2

BROOKLYN WATER WORKS.

REPORT

ON THE POSITION OF THE

Prospect Hill Engine House.

WITH NOTES OF CERTAIN EXPERIMENTS MADE ON THE WATER DELIVERIES OF PORTIONS OF THE CROTON AND THE JERSEY CITY PIPE MAINS.

1858.

NEW YORK:
HOSFORD & CO., PRINTERS AND STATIONERS,
57 & 59 WILLIAM STREET.

1858.

Engineer's Office, Brooklyn Water Works,
November 8th, 1858.

JOHN H. PRENTICE, Esq.,
President:

Sir—As it will soon become necessary to select a site for the Prospect Hill Engine House, I beg to make a statement of the reasoning which has assisted me in determining the height above tide water, at which I would propose to place it.

The Pump Well of the Prospect Hill Engine House is to be supplied with water by a branch pipe from the 36 inch main which has just been laid in De Kalb Avenue; a part of this branch pipe will be of 30 inches diameter, and part of 20 inches.

It is a difficult point to determine exactly the height on the Prospect Hill slope, at which the required amount of water (156,250 gallons per hour) for that secondary service can be delivered, under all the conditions of the city consumption.

During the first or second season after the receipt of water into the city, when its use by the citizens will be comparatively limited, a difference of level of but 20 feet below the water of the Ridgewood Reservoir would probably secure the desired delivery on Prospect Hill; but this difference would become entirely insufficient, when the use of the water in the city became as general as it now is in the City of New York.

I have assumed that the Prospect Hill Pump Well should be situated low enough to secure a sufficient delivery of water there when the flow through the 36 inch main, laid from Ridgewood Reservoir, is equal to the flow at this time through the same size of main into New York.

From experiments made recently by Mr. G. S. Greene, with Mr. Craven's permission, on the New York Works, to ascertain, among other points, the delivery of the two 36 inch mains from the Receiving Reservoir at Eighty-sixth Street into the Distributing Reservoir at Forty-second Street (see Note 1), the flow into the city by each of the two effluent mains (36″) which convey the water from the south side of the *Distributing* Reservoir for the city consumption, was ascertained to be 647,101.5 cubic feet during the eight hours between 10 A. M. and 6 P. M. of Saturday, the 10th of July, 1858, = 22.469 cubic feet per second.

For the twelve hours of day between 6 A. M. and 6 P. M., assuming the same rate of delivery to prevail, This would give	970,652	cub. ft.
For the twelve night hours, assume the consumption to be one fourth of the above, viz...	242,663	"
Total flow in 24 hours for this 36 inch pipe ..	1,213,315	"
The Croton water is delivered from the Receiving Reservoir aforesaid into New York by four mains, two of 36 inches diameter each, and two of 30 inches diameter.		
The aggregate consumption of the City of New York at the above rate would sum up as follows:		
The second 36 inch main..................	1,213,315	"
Flow through the two 30 inch mains, nearly in proportion to the areas of the 36 inch and 30 inch pipes, or more accurately, as $\sqrt{d^5}$	1,538,333	"
Total daily consumption in cubic feet........	3,964,963	

This is equal to 24,781,019 imperial gallons, or 30,976,273 New York gallons, in twenty-four hours.

It has been shown that the delivery of the 36 inch main into New York during the twelve hours of the day, amounts to 970,652 cubic feet, = 7,583,219 New York gallons.

I will assume the 36 inch main from the Ridgewood Reservoir to be delivering at this rate into Brooklyn and Williamsburg, when the Pump Well at Prospect Hill is receiving its quota of water.

This would make the delivery per hour from Ridgewood Reservoir 631,935 gallons, say 632,000 New York gallons.

Assuming one fourth of this quantity to pass on by the 30 inch branch main to Williamsburg, there would flow on into Brooklyn proper a rate per hour of 474,000 gallons.

The Prospect Hill pumping engine is required to be of sufficient capacity to raise 156,250 gallons per hour, and must consequently be supplied at that rate—call the rate 166,666 gallons per hour through its supply pipe, to allow for the effect of the two 12 inch branches upon this pipe, one at Gates Avenue and the other at Fulton Avenue.

Applying the proper distances, we have now the following data:

15,637 feet of 36 inch main, between Ridgewood Reservoir and the junction of De Kalb Avenue with Division Avenue, delivering at the rate of 632,000 gallons per hour.

10,425 feet of 36 inch main, from the last mentioned point along De Kalb Avenue to the crossing of Washington Avenue, delivering at the rate of 474,000 gallons per hour.

4,600 feet of 30 inch and 20 inch main, from the last point to the supposed position of the pump well, delivering at the rate of 166,666 gallons per hour.

Assuming, in the first place, the above mains or pipes to be straight and unbroken by branches, the following table will show the calculated head necessary to produce the rates of flow above indicated.

Table A.

LOCATION.	Length of Pipe, in feet.	Diameter of Pipe, in inches.	Rate of Flow, in N.Y. gallons per hour.	Rate of Flow, in cubic feet per second.	Calculated head to produce the given flow by the formula, $h=0.00046749\frac{L}{d}(v+0.397)^2$
Reservoir to De Kalb Avenue	15,637	36	632,000	22.471	31.160 feet.
De Kalb Avenue to Washington Avenue	10,425	36	474,000	16.853	12.5663 "
Washington Avenue to Pump Well	3,000	30	166,666	5.9259	1.4437 "
	1,600	20	166,666	5.9259	4.3497 "
	30,662				49.5197 "

The above formula is derived from a formula of Prony's, which has been altered in its constants, so as to correspond very nearly with the results of recent experiments on the ordinary deliveries of the connecting pipes of the New York Reservoirs and of the Jersey City Reservoirs.

The head required to produce, under the given circumstances, the necessary delivery at the Prospect Hill pump well, according to the New York and Jersey City experiments, is . 49.52 feet.

For the effect of the branch pipes to be connected hereafter with these mains, add	10.00	"
Total head lost	59.52	"

This last mentioned allowance of 10 feet will be adverted to again.

The surface of Ridgewood Reservoir, when full, is 170 feet above mean high water of Brooklyn Harbor. Assume that the height of water in the Reservoir (except in extreme cases) is

not allowed to fall below	164.0	feet.
Deduct the head lost as above	59.5	"
Height of water in Prospect Hill Pump Well above tide	104.5	"
The floor of the Engine House may be situated 12 or 15 feet above the water of the Pump Well, say	15.0	"
Height of this floor above tide	119.5	"

The ground for the site of the Engine House may be conveniently 4 or 5 feet below the level of this floor, say 115 feet.

This height of 119.5 feet, if our calculations are correct, should enable you to control a liberal supply of water at the Prospect Hill Engine House, when the delivery of the 36 inch main into Brooklyn is about its maximum in practice.

Another line of similar pipe from the Reservoir will, in all probability, be laid before the rate of flow into the city, which has been assumed for this one, is exceeded.

In the interim, the free delivery at the Prospect Hill Pump Well would begin, as already stated, by being much in excess of the contract requirements, but would approximate with every additional year more nearly to our calculations. The excess of head during the early years can be controlled by the stop-cock, and might be used to assist the action of the engine and reduce the consumption of fuel.

To enable me to understand how much to allow beyond the results which any calculations can well give for the confusing influences of the various connecting pipes hereafter to be applied on this section of the city "distribution," I made, with Mr. Craven's permission, two experiments on the New York City mains, at points near the centre of the city.

One of the 36 inch delivering mains of the Distributing Reservoir passes down the Fifth Avenue into Broadway, and down Broadway to opposite Houston Street, where it is reduced to a 30 inch main, which last continues down Broadway to about opposite the Hospital.

At Canal Street a 20 inch pipe branches from the 30 inch main last mentioned. Upon this 20 inch pipe, within 12 feet of the 30 inch main, I placed an Ashcroft guage, and had its indications noted every quarter hour between 7 A. M., and 5 P. M., of the 23d of July last.

The readings varied from 26 lbs. at 7 A. M., to 24½ lbs. at 9 and 10 o'clock, A. M.; thence back to 26½ lbs. at 5 P. M. The average and more general reading was 25 lbs., equal to a head of 57 feet.

The distance of this point from the Distributing Reservoir is 13,130 feet, and from the Receiving Reservoir 24,430 feet, all of which length consists of 36 inch pipe, with the exception of about 2,300 feet of 30 inch pipe between Houston and Canal Streets. Between the Distributing Reservoir and Canal Street, (13,130 feet) branch pipes connect at intervals, as hereinafter enumerated.

