Appendix No 2.

COMPARISON OF THE ORIGINAL COMPUTATIONS AND THE ACTUAL GAUGINGS OF THE NEW STEEL CONDUIT.

By E. Kuichling.

I. *Computation of Diameter.*—The considerations which led to the selection of a diameter of 38 inches for the new riveted steel conduit were as follows: It was deemed expedient by all of the engineers who had investigated the subject of an additional water supply for the city, to make provision in the new works for a delivery of 15,000,000 gallons per day. From the hydrological studies of the problem by the writer, it was computed that the average yield of the combined watershed of Hemlock and Canadice lakes, amounting to 62.43 square miles, would be about 32,000,000 gallons during a period of three consecutive years of minimum rainfall, and that the abstraction of such average daily yield during said period would result in temporarily reducing the present mean low-water level of the lakes about 12 feet. As it was anticipated that the city would eventually construct another conduit for the remainder of the average yield of this watershed before seeking a different source of supply, and also because the first ten miles of the original conduit would then become useless on account of its high elevation and light grade, it was determined to give the new pipe a capacity of one-half of the said average yield, or 16,000,000 gallons per day.

In dealing with the discharge of iron pipes, however, it is necessary to take into account the inevitable reduction of delivery which occurs in such a conduit after it has been in use for a long period. Experience has demonstrated that a reduction of 20 per cent. after ten years service is not uncommon, and in the case of the old conduit, it was found in July, 1890, that the loss in delivery amounted to 22 per cent. in about fourteen and one-half years; hence in designing the new pipe, provision was made for a possible reduction of about 25 per cent., or in other words, the diameter was computed on the basis that the pipe should deliver about 25 per cent. more water while it was new than after its interior had become rough by accretions of rust, scale and organic growths. The "ultimate" capacity of the new pipe was therefore taken at 16,000,000 gallons per day, or 24.75 cubic feet per second, and it was expected that soon after completion it would give a discharge of 20,000,000 gallons per day, or 30.94 cubic feet per second.

From the preliminary surveys it was found that the grade of the pipe, from its southern end to Mt. Hope reservoir, could be taken at about 1 in 570; and from the most recent investigations based on the discharge of new, smooth and clean cast-iron pipes of large diameter, the required diameter of such a pipe was computed at 34.5 inches. As the nearest commercial size of cast-iron pipe is 36-inch, the latter was accordingly adopted as the standard for the new conduit, even though it might give a somewhat larger delivery than as assumed above. It may also be of interest in this connection to note that in the computation just indicated, the coefficient (c) in the fundamental formula for the velocity: $v=c\sqrt{rs}$, was given the value: $c=135$; and that from the formulas of Lampe, Kutter and Smith, the deduced value of (c) was respectively, $c=135.66$, 134.18 and 134.0 for the given data.

Having thus adopted a 36-inch cast-iron pipe as a standard of comparison, it next became important to determine the proper diameter of a riveted steel pipe of the same capacity, as it was considered that the numerous projecting rivet heads and laps of the plates at the round seams would involve a considerable loss of head. No exact experiments with riveted pipe of such plate thickness and diameter being available at the time (in November, 1890), this loss was computed on the basis that the rivet heads in the round seams formed a narrow but continuous ring or constriction, 0.375 inch thick, projecting into the interior of the pipe at every seam, and that a sudden enlargement of the diameter also occurred at every seam, due to the lap of the inside and outside courses or cylindrical sections. For this purpose, use was made of Weisbach's formulas for the loss of head from such causes, the average plate thickness being taken at 0.3125 inch, and hence also the difference in the diameter of the inside and outside courses at 0.625 inch. The diameter of the inside courses was furthermore chosen as the standard with which the velocity or discharge was to be computed, and it was also assumed that there would be at least 773 round seams per mile of pipe.

These computations showed that the loss of head due to the assumed constrictions was in every case very much larger than that due to the sudden enlargements of diameter; and after several trials with different standard diameters, it was found that the aggregate loss of head from said causes in a 38 inch riveted pipe, made as above described, was about 17 per cent. of the total available head; also that such a 38-inch pipe on the reduced grade gave, while new, about the same discharge as a new and smooth 36-inch cast-iron pipe on the original grade. It thus appeared that a riveted steel pipe should have a diameter about 5 per cent. larger than that of an equivalent cast-iron pipe. There was, however, no direct proof then available that the principles deduced from Weisbach's experiments with small pipes were applicable to tubes of 3 feet diameter, and hence it was deemed expedient to make some new investigations on the old conduit, with the view of ascertaining exactly the relative losses of head in riveted wrought-iron and cast-iron sections of the same diameter and length.

