contemplated. I propose the height of the dam to be 12 feet above the flow-line, or 6 feet above the greatest rise that may be anticipated. This may appear rather large, but the case is one in which no room should be left for doubt. The width at top I propose to be 20 feet.

The location of weir is very favorable for construction. The discharge will be on solid rock and not high. It is necessary to bear in mind the force of the waste column will be great. It will remove solid rock and gradually increase its fall. It will be necessary to excavate to give proper form to the waste channel.

The great point of care is to so form the lower part of the dam or waste as to gradually convert its force from a vertical to a horizontal direction. The O. G. form in the old dam has effected this better than any other method I have known.

You may suppose the fall is small and the rock-bed will be sufficient, regardless of further security. But I would not trust this. The waste column may be resisted for a time by the rock over which it flows, and if the descent was small, might be safe for a long time. You have to provide for a fall of 200 feet in a short distance, not much over a half a mile, and the waste volume of a flood of 5 feet on a 500 feet waste, will scatter rocks in its movement and make itself channels not anticipated.

It is prudent to carefully guard the action of this force.

I think I have answered the fourth question.

FIFTH QUESTION.—*Conduit in Tunnel as much as possible, instead of on Embankments or in Slight Excavations.*

There can be no question that a conduit in a tunnel through solid rock will be more safe and require less repair than on any kind of filling, or in light cuttings.

In some cases the cost of filling in low grounds would be greater than that of tunnel in sound rock. In this you must be careful to secure by thorough arching any weak places in the rock. With the experience of the old aqueduct you need not fear to make any part perfectly safe; but it will be at greater expense. In any contingency the rock tunnel must be regarded as having the most absolute safety.

SIXTH QUESTION.—*Difference in Cost of Conduit of, say,* 150,000,000 *daily, and one of, say,* 200,000,000 *to* 250,000,000, *not Equal to the Value of the Increased Capacity.*

It would require more calculations than I am now able to make to determine what the difference of value may be. There is, however, no doubt the large conduit will be less expensive as compared to capacity than the smaller one.

SEVENTH QUESTION.—*Level of Central Park Reservoir to be Maintained in New Works; but General Head throughout the City to be greatly improved by Additional Supply, probably without New Mains at first.*

The new aqueduct will greatly improve the facility for keeping full head in the city reservoirs, and consequently maintain more efficiency in the pressure on the distribution pipes. Whether an increase of the city mains may be found necessary, will depend on the experience of the effect of a full head in the reservoirs.

No doubt the existing mains will be more efficient when the new aqueduct is brought into use; but I think you cannot now decide that the present mains are fully all that may be found necessary.

I suppose it best to leave this until the effect of the new aqueduct is experienced.

EIGHTH QUESTION.—*Danger to a City of the Importance and Magnitude of New York, of depending wholly on one Aqueduct.*

I have in part answered this in my reply to the first question.

As to the propriety of a second aqueduct there can be no doubt.

I fully appreciate the good judgment and success that has attended the efforts of the Water Department to maintain the aqueduct so far, and have no doubt these efforts will be successful except in cases where the foundation has settled. From what I learn from the Engineer in charge of the aqueduct, it is evident there are places in which the foundation has settled, and probably continues to settle. I know of no method to reach and repair such places, with the aqueduct in use. The only way is, to construct a new piece of conduit to take the water past the defective part. This can easily be done by curving out and in from the sound part. You need not fear a curve of 100 feet radius in the new piece, as with the current of the aqueduct it will make no appreciable difference in the flow. It will not be necessary to adopt a sharper, and probably not as sharp, a curve, to join the existing work.

You can make this new part, bringing the ends close to the old work, and take the opportunity when the water is out for general examination and repairs to make the connection.

Of course you will see what is necessary to make this new section perfectly stable. I recommend strict care in securing a foundation and the supporting wall to be hydraulic masonry ; this wall to be carried up in width to support the entire aqueduct and the thrust of the arch. No outside filling of earth except so far as may be necessary to throw any land drainage of water from the foundation.

With the methods of repair already adopted, and new sections in the places referred to, you may maintain the office of the aqueduct indefinitely. It will be some expense to follow this plan, but the places are short and in view of the object the expenditure of a quarter or half, or a million of dollars should not prevent the most efficient repairs.

It may be that you can keep up the uninterrupted use of the aqueduct at less expense than I propose, and were it an ordinary service that is to be secured, it might do to venture it. But the supply of the daily wants of a large city with water depending on one conduit, is a most serious responsibility. If there was nothing to indicate danger, and it should come in some unlooked-for manner, no complaint could be made. In my judgment there is danger, and the means of guarding against it are within your reach. It will not do for you to say, when calamity occurs, "You thought you could secure the work without so much expense."

It will be several, not less than three or probably four, years before you can bring the new aqueduct into use. For this time

the city must depend on the present aqueduct, and especially during this interval, nothing should be left to guard its full capacity as the only source for water the city can depend on. Pardon me for the urgency in which I regard this matter. It is a solemn responsibility, and I urge it as at least a precautionary measure, called for by too manifest a danger—a danger too well known to excuse such a calamity as the cutting off the supply of water from a large city. I believe I have now answered all your questions.

If I have gone into some matters not strictly called for by your questions, I think the varied interest and the magnitude of the enterprise will excuse me.

General Summary.

1st. The dam you propose is practicable.

2d. It is the best, and in fact the only plan that can secure the whole source of the Croton valley for the supply of its waters to the city of New York.

3d. It furnishes a reservoir of large capacity, and thus provides for a supply of water in the purest condition practicable.

4th. Though there will be more or less embarrassment from the floods of the river during construction, there is no reason to doubt they may be successfully overcome by the engineering skill you will be able to exercise in this respect.

5th. As to the line and plan of aqueduct you propose, I see nothing to suggest. Your view of this I regard as well taken.

Allow me to suggest, if this great work be authorized, as I think it will, the importance of care in the selection of contractors. These should be men of ability and fidelity, willing to conduct the work on sound business principles, giving it their personal supervision, and conforming strictly to your specifications. There will be great danger that a work of such magnitude as the dam will tempt speculation and fall into the hands of contractors who will, on account of their great power, control you instead of your directing them.

You cannot be too careful and explicit in your specifications, in the enforcement of which you will need several assistants, of undoubted fidelity and firmness and willingness, at all times in all kinds of weather, to look after the interests of the work.

With such contractors and assistants as you would no doubt select, if in your power, and your own watchfulness, never allowing a deviation from your specifications that could by any possibility endanger the work, you will have the pleasure of completing that great structure, the dam, as well as the tunnels, in an economical, substantial, and satisfactory manner.

I hope no one will be offended by these remarks; but I have had so much experience of this kind, that I feel it would be a calamity, indeed, to have the construction of so great a work entrusted to any other contractors than those of sound business principles.

When the dam is carried to the height of the gate chamber, you can occupy the new aqueduct, should it be ready. This you will see.

With sincere wishes for your success in the construction of this rather bold, but eminently important and, as I believe, quite practicable work, I submit this paper.

Very respectfully,

JOHN B. JERVIS,
Consulting Engineer.