The height of the Receiving Reservoir above tide, when full, as it was in this instance, is........................114.0 feet.

The height of the pipe in question at this point (Canal Street) above tide..........................	4.5	"
The difference in level, therefore....................	109.5	"
Guage indication of head available at Canal Street..	57.0	"
Loss of head..........................	52.5	"

In this case $52\frac{1}{2}$ feet of head are absorbed in a distance of 4.63 miles.

The distance between the Ridgewood Reservoir of the Brooklyn Water Works and the Prospect Hill Engine House is 5.81 miles.

The other experiment was made on the 30 inch main in Avenue A, opposite Tompkins Square.

This 30 inch main, after leaving the vaults of the Receiving Reservoir, follows down Fifth Avenue to Seventy-ninth Street, thence along Seventy-ninth Street to Third Avenue, along Third Avenue to Fourteenth Street, along Fourteenth Street to Avenue A, and along Avenue A to Tompkins Square.

The distance along its line from the Receiving Reservoir to the point where the Ashcroft guage was applied, is 23,400 feet. The distributing pipes branching from it are shown in the accompanying sketch.

The guage indicated an average pressure of $25\frac{1}{2}$ lbs., equal to a head of 58 feet.

The difference in level between the surface of the water in the Receiving Reservoir and the

Pipe at this point is	102	feet.
Average head, by the guage, available at Tompkins Square..................................	58	"
Loss of head........................	44	"

In this case 44 feet of head are absorbed in a distance of 4.43 miles.

In Table D, I have divided that part of the Fifth Avenue and Broadway main, applicable to our experiment, into two sections, viz.: the portion between the two Reservoirs, and the portion between the Distributing Reservoir and Canal Street.

The first length measures 11,217 feet, and the difference of level of the surface waters of the two Reservoirs averaged, during Mr. Greene's experiment, 20.215 feet.

The second length measures 13,130 feet, and the difference of level between the surface of the water in the Receiving Reservoir and the surface of the pipe in Canal Street, is 109.5 feet.

In this Table, I have compared the actual head in practical use, as ascertained in the first section by levelling and in the second by the guage, with the calculated heads which some of the best formulas show, under the supposition of an unbroken pipe line and certain given deliveries.

On the first section of the 36 inch main between the two Reservoirs, there were no side connections open to interfere with the regular flow in the pipe during the time of the experiment already mentioned (see Note 1).

It will be observed that in this first section the calculated head (20.17) by the assumed formula "I" in column 8, necessary to pass the water which was delivered by each 36 inch main, agrees very nearly with the actual head 20.2, as obtained by levelling between the two surfaces. The well established formulas of columns 9 and 10, give 14.90 and 14.83 for the requisite head.

The formula ("I") referred to, is derived from one of Prony's, the constants of which have been modified, so as to render it an exponent of the experiments made on the New York and the New Jersey mains, as will be further explained.

In the portion of the main *below* the Distributing Reservoir,

Tabular Statement in regard to the Experiments upon the New York Mains. D.

1	2	3	4	5	6	7	8		9	10
Head lost, in feet.	How ascertained.	Difference in level between the points, in feet.	Delivery in N. Y. Gallons per hour.	Delivery in cubic feet per second.	Length of Pipe, in feet.	Diameter of Pipe, in feet.	Calculated head to produce the given flow, by the formula, $h=0.00046749\frac{l}{d}(v+0.397)^2$ (*I.*)		Calculated head to produce the given flow, by Prony's formula (2). (*D.*)	Calculated head to produce the given flow, by Hawkesley's formula. (*A.*)
SECTION 1.		**Pipe Main between the Receiving Reservoir and the Distributing Reservoir.**								
20.215	By levelling between the Reservoir surfaces.	20.215	596,352	21.2036	11,217	3	20.1670	20.1670	14.899	14,833
SECTION 2.		**Pipe Main between the Distributing Reservoir (down Broadway) and Canal Street.** **The total distance is divided up, as in column 6, for convenience of calculation.**								
		89.28	632,000	22.471	3,050	3	6.0778		4.5175	4.6938
			570,000	20.267	2,250	3	3.7357		2.7371	2.8670
			480,000	17.067	2,850	3	3.5103		2.5032	2.5389
			420,000	14.933	2,650	3	2.6008		1.8113	1.8148
			350,000	12.444	2,330	2.5	3.7461		2.6925	2.7792
52.5	By an Ashcroft guage applied to the pipe.	109.5					19.6707	19.6707		
								39.8377		

Similar Statement for the Mean of Experiments upon the 20 inch Main of the Jersey City Water Works.

	How ascertained.	Actual head, in feet.	Delivery in N. Y. Gallons per hour.	Delivery in cubic feet, per second.	Length of Pipe, in feet.	Diameter of Pipe, in feet.	Calculated head to produce the given flow, by the formula, $h=0.00046749\frac{l}{d}(v+0.397)^2$ (*I.*)	Calculated head to produce the given flow, by Prony's formula (2). (*D.*)	Calculated head to produce the given flow, by Hawkesley's formula. (*A.*)
28.1285	By levelling between the Reservoir surfaces.	28.1285	88,231.5	3.13712	29,715	1.6667	28.064	17.921	16.056

Note (*a.*)—The first of the New York Mains has three right angled curves, of 90 feet radius, which are taken into account in the calculations. The Jersey City Main is enlarged, for a distance of 128 feet, to 24 inches diameter. Allowance is made, in the calculation, for this enlargement and the curves in the pipe.

Note (*b.*)—The formula (*I*) is used only as an exponent of the experimental delivery of the first section of the New York Mains, and also of the delivery by experiment of the Jersey City Main, to make a convenient application of their general results to a similar case in Brooklyn.

Note (*c.*)—The Pipes branching from the 36 inch Main, situated in Fifth Avenue and Broadway, within the distance given in this table, are as follows: (See Sketch S.)

At 29th Street,	a 20	inch	pipe	branches	East and West.
" 20th "	a 20	"	"	"	East and West.
" 10th "	a 20	"	"	"	West.
" Houston St.	a 20	"	"	"	East and West.
" Canal "	a 20	"	"	"	West.
and	a 6	"	"	"	East.

The flow of water into the Main at the point where it leaves the Distributing Reservoir, has been ascertained by experiment. The reduced flow, beyond the several points where the pipes above mentioned branch off, is assumed, and cannot be exactly determined.

Formulas used in Table D.

(*A.*) Hawkesley's $h=0.0004338027\frac{v^2\,[L+54d]}{d}$

(*D.*) Prony's (2) $h=0.00040085\frac{L}{d}[(v+0.15412)^2-0.02375]$

(*I.*) Expressing the mean result of the New York and the Jersey City experiments $h=0.00046749\frac{L}{d}(v+0.397)^2$

Where v=Velocity, in feet per second.
h=the Head, in feet.
d=Diameter of the pipe, in feet.
L=Length of the pipe, in feet.

where the distributing pipes for the city consumption radiate from it on either side, the *actual* head absorbed between this Reservoir and Canal Street, in producing the flow occurring there, is 32.28 feet. Assuming the pipe to be straight, and the quantities to be as in the table, the *calculated* head required to produce the same flow of water, is by formula "I" 19.67 feet—showing a difference of 12.61 feet.

The difference by the other formulas is much greater.

The great difference in this case between calculation and the guage indication, must be attributed largely to the effect of the many connecting pipes which occur on this section, involving eddies inside the pipe, and confused action, which these formulas were not intended to express; but there must be other reasons growing out of circumstances connected with the condition of the pipe, unknown to me, producing this large difference: these circumstances, however, might obtain on the Brooklyn pipe also, and it has been thought best, therefore, to make an allowance for them.

The accompanying sketch S will show the position of the branching pipes known to me, as well as their sizes.

There are five 20 inch pipes branching from the west side of this 36 inch main, and three from the east side, being eight 20 inch pipes in all, drawing their supplies from this main between the defined points.

These eight pipes have a water area of 17.45 square feet.

The delivery area of the main, when it leaves the Distributing Reservoir, is 7.07 square feet: when it reaches Canal Street it has virtually increased to the united areas of one 30 inch pipe and eight 20 inch pipes, equal to 22.36 square feet of water space.

The loss of head resulting from this rapid enlargement, in effect, of the original main, could be counteracted and to a certain extent neutralized by a liberal addition of auxiliary mains from the Reservoirs, and of cross mains throughout the small pipe distribution.

This kind of correction of the difficulty has already been begun, but it will involve, probably, an increased expenditure of water.

So far as the loss of head may result from accidental collections of air in the pipes, it could to that extent be remedied by a more liberal supply and more frequent use of air-cocks.

The reasons will now be understood which influenced me in making an allowance of 10 feet for the effect of branches, &c., in the calculations of head required to secure the Prospect Hill supply.

The branchings in this case are not likely, for a very long time, to equal in extent those on the New York section referred to, and I have not, therefore, allowed as much.

To recapitulate,

1st. In a distance of 4.63 miles on the New York 36 inch main the head lost is $52\frac{1}{2}$ feet.

2d. In a distance of 4.43 miles on the New York 30 inch main the head lost is 44 feet.

(The guage varied considerably in this experiment on the 30 inch main. The morning readings would have given a much greater loss than the above.)

3d. In a distance of 5.81 miles of 36, 30, and 20 inch pipes in the Brooklyn case referred to, the loss of head will amount, it is calculated, to 56 feet, some five to ten years hence, when the use of the water has become very general throughout the city.

The experiment made upon the two Croton Reservoirs, to ascertain the actual delivery of the two intervening 36 inch mains under a given head, gave results considerably below those which the usual formulas would have promised under the same conditions.

The discrepancy may have grown out of various causes of disturbance to which all lines of pipes are subject, some of these beyond the reach of correction, and others controllable by the exercise of constant care and attention.

Among the first may be instanced the tubercular corrosion, which on these pipes is considerable, as I have ascertained by inspection.

Among the second may be instanced the collection of air on the high points of the line, and some sedimentary deposits at low points.

Both of these last causes might have been more or less got rid of by blowing off at the depressions when there exists the means of doing so, and by opening the air-cocks which are provided, and adding others where necessary.

But the experiment was more interesting and pertinent to the case in point without such previous preparation of the pipes. It was desirable to understand the rate of flow under the ordinary condition and superintendence of the service, rather than under a special condition of it.

To ascertain whether the discrepancy adverted to was exceptional, or whether it arose more or less from some speciality in the character of this experiment, I have had, with the consent and assistance of Mr. G. H. Bailey, the Engineer of the Jersey City Water Works, a somewhat similar experiment made on the pipe which connects the two Reservoirs of these Water Works, the one situated near Belleville, the other in Hudson City.

The length of the pipe connecting these two Reservoirs is 29,715 feet.

The diameter is 20 inches, except at the crossing of the Hackensack River, where it is increased to 24 inches for 128 feet of its length.

During the experiment no water was received into the Belleville Reservoir from the Pumping Engine.

At the beginning of the experiment the difference in level of the surface water of the two Reservoirs was 30.529 feet.

At the end of the experiment it was 25.646 feet.

The experiment was made on the 25th, 26th, and 27th of September, 1858.

Mr. C. W. Boynton, one of our assistant engineers, took the principal observations, and has made for me the calculations presented in Table J.

In this Table we have brought together a number of well-known formulas, and compared the velocities which they give for the head and size of pipe, with the actual velocity as obtained from this experiment (see Note 2): the same comparison is there made with the results of the Croton Reservoir experiment.

It will be seen that in both cases all these formulas gave velocities considerably greater than the actual velocity which prevailed in each experiment.

The Jersey Reservoir experiment, therefore, corroborates the Croton Reservoir experiment, in giving deliveries and velocities below the quantities which the formulas gave.

Preferring to take these experiments for my guide, the circumstances of which elucidate so well the case which is presented on the Brooklyn Works, I have had one of Prony's formulas modified in its constants, to meet very nearly the results of both experiments, and have used it as thus modified to ascertain the probable loss of head in the Brooklyn case already detailed.

This exceptional equation (given elsewhere) has also been transformed for our convenience so as to express the *head* required under the conditions defined, instead of the *velocity*.

The modified form of Prony's formula I do not introduce as applicable elsewhere, or as a correction of well-established

Tabular Comparison of the New York and Jersey City Experiments. J.

EXPERIMENTS: Where, and by whom, made.	Diameter of the Pipe, in feet.	Length of Pipe, in feet.	Mean Heads under which the discharge occurred.	VALUES OF THE VELOCITY, IN FEET PER SECOND.								
				As deduced from the discharge.	By Hawkesley's formula. *(A.)*	By Blackwell's formula. *(B.)*	By Prony's formula (1). *(C.)*	By Prony's formula (2). *(D.)*	By Eytelwein's formula. *(E.)*	By D'Aubuisson's formula (1). *(F.)*	By D'Aubuisson's formula (2). *(G.)*	By Weisbach's formula. *(H.)*
On the 20 inch Main between the Reservoirs	1.6667	29,715	30.262	1.4924	1.97399	1.97624	1.9206	1.91068	1.97063	1.927302	1.92923	2.03255
of the Jersey City Water Works.	1.6667	29,715	29.758	1.51337	1.9575	1.9597	1.9039	1.89338	1.95416	1.9105	1.9123	2.01294
By G. H. Bailey and C. W. Boynton.	1.6667	29,715	29.317	1.44893	1.94293	1.94514	1.8891	1.87838	1.93963	1.8957	1.8976	1.99688
128 feet of this Main is 24 inches diameter.	1.6667	29,715	28.365	1.45795	1.91112	1.9133	1.8570	1.8453	1.90789	1.8632	1.8650	1.95938
Allowance is made in the calculation for this	1.6667	29,715	27.302	1.39107	1.8750	1.877115	1.8204	1.8077	1.87180	1.8263	1.8282	1.91797
enlargement, and the curves in the pipe.	1.6667	29,715	26.325	1.381155	1.84115	1.84323	1.7861	1.7726	1.83801	1.7918	1.7936	1.87943
Jersey City Water Works. Mean result.	1.6667	29,715	28.1285	1.43795	1.90031	1.9053	1.8489	1.837	1.8999	1.855	1.857	1.9502
New York 36 inch Main between Receiving and Distributing Reservoirs. By G. S. Greene. This pipe has three right angled curves of 90 feet radius, which are taken into account in the calculation.	3.0	11,217	20.215	2.99967	3.5016	3.5230	3.484	3.514	3.4917	3.4891	3.506	3.848

The formula, which very closely expresses the results of the New York and the Mean of the Jersey City Experiments, is: $v=46.2502\sqrt{\frac{hd}{L}}-0.397$, whence, $h=0.00046749\frac{L}{d}(v+0.397)^2$

Formulas used in Table J.

(*A.*) Hawkesley's. $v=48.0125\sqrt{\frac{hd}{L+54d}}$

See Civil Eng. and Architects' Journal, Vol. XVIII., p. 99, *line* 28.

(*B.*) Blackwell's. $v=47.913\sqrt{\frac{hd}{L}}$ This formula takes into account the curves of the pipe.

See Hughes on Water Works. Formula (33), *p.* 336.

(*C.*) Prony's (1). $v=\sqrt{\left(2354.9375\frac{hd}{L}+0.00665\right)}-0.0816.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 184.

(*D.*) Prony's (2). $v=\sqrt{\left(2494.69\frac{hd}{L}+0.02375\right)}-0.15412.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 210.

(*E.*) Eytelwein's. $v=47.8731\sqrt{\frac{hd}{L+54d}}$

See Memoires de l'Academie des Sciences de Berlin, 1814 *et* 1815, *p.* 165.

(*F.*) D'Aubuisson's (1). $v=\sqrt{\frac{h}{0.000417568\frac{L}{d}+[0.015536]}+\left[\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}\right]^2}-\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}$

See D'Aubuisson's Hydraulics, (Bennett's translation,) p. 206, *top.*

(*G.*) D'Aubuisson's (2). $v=\sqrt{\left(2394.82\frac{hd}{L}+0.00814\right)}-0.090224.$

See Neville's Hyd. Formulæ (109), *p.* 118. *Simplification of* [*F*], *by omitting the constant* [0.015536], *and reducing.*

(*H.*) Weisbach's. $h-0.015538v^2=0.015538\frac{v^2L}{d}\left[0.01439+\frac{0.0171552}{\sqrt{v}}\right]$

See Julius Weisbach's Ingenieur und Maschinen Mechanik. Vol. I., p. 748

Where v=Velocity, in feet per second.
h=the Head, in feet.
d=Diameter of pipe, in feet.
L=Length of pipe, in feet.

Comparison of Calculations from Established Formulas, with the Results of Various Experiments on Pipes. M.

EXPERIMENTS: WHERE, AND BY WHOM, MADE.	Character of the Water.	Age of the Pipe laid, in years.	Diameter of Pipe, in feet.	Length of Pipe, in feet.	Head of Water, in feet.	VELOCITIES, IN FEET PER SECOND.				
						As taken from the Experiments.	By Prony's formula (2). *(D.)*	By D'Aubuisson's formula (1.) *(F.)*	By Hawkesley's formula. *(A.)*	By Eytelwein's formula. *(E.)*
Jersey City Water Works. Main from the Belleville Reservoir to the Hudson City Reservoir. By G. H. Bailey and C. W. Boynton. Of this Main 128 ft. is 24 inches diameter. Correction for this enlargement, as also for the curves, is made in the calculation......	Soft.		20 in.=1.6667	29,715	30.262	1.4924	1.91068	1.927302	1.97399	1.97063
	Soft.	4	1.6667	29,715	29.758	1.51337	1.89338	1.9105	1.9575	1.95416
Jersey City Water Works. Mean result..................................	Soft.	4	1.6667	29,715	28.1285	1.43795	1.837	1.855	1.90031	1.8999
Croton Aqueduct. Main from the Receiving Reservoir to the Distributing Reservoir. By G. S. Greene. There are in this Main three right angled curves of 90 ft. radius, for which allowance is made in the calculations..............	Soft.	16	36 in.=3.0	11,217	20.215	2.99967	3.514	3.4891	3.5016	3.4917
Crawley Pipe. Crawley to Edinburgh. Experiment by Mr. James Leslie.....	Soft.	29	15 in.=1.25	44,400	226.	3.4634	3.833		3.8268	
Colington Pipe. From Clubbie Dean Reservoir to Castle Hill. By Mr. Leslie.	Soft.	8	16 in.=1.333	29,580	420.	6.8158	6.7199		6.59805	
Do. From Torduff Cistern to Castle Hill. do. do.	Soft.	8	1.333	25,765	230.	5.2521	5.291		5.2307	
Do. From Clubbie Dean Reservoir to Torduff Cistern. do.	Soft.		1.333	3,815	184.	14.5030	12.498		12.062	
Main from Belvidere Road to Brixton. By Mr. James Simpson..............	Hard.		19 in.=1.58333	22,440	41.0	2.73411	2.5367		2.5775	
Do. do. do. do.	Hard.		1.58333	22,440	43.5	2.80183	2.6173		2.6549	
Do. do. do. do.	Hard.		1.58333	22,440	34.0	2.5225	2.2971		2.3472	
Do. do. do. do.	Hard.		1.58333	22,440	27.5	2.2601	2.0514		2.11095	
Do. do. do. do.	Hard.		1.58333	22,440	24.0	2.0569	1.9070		1.9720	
Do. from Ditton to Brixton. do.	Hard.		30 in.=2.5	54,120	25.0	1.7690	1.5502		1.6296	

NOTE.—The Crawley Pipe is of three sizes, viz.: 20, 18, and 15 inches diameter. It has been calculated above as if of 15 inches diameter throughout. A closer calculation would give a greater difference between the actual delivery and the results from the formulas.

Formulas used in Table M.

(*A.*) Hawkesley's. $v=48.0125\sqrt{\frac{hd}{L+54d}}$

See Civil Eng. and Architects' Journal, Vol. XVIII., p. 99, line 28.

(*D.*) Prony's (2). $v=\sqrt{(2494.69\frac{hd}{L}+0.02375)}-0.15412.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 210.

(*E.*) Eytelwein's. $v=47.8731\sqrt{\frac{hd}{L+54d}}$

See Memoires de l'Academie des Sciences de Berlin, 1814 *et* 1815, *p.* 165.

(*F.*) D'Aubuisson's (1). $v=\sqrt{\frac{h}{0.000417568\frac{L}{d}+[0.015536]}+\left[\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}\right]^2}-\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}$

See D'Aubuisson's Hydraulics, (Bennett's translation,) p. 206, *top.*

Where v=Velocity, in feet per second.

h=the Head, in feet.

d=Diameter of pipe, in feet.

L=Length of pipe, in feet.

formulas, but simply as an expression from the results of the particular experiments made this season, by which I prefer to be ruled in our own case.

Mr. James Leslie, Civil Engineer, in his paper on the flow of water through pipes, read before the London Institution of Civil Engineers, and in part printed for their use, mentions several experiments made by him on the rates of delivery of the Edinburgh mains.

In the same pamphlet, Mr. James Simpson, the President of the Institution, gives the result of some experiments made by himself on the water deliveries of pipe lines of different diameters.

Some of these are presented in Table M, for the purpose of comparison.

In these experiments the deliveries given, generally agree very tolerably with the established formulas given in our Table.

The delivery of the Edinburgh pipe is an exception.

I am not able to give sufficient reasons why these experiments of Mr. Simpson and others should correspond quite nearly with the formulas, from which our experiments differ so importantly.

The good condition of the pipes as respects corrosion, sediment and collections of air, would probably in a great measure explain the difference.

The pipes experimented on by Mr. Simpson carry the hard waters of the London Basin, which do not produce tubercular corrosion; they were probably clean pipes of their original capacity: the New York pipes carry soft water, and show already considerable tubercular incrustation.

The old Crawley pipe of Edinburgh is effected in the same way, as are also the Jersey City mains.

I had hoped to have been able to use the modified formula proposed by Mr. Leslie, and found to agree so well with the experiments detailed by him, but it does not correspond sufficiently nearly with the results of our experiments on the Croton and Jersey City pipes, made under the ordinary every-day conditions of their water deliveries.

Respectfully submitted,

JAMES P. KIRKWOOD.

NOTE 1.

Conditions of an Experiment made by George S. Greene, Esq., Civil Engineer, to ascertain the rate of flow of the water passing through the two 36 *inch mains situated between the Receiving Reservoir of the Croton Works, and what is called the Distributing Reservoir at Forty-second Street, New York City.*

The length of each main is 11,217 feet.

There are three horizontal curves on each main of 90° each; each curve is about 90 feet radius.

The grade of the avenue on which the pipes are laid undulates considerably, but there exists no abrupt vertical curvature.

The Receiving Reservoir is divided into two divisions by an earthen embankment.

The southern division was the one used in this experiment, and when the *Receiving* Reservoir is mentioned here it is to be understood as the southern division of that Reservoir simply.

The Distributing Reservoir is also divided into two apartments, but they were used as one in this experiment.

During this experiment the "Receiving Reservoir" was receiving no water from the Croton Conduit, the sluice gates having been all shut down some hours before the commencement, nor from any other source: and no water passed out of it except through the two 36 inch mains which are laid in the Fifth Avenue; the stop-cocks of the other mains communicating with it were shut down.

All connections with the two 36 inch mains were shut down, and the mains themselves were open only for delivery of water into the Distributing Reservoir.

The Distributing Reservoir received no water except from these two 36 inch mains.

From the southern side of this Reservoir, two similar 36 inch mains were open delivering water into the city.

These were the only mains open to the passage of water *out of* the Distributing Reservoir.

The water in this Reservoir rises every night from three to five feet, and falls proportionately every day, the consumption of water by the city being less during the night than the Reservoir's receipt of water from above; and more during the day.

The experiment was made on Saturday the 10th of July, between the hours of 10 A. M. and 6 P. M.

During the eight hours above mentioned, the Receiving Reservoir fell 2.16 feet, and delivered into the Distributing Reservoir (=21.204 cubic feet per pipe, per second) .... 1,221,328 cub. ft.

During the same time the water fell in the Distributing Reservoir (which is small compared with the other Reservoir) 3.448 feet.

The two city pipes on the south side were therefore drawing off more from the Forty-second Street Reservoir than it was receiving by the two pipes delivering into it from the upper Reservoir.

The delivery into the city in excess of the amount received here was, by calculation, ...	72,875	"
Total delivery from the Distributing Reservoir *into the city* during the eight hours aforesaid by the two 36 inch *effluent* pipes	1,294,203	"
Delivery into the city by one of these pipes in the same time	647,101.5	"
Delivery in twelve hours of the day (6 A. M. to 6 P. M.) at same rate	970,652	"
Delivery during the twelve hours of night, from 6 P. M. to 6 A. M., taken at one fourth of that for the twelve day hours.	242,663	"
	1,213,315	"
Equal to, in New York gallons	9,479,023	
The second 36 inch effluent main, the same . .	9,479,023	

Besides the two 36 inch mains delivering water into the city from the Distributing Reservoir, there are two 30 inch mains which deliver into the city directly from the "Receiving Reservoir."

I will suppose these 30 inch mains, (acting under the same head here as the 36 inch mains,) to deliver in such proportion to their diameters as the formula prescribes, or as $\sqrt{d^5}$.

This gives for one 30 inch main a delivery of	6,009,113
And for the other the same................	6,009,113
Total estimated consumption of New York City per twenty-four hours	30,976,272 galls.

Equal to 24,781,019 imperial gallons, equal to 3,964,963 cubic feet.

The only point in these calculations which is assumed and not well ascertained from experiment, is the consumption of water during the twelve night hours, viz.: from 6 P. M. to 6 A. M.

I have judged this to amount to one quarter of the day consumption.

But Mr. Greene believes that it amounts to at least one third. On account of the inconvenience which the lowering of the Reservoir a few feet produces to the consumers in the high parts of the city, we refrained from continuing the experiment through the whole twenty-four hours.

The two pipes (36 inch) laid over the Harlem High Bridge, when empty of water in October last, were examined inside and found to be very considerably encrusted with tubercles.

These tubercles were generally conical in shape, and varied from one quarter to five eighths of an inch in height.

The pipes experimented on between the two Reservoirs have not been examined, that I am aware of, with this view since they were laid; but as they have been in use as long as these pipes over the High Bridge, and the water passes through them at a less velocity, they are probably corroded in the same way.

NOTE 2.

Report by C. W. Boynton, Assistant Engineer, of an experiment upon the cast iron main leading from the Receiving Reservoir to the Distributing Reservoir of the Jersey City Water Works.

The object of this experiment was to ascertain the amount of water flowing in a given time from one of these Reservoirs to the other, and consequently the discharging capacity of the connecting main.

It will be necessary to give a general description of the relative situations of the Reservoirs and of the pipe line.

The Receiving Reservoir, situated on the elevated land east of the Passaic River, near Belleville, was the basin in which the quantity of water passing through the pipe was measured.

The dimensions of this Reservoir were obtained by a survey of its flowage line at an elevation of 157* feet above high water in the Passaic River.

The slopes of the Reservoir are covered with brick laid in cement, and their inclination is $1\frac{1}{2}$ to 1.

Through the kindness of Mr. G. H. Bailey, Chief Engineer of the Jersey City Water Works, we have the following information in regard to the connecting main.

The main is enlarged by a mouth piece, at the Receiving Reservoir, to a form very nearly that of the contracted fluid vein, so that there is no obstruction to the free discharge of the water there.

The entire length of the main is 29,715 feet, of which all but 128 feet, where the pipe is turned downwards as an inverted syphon beneath the draw at the Hackensack River, is 20 inches in diameter; the remainder having a diameter of 24 inches.

---

* This is upon the supposition that the 130 *feet mark* on the guage rod at the Pipe Tower of the Distributing Reservoir, *the point* to which I referred my levels, is accurately 130 feet above high water in the Passaic.

In this main there are the following curves:

IN THE PORTION OF 20 INCHES DIAMETER.

Radius of Curve.	Amount of Deflection.
Feet.	
3	90°
20	96°
25	38° 30′
60	70°
180	42°
200	79°
950	32°
Unknown but over 200	22° 30′

IN THE PORTION OF 24 INCHES DIAMETER UNDER THE DRAW AT THE HACKENSACK RIVER.

Radius of Curve.	Amount of Deflection.
Feet.	
4.9	90°
4.9	90°
4.9	90°
4.9	90°

The Distributing Reservoir is situated upon Bergen Hill, in Hudson City.

The ends of the connecting main in both Reservoirs were covered with water, and therefore the difference of level between the surface of the water in the two Reservoirs at any time, gave the head under which the discharge was then taking place.

The difference in elevation of two fixed points, one at each Reservoir, was carefully determined by levelling between them, and the surface of the water was, at its various elevations, referred to these points.

At the Receiving Reservoir, a portion of the well of the gate house was separated by a temporary partition from the remainder.

This partition extended below the water surface sufficiently far to prevent the disturbance of the latter, in the separated portion, by currents of water entering the main, and still permitted free communication from below with the main part of the well, so that the water would maintain the same level inside the partition as in the Reservoir itself.

Within the part of the well thus separated the elevation of the water surface was determined, during the experiment, by means of a float and attached guage staff.

The height of the water surface was also noted outside of the gate house by measurement with a levelling rod, (when darkness did not prevent,) and the records were found to agree very nearly with the first measurement.

The mean of both observations was the one used in arriving at the result.

At the Distributing Reservoir observations were taken from the guage rod on the pipe tower.

The following are the recorded observations at the two Reservoirs:

At the Receiving Reservoir.		At the Distributing Reservoir.	
Time of Observation.	Elevation of Water Surface.	Time of Observation.	Elevation of Water Surface.
	Feet.		Feet.
Sept. 25th, 1858.		Sept. 25th, 1858.	
6h 33½m, A.M.	155.029	6h 00m, A.M.	124.5
*7h 16m, "	154.989		
*11h 33½m, "	154.669		
12h 16m, P.M.	154.482	12h 00m, M.	124.48
5h 16m, "	153.992	6h 00m, P.M.	124.48
9h 16m, "	153.614	Sept. 26th.	
Sept. 26th.		6h 00m, A.M.	124.54
12h 16m, P.M.	152.166	12h 00m, M.	124.56
6h 16m, "	151.604	6h 00m, P.M.	124.604
Sept. 27th.		Sept. 27th.	
7h 29m, A.M.	150.356	6h 00m, A.M.	124.71

The annexed Table I gives a statement of the information obtained by the experiment.

Column (1) contains the recorded elevations of the water surface at the Receiving Reservoir.

Column (2) is obtained by calculation from the dimensions of the Reservoir.

Column (3) gives the difference between the elevations in column (1).

* These observations, taken so near the time of the preceding and following ones, are not used in calculating the result.

Column (4) contains the quantities discharged from the Reservoir, as calculated from columns (2) and (3).

Column (5) gives the difference in the recorded times of observation.

Columns (6), (7) and (8) need no explanation.

Column (9) is obtained by subtracting from the elevation of the water surface in the Receiving Reservoir, the elevation of the surface of the water in the Distributing Reservoir at the same time, as deduced from the observations made at the latter, which, it will be seen, were not simultaneous with those at the Receiving Reservoir.

Column (10) is obtained from column (9) by the formula

$$h=\left[\frac{\sqrt{H_1}+\sqrt{H_2}}{2}\right]^2+A$$

Where H_1 = the head at the commencement of the discharge.

H_2 = " " end of the discharge.

h = mean head under which the discharge occurs.

and A = the distance of the *centre of gravity* of the water prismoid above the middle point of its altitude.

Some discrepancies will be observed in the results of the Table; these were doubtless caused by small errors in the determination of the elevations of the water surface. Such could hardly be avoided without more accurate means of measurement than were at our disposal.

It remains to compare our results with those obtained from the various formulas in ordinary use for determining the discharge of water through pipes.

The following have been considered the most reliable.

As expressed by their authors, the units employed are various, but for convenience in comparison and calculation, I have reduced all to their equivalent expressions in English feet.*

(*A.*) Hawkesley's. $v=48.0125\sqrt{\frac{hd}{L+54d}}$

***See Civil Eng. and Architect's Journal, Vol. XVIII., p. 99, line* 28.**

* In these reductions I have taken

The French metre = 3.28089 English feet.

" Prussian Foot = 1.02972 "

TABLE I.

Tabular Statement of the Results of Experiments on the Jersey City Water Works.

1	2	3	4	5	6	7	8	9	10
Successive Elevations of the Water Surfaces.	Area included within the flowage line at these Elevations.	Fall of the Surface.	Quantity discharged from Reservoir.	Time, in Seconds.	Discharge, in Cubic Feet per Second.	Area of Discharge, in Square Feet.	Mean velocity, in feet per Second.	Heads.	Mean Heads under which Discharge occurs.
FEET.	SQAURE FEET.	FEET.	CUBIC FEET.						
155.029	122869.79							30.529	
		0.547	66910.00	20550	3.25595	2.18167	1.4924		30.262
154.482	121773.32							30.002	
		0.490	59430.00	18000	3.3017	"	1.51337		29.758
153.992	120797.65							29.512	
		0.378	45520.00	14400	3.1611	"	1.44893		29.317
153.614	120047.92							29.119	
		1.448	171762.00	54000	3.1808	"	1.45795		28.365
152.166	117191.86							27.606	
		0.562	65553.00	21600	3.0348	"	1.39107		27.302
151.604	116091.81							27.000	
		1.248	143369.00	47580	3.01322	"	1.381155		26.325
150.356	113664.18							25.646	

Mean of above Experiments on the Jersey City Water Works.

			Total Quantity discharged from the Reservoir.	Total Time of Discharge, in Seconds.	Discharge, in Cubic Feet per Second.	Area of Discharge, in Square Feet.	Mean velocity, in feet per Second.		Mean Head under which Discharge occurs.
			CUBIC FEET.						
			552544.00	176130	3.13714	2.18167	1.43795		28.1285

(*B.*) Blackwell's. $v=47.913\sqrt{\frac{hd}{L}}$

This formula takes into account the curves of the pipe.

See Hughes on Water Works. Formula (33), p. 336.

(*C.*) Prony's (1). $v=\sqrt{(2354.9375\frac{hd}{L}+0.00665)}-0.0816.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 184.

(*D.*) Prony's (2). $v=\sqrt{(2494.69\frac{hd}{L}+0.02375)}-0.15412.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 210.

(*E.*) Eytelwein's. $v=47.8731\sqrt{\frac{hd}{L+54d}}$

See Memoires de l'Academie des Sciences de Berlin, 1814 *et* 1815, *p.* 165.

(*F.*) D'Aubuisson's (1).

$$v=\sqrt{\frac{h}{0.000417568\frac{L}{d}+[0.015536]}+\left[\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}\right]^2}-\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}$$

See D'Aubuisson's Hydraulics, (Bennett's translation,) p. 206, *top.*

(*G.*) D'Aubuisson's (2). $v=\sqrt{(2394.82\frac{hd}{L}+0.00814)}-0.090224.$

See Neville's Hyd. Formulæ (109), *p.* 118. *Simplification of* [*F*], *by omitting the constant* [0.015536], *and reducing.*

(*H.*) Weisbach's.

$$h-0.015538v^2=0.015538\frac{v^2L}{d}\left[0.01439+\frac{0.0171552}{\sqrt{v}}\right]$$

See Julius Weisbach's Ingenieur und Maschinen Mechanik. Vol. I., p. 748.

In all the above

v=Velocity, in feet per second.
h=the Head, in feet.
d=Diameter of pipe, in feet.
L=Length of pipe, in feet.

None of these formulas except Blackwell's [B], which takes into account the curves, make any allowance for changes of direction or capacity of the pipe.

In the Jersey City main there are no abrupt bends, and for the determination of the loss of head by the curves, I have employed the formula of Julius Weisbach.

$$h_c = \frac{\Phi}{180} \times \left[0.131 + 1.847 \left(\frac{r}{R}\right)^{\frac{7}{2}} \right] \frac{v^2}{2g}$$

See Weisbach's Ingenieur und Maschinen Mechanik. Vol. I., p. 770.

When h_c=Head lost by the resistance of the curves, in feet.

Φ=the deflection of the pipe from its right line direction, in degrees.

r=the radius of the interior of the pipe, in feet.

R= the radius of curvature of the axis of the pipe, in feet.

v=the Velocity of the water passing through the pipe, in feet per second.

g=32.18=acceleration due to gravity.

By means of this formula the values of the total loss of head from curves in the pipe has been calculated for as great a range of *velocities* as will result in the use of the formulas above employed for *their* calculation.

These are inserted in the following Table.

Table 2.

Values of the Velocity.	1.7	1.8	1.9	2.0	2.1
Total loss of head from resistance of curves.	0.0218	0.0244	0.0272	0.0302	0.0333

The enlargement of the pipe in passing the draw at the Hackensack River, and its subsequent contraction, are made by means of reducers, five feet long, and therefore the change in velocity is so gradual that we may consider the loss of head from this cause inappreciable.

We have, however, a gain of head, equal to the difference between the head lost by the friction of the water in passing through 128 feet of 20 inch, and the same length of 24 inch pipe.

This difference I have calculated, by Weisbach's formula [H], for various velocities of the water in the 20 inch pipe, and the values thereof are appended in the following Table.

Table 3.

Velocity of the water in the 20 inch pipe..	v=1.7	v=1.8	v=1.9	v=2.0	v=2.1
Gain of head of 128 ft. of 24 inch pipe over the same length of 20 inch pipe.......	0.0532	0.0589	0.0648	0.0710	0.0774

Since the loss of head by the influence of the curves, and its gain by the enlargement of the main, depend for their value upon the velocity of the water in the pipe, it is necessary in employing any of the above formulas for finding the velocity, to first calculate the latter approximately, by the formula which we intend using, neglecting in this calculation the influence upon the head of the curves and enlargements.

The velocity being in this manner determined, Tables (2) and (3) give the correction to be applied to the head; that obtained from (2) being a subtractive, and that from (3) an additive correction.

From this corrected head a closer approximation to the velocity is obtained by the formula.

The value of the velocity thus resulting, gives us more nearly the value of the resistances of curves and enlargements, and thus a still more accurate value of the corrected head, from which, by again applying the formula, a value of the velocity is obtained sufficiently accurate for comparison with the results of the experiment.

These values of the velocity have been calculated by all the formulas above given, and the results, together with those derived by actual experiment, are inserted in the accompanying tabular statement marked K.

Tabular Comparison of the New York and Jersey City Experiments. K.

EXPERIMENTS: Where, and by whom, made.	Diameter of the Pipe, in feet.	Length of Pipe, in feet.	Mean Heads under which the discharge occurred.	VALUES OF THE VELOCITY, IN FEET PER SECOND. As deduced from the discharge.	By Hawkesley's formula. (A.)	By Blackwell's formula. (B.)	By Prony's formula (1). (C.)	By Prony's formula (2). (D.)	By Eytelwein's formula. (E.)	By D'Aubuisson's formula (1). (F.)	By D'Aubuisson's formula (2). (G.)	By Weisbach's formula. (H.)
On the 20 inch Main between the Reservoirs	1.6667	29,715	30.262	1.4924	1.97399	1.97624	1.9206	1.91068	1.97063	1.927302	1.92923	2.03255
of the Jersey City Water Works.	1.6667	29,715	29.758	1.51337	1.9575	1.9597	1.9039	1.89338	1.95416	1.9105	1.9123	2.01294
By G. H. Bailey and C. W. Boynton.	1.6667	29,715	29.317	1.44893	1.94293	1.94514	1.8891	1.87838	1.93963	1.8957	1.8976	1.99688
128 feet of this Main is 24 inches diameter.	1.6667	29,715	28.365	1.45795	1.91112	1.9133	1.8570	1.8453	1.90789	1.8632	1.8650	1.95938
Allowance is made in the calculation for this	1.6667	29,715	27.302	1.39107	1.8750	1.877115	1.8204	1.8077	1.87180	1.8263	1.8282	1.91797
enlargement, and the curves in the pipe.	1.6667	29,715	26.325	1.381155	1.84115	1.84323	1.7861	1.7726	1.83801	1.7918	1.7936	1.87943
Jersey City Water Works. Mean result.	1.6667	29,715	28.1285	1.43795	1.90031	1.9053	1.8489	1.837	1.8999	1.855	1.857	1.9502

Formulas used in Table K.

(*A.*) Hawkesley's. $v=48.0125\sqrt{\frac{hd}{L+54d}}$

See Civil Eng. and Architects' Journal, Vol. XVIII., p. 99, line 28.

(*B.*) Blackwell's. $v=47.913\sqrt{\frac{hd}{L}}$ This formula takes into account the curves of the pipe.

See Hughes on Water Works. Formula (33), p. 336.

(*C.*) Prony's (1). $v=\sqrt{\left(2354.9375\frac{hd}{L}+0.00665\right)}-0.0816.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 184.

(*D.*) Prony's (2). $v=\sqrt{\left(2494.69\frac{hd}{L}+0.02375\right)}-0.15412.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 210.

(*E.*) Eytelwein's. $v=47.8731\sqrt{\frac{hd}{L+54d}}$

See Memoires de l'Academie des Sciences de Berlin, 1814 *et* 1815, *p.* 165.

(*F.*) D'Aubuisson's (1). $v=\sqrt{\frac{h}{0.000417568\frac{L}{d}+[0.015536]}+\left[\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}\right]^2}-\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}$

See D'Aubuisson's Hydraulics, (Bennett's translation,) p. 206, top.

(*G.*) D'Aubuisson's (2). $v=\sqrt{\left(2394.82\frac{hd}{L}+0.00814\right)}-0.090224.$

*See Neville's Hyd. Formulæ (*109*), p.* 118. *Simplification of* [*F*], *by omitting the constant* [0.015536], *and reducing.*

(*H.*) Weisbach's. $h-0.015538v^2=0.015538\frac{v^2L}{d}\left[0.01439+\frac{0.0171552}{\sqrt{v}}\right]$

See Julius Weisbach's Ingenieur und Maschinen Mechanik. Vol. I., p. 748.

Where v=Velocity, in feet per second.

h=the Head, in feet.

d=Diameter of pipe, in feet.

L=Length of pipe, in feet.

Comparison of Calculations from Established Formulas, with the Results of Various Experiments on Pipes. M.

EXPERIMENTS: WHERE, AND BY WHOM, MADE.	Character of the Water.	Age of the Pipe laid, in years.	Diameter of Pipe, in feet.	Length of Pipe, in feet.	Head of Water, in feet.	VELOCITIES, IN FEET PER SECOND. As taken from the Experiments.	By Prony's formula (2). *(D.)*	By D'Aubuisson's formula (1.) *(F.)*	By Hawkesley's formula. *(A.)*	By Eytelwein's formula. *(E.)*
Jersey City Water Works. Main from the Belleville Reservoir to the Hudson City Reservoir. By G. H. Bailey and C. W. Boynton. Of this Main 128 ft. is 24 inches diameter. Correction for this enlargement, as also for the curves, is made in the calculation......	Soft.		20 in.=1.6667	29,715	30.262	1.4924	1.91068	1.927302	1.97399	1.97063
	Soft.	4	1.6667	29,715	29.758	1.51337	1.89338	1.9105	1.9575	1.95416
Jersey City Water Works. Mean result..........	Soft.	4	1.6667	29,715	28.1285	1.43795	1.837	1.855	1.90031	1.8999
Croton Aqueduct. Main from the Receiving Reservoir to the Distributing Reservoir. By G. S. Greene. There are in this Main three right angled curves of 90 ft. radius, for which allowance is made in the calculations.............	Soft.	16	36 in.=3.0	11,217	20.215	2.99967	3.514	3.4891	3.5016	3.4917
Crawley Pipe. Crawley to Edinburgh. Experiment by Mr. James Leslie.....	Soft.	29	15 in.=1.25	44,400	226.	3.4634	3.833		3.8268	
Colington Pipe. From Clubbie Dean Reservoir to Castle Hill. By Mr. Leslie.	Soft.	8	16 in.=1.333	29,580	420.	6.8158	6.7199		6.59805	
Do. From Torduff Cistern to Castle Hill. do. do.	Soft.	8	1.333	25,765	230.	5.2521	5.291		5.2307	
Do. From Clubbie Dean Reservoir to Torduff Cistern. do.	Soft.		1.333	3,815	184.	14.5030	12.498		12.062	
Main from Belvidere Road to Brixton. By Mr. James Simpson..............	Hard.		19 in.=1.58333	22,440	41.0	2.73411	2.5367		2.5775	
Do. do. do. do.	Hard.		1.58333	22,440	43.5	2.80183	2.6173		2.6549	
Do. do. do. do.	Hard.		1.58333	22,440	34.0	2.5225	2.2971		2.3472	
Do. do. do. do.	Hard.		1.58333	22,440	27.5	2.2601	2.0514		2.11095	
Do. do. do. do.	Hard.		1.58333	22,440	24.0	2.0569	1.9070		1.9720	
Do. from Ditton to Brixton. do.	Hard.		30 in.=2.5	54,120	25.0	1.7690	1.5502		1.6296	

NOTE.—The Crawley Pipe is of three sizes, viz: 20, 18, and 15 inches diameter. It has been calculated above as if of 15 inches diameter throughout. A closer calculation would give a greater difference between the actual delivery and the results from the formulas.

Formulas used in Table M.

(*A.*) Hawkesley's. $v=48.0125\sqrt{\frac{hd}{L+54d}}$

See Civil Eng. and Architects' Journal, Vol. XVIII., p. 99, line 28.

(*D.*) Prony's (2). $v=\sqrt{(2494.69\frac{hd}{L}+0.02375)}-0.15412.$

See Prony's Recherches Physico—Mathématiques sur la théorie des Eaux Courantes, § 210.

(*E.*) Eytelwein's. $v=47.8731\sqrt{\frac{hd}{L+54d}}$

See Memoires de l'Academie des Sciences de Berlin, 1814 *et* 1815, *p.* 165.

(*F.*) D'Aubuisson's (1). $v=\sqrt{\frac{h}{0.000417568\frac{L}{d}+[0.015536]}+\left(\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}\right)^2}-\frac{0.00003767485\frac{L}{d}}{0.000417568\frac{L}{d}+[0.015536]}$

See D'Aubuisson's Hydraulics, (Bennett's translation,) p. 206, *top.*

Where v=Velocity, in feet per second.

h=the Head, in feet.

d=Diameter of pipe, in feet.

L=Length of pipe, in feet.

NOTE 3.

Extract from Proceedings of Institution of Civil Engineers, London, February, 1855.

"Mr. Murray had prepared the following table, showing the delivery of water, by pipes of small and of large dimensions, through moderate and more extended lengths and under various pressures, and he contended, that far from throwing discredit upon the researches of the experimenters, whose works he had mentioned, the accuracy of the formulæ had been satisfactorily confirmed by practice.

DISCHARGE THROUGH PIPES, CALCULATED BY SEVERAL FORMULÆ.

Diameter of Pipe.	Length.	Head or Pressure.	Discharge per Minute.	Calculated Discharge per Minute.	——
INCHES.	FEET.	FEET.	CUB. FEET.	CUB. FEET.	
2	3,300	12.75	1.617	1.507	Du Buat.
....	....	....	....	1.609	Prony.
....	....	....	....	1.509	Eytelwein.
....	....	....	....	1.59	Poncelet.
$4\frac{1}{2}$	14,930	51.00	11.333	11.252	Du Buat.
....	....	....	....	11.491	Prony.
....	....	....	....	10.784	Eytelwein.
....	....	....	....	11.281	Poncelet.
12.789	3,837	12.90	155	158	Du Buat.
....	....	....	....	155	Prony.
....	....	....	....	145	Eytelwein.
....	....	....	....	141	Poncelet.
12.789	14,963	21.582	111	99	Du Buat.
....	....	....	....	102	Prony.
....	....	....	....	99	Eytelwein.
....	....	....	....	98	Poncelet.
19.184	5,052	4.929	217	223	Du Buat.
....	....	....	....	230	Prony.
....	....	....	....	215	Eytelwein.
....	....	....	....	226	Poncelet.
30	5,280	9.00	880	926	Du Buat.
....	....	....	....	932	Prony.
....	....	....	....	865	Eytelwein.
....	....	....	....	910	Poncelet.

In explanation of the Table it was stated, on the authority of Dr. Robinson, (vide Robinson's 'Mechanical Philosophy,' vol. ii, p. 441) that water was brought into the town of Dunbar, in East Lothian, from a spring, through pipes, the first length of which was 1,100 yards, of 2 inches diameter, with a declivity of 12 feet 9 inches.

The actual quantity discharged was 1.617 cubic foot per minute. The mean calculated quantity was 1.5539 cubic foot per minute.

Again it was shown by Mr. Jardine, (vide Brewster's Encyclopædia; Art. 'Hydrodynamics,' p. 526) that the main pipe of the Edinburgh Water Works, extending from the fountain head, at Comiston, to the reservoir at the Castle Hill, Edinburgh, was of lead throughout, 14,950 feet in length, 4½ inches in diameter, and the head was 51 feet above the point of delivery. The maximum discharge during five consecutive years, was 11.333 cubic feet per minute.

The mean calculated quantity was 11.202 cubic feet per minute.

The next three results were taken from Bossut's 'Treatise on Hydrodynamics' brought into English measures, and they were stated to be his own experiments, combined with those of Couplet. The pipes were of iron with several horizontal and vertical bends, which were taken into account in the lengths mentioned:—

	Cubic Feet per Minute.	Mean calculated quantity.
The first yielded	155	150 cub. ft. per min.
The second "	111	99.5 " "
The third "	217	223.5 " "

The last statement of the table was obtained from the late Mr. Chapman, C. E., of Newcastle; but whether it was derived from actual measurement, or was simply the result of his experience, was uncertain. From a pipe of 30 inches diameter, with a fall of 9 feet per mile, the actual quantity discharged was 880 cubic feet per minute.

The mean calculated quantity was 908 cubic feet per minute.

The following were the formulæ employed in the calculations of the table:—

Du Buat's Formula reduced to English Measure

$$V=\frac{307(\sqrt{R}-0.1)}{\sqrt{S}-L(\sqrt{S+1.6})}-0.3(\sqrt{R}-0.1)$$

V=velocity in inches per second.

R=hydraulic mean depth=$\frac{1}{4}$ diameter.

*S=slope or difference of level.

L=hyperbolic logarithm, and found by multiplying the common logarithm by 2.3026.

In the following formulæ English feet were employed :—

V being the velocity per second.

D " diameter
H " head of pressure, } of the pipe.
L " the length

Prony's simple Formula.

$$V=48.449\sqrt{\frac{DH}{L}}$$

Eytelwein's Formula, as given by Tredgold (vide Tredgold's 'Tracts on Hydraulics,' p. 2:5.)

$$V=45.5\sqrt{\frac{DH}{L+47D}}$$

Poncelet's formula.

$$V=47.95\sqrt{\frac{DH}{L+54D}}$$

---

* The explanation of the value of S here given, is, as will be evident by an examination of the formula, erroneous.

$$\text{Really } S=\frac{\text{Length of the pipe.}}{\text{Head of pressure.}}$$

NOTE 4.

The following (furnished me by J. C. Brevoort, Esq.) is the formula proposed by M. Mary, of the French Academy of Sciences, for determining the flow of water in pipes:

$$v=C\sqrt{\frac{hd}{L}}$$

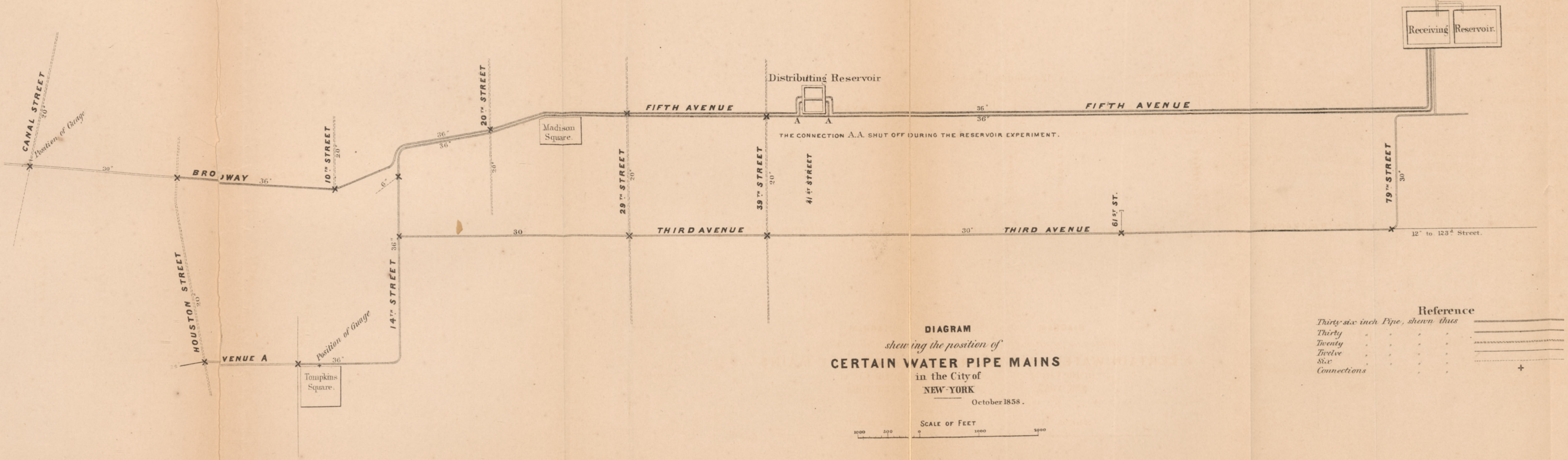
Where v = Velocity, in feet per second.
h = the Head, in feet.
d = Diameter of the pipe, in feet.
L = Length of the pipe, in feet.
C = a Constant which varies with the velocity, and the values of which are obtained from the following Table.

Values of v.	0.164	0.328	0.656	0.984	1.312	1.640	3.281	6.562	Infinity.
Values of C.	34.723	39.722	43.417	44.975	45.753	46.297	47.420	47.945	48.470

In the use of this formula, the value of v is obtained by approximation. A mean value of C being first assumed, the value of v is approximately calculated, which gives us more accurately the value of C; thence results a value of v more nearly correct than the preceding.

By two or three applications of the formula, in this manner, the value of v is deduced with sufficient accuracy.

S


Receiving Reservoir.
Distributing Reservoir
FIFTH AVENUE
FIF'TH AVENUE
THE CONNECTION A.A. SHUT OFF DURING THE RESERVOIR EXPERIMENT.
Madison Square.
CANAL STREET
Position of Guage
BROADWAY
10TH STREET
20TH STREET
29TH STREET
39TH STREET
41ST STREET
61ST ST.
79TH STREET
THIRD AVENUE
12" to 123d Street.
HOUSTON STREET
AVENUE A
Position of Guage
Tompkins Square.
14TH STREET
Reference
Thirty-six inch Pipe, shewn thus
Thirty
Twenty
Twelve
Six
Connections
DIAGRAM
shewing the position of
CERTAIN WATER PIPE MAINS
in the City of
NEW-YORK
October 1858.
SCALE OF FEET
1000 500 0 1000 2000

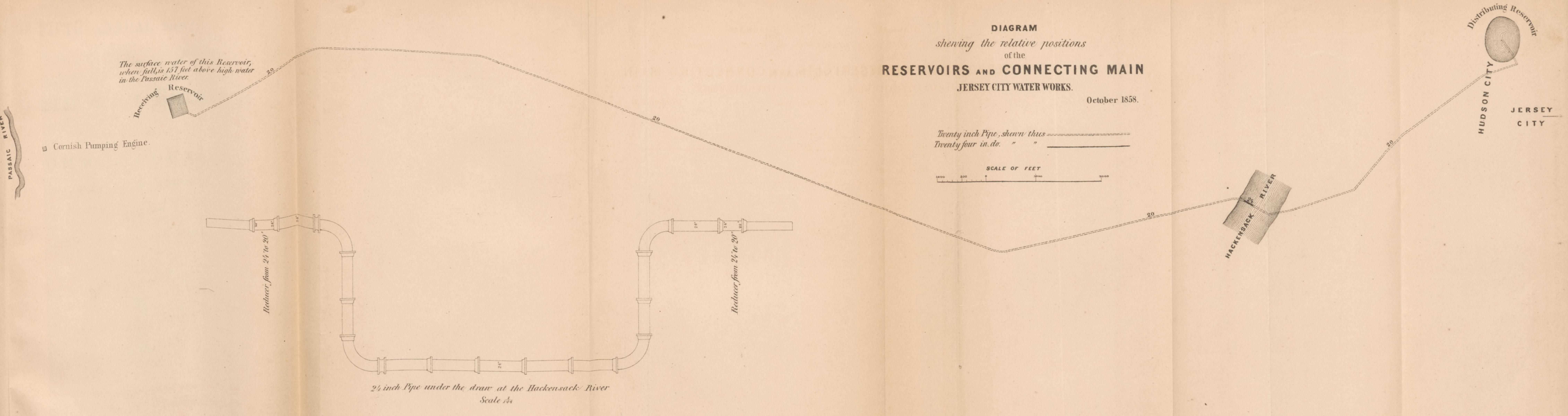


DIAGRAM
shewing the relative positions
of the
RESERVOIRS AND CONNECTING MAIN
JERSEY CITY WATER WORKS.
October 1858.
Twenty inch Pipe, shewn thus
Twenty four in. do. " "
SCALE OF FEET
1000
500
0
1000
2000
The surface water of this Reservoir, when full, is 157 feet above high water in the Passaic River.
Receiving Reservoir
Cornish Pumping Engine.
PASSAIC RIVER
20
20
20
20
HACKENSACK RIVER
Distributing Reservoir
HUDSON CITY
JERSEY CITY
Reducer from 24 to 20
Reducer from 24 to 20
24 inch Pipe under the draw at the Hackensack River
Scale 1/24