To accomplish this end, a special gauge for closely measuring differences of water-pressure by means of a column of mercury, was devised and applied in 1891 on the several sections of the old 24-inch conduit between Rush reservoir and North Bloomfield. The results of these measurements showed clearly that the loss of head in the riveted wrought-iron sections was considerably greater than that in the cast-iron sections of the same length and nominal diameter, and was even somewhat greater than as computed with Weisbach's formulas mentioned above. The applicability of the latter was thus definitely established, and in order to err on the safe side, it was then proposed to make the diameter of the new steel conduit 40 inches, and to regard such a pipe as equivalent to a 36-inch cast-iron pipe. The original specifications for steel pipe were prepared on this basis, but they were subsequently modified so as to cause bids to be submitted for both 38-inch and 40-inch pipe, and to allow the Executive Board to choose between these two sizes. In view of the considerable difference in price, the 38-inch pipe was finally selected.

It should also be remarked that the above-described method of computing the size of a riveted plate pipe is equivalent to making a certain reduction in the value of the coefficient (c) in the fundamental formula: $v = c\sqrt{rs}$, and retaining the original grade (s) and mean radius (r). In the present case, the loss of head due to rivets and seam laps in a 36-inch riveted pipe, is about 25 per cent. of the total available head, so that only 75 per cent. of the latter head is left for producing the velocity (v) and overcoming other frictional resistances; hence by substituting ($0.75\,s$) for (s) in the above equation, there follows: $v = 0.866\ c\sqrt{rs}$ for the riveted pipe, while for the cast-iron pipe we would have: $v = c\sqrt{rs}$. Under these conditions, the velocity or discharge in a new riveted pipe is therefore 86.6 per cent. of that in a cast-iron pipe of the same size and grade; and the value of (c) given above, (viz: $c = 135$ for a new and smooth 36-inch cast-iron pipe on a grade of 1 in 570), would accordingly be reduced to $c = 116.9$. It is also evident that a similar result is reached by increasing the diameter and considering the grade and discharge to remain unchanged. Thus, by taking the diameter of the riveted pipe 5 per cent. larger than for the cast-iron pipe, the coefficient (c) in the former case will be 88.5 per cent. of that for the latter with the same grade and discharge. In the present case, the diameter was increased from 36 to 38 inches, or 5.556 per cent., with the expectation that this would compensate for the loss of head due to rivets and seam laps; and for the same grade and discharge, the coefficient (c)

thus became 87.356 per cent. of that for the 36-inch cast-iron pipe, or $c=117.93$ for the steel pipe while it was new.

It now becomes of interest to note how these original computations for the new steel pipe compare with the actual gaugings. Unfortunately, the large amount of work in progress at many different points, both in the city and along the line of the conduit, rendered it impossible for either the writer or his principal assistants to make any reliable gaugings of the discharge of the new pipe until the autumn of 1895; and hence when this work was finally undertaken, the upper portions of the conduit were more than two years old, and the average age of the entire line of pipe, after being filled with water, was nearly two years. It is also unfortunate that the permanent inlet works for the new conduit at the two reservoirs have not yet been completed, owing to the lack of the necessary funds for the purpose, and that gauging operations are now limited to the capacity of the temporary 16-inch inlet pipes at said reservoirs. Tho full delivery of the conduit can therefore be determined only by computation from the discharge through the said temporary inlet pipes.

II. Gaugings between Hemlock Lake and Rush Reservoir.—The gaugings were made by carefully measuring the rise of the water in Rush reservoir during a known period of time, while the temporary 16-inch inlet pipe was discharging at full capacity; also by ascertaining the hydraulic pressure in the conduit near its connection with the said inlet pipe, by means of a properly calibrated open column of mercury, and at the same time noting the elevation of the water surface in the feeding chamber at the head or beginning of the conduit. By reducing the observed height of the mercury column at the reservoir to its equivalent head in feet of water, and thence also to its proper topographical elevation, the total fall or hydraulic grade (s) in the known length of conduit was obtained; and as the volume discharged into the reservoir during a known period of time was determined from the observed rise and the previously measured area of the water surface, the rate of discharge (Q) in cubic feet per second, as well as the mean velocity (v) of the water at the conduit, was also readily computed. It should be remarked that the velocity was deduced by reference to the nominal internal diameter of the conduit, which is exactly 38 inches for all "inside" courses. In this manner the factors (v), (r) and (s) became known, and from them the value of the coefficient (c) in the fundamental formula: $v=c\sqrt{rs}$, may at once be derived.

The data relating to two gaugings which were made with great care on the section of 17.356 miles, extending from the overflow chamber near Hemlock Lake to Rush reservoir, are herewith submitted. In the first experiment some slight fluctuations occurred in the mercury piezometer, which may possibly have been caused by some entrained air, although none was discovered; in the second experiment, however, no appreciable fluctuations in the piezometer were noticed, and all conditions appeared to be favorable for obtaining accurate results. From Table No. 1, it will be observed that the deduced value of the coefficient (c) was 116.65 on October 4, 1895, while eighty days later, or on December 23, 1895, it was only 113.97. Whether the difference between these two values is due to the change in the temperature of the water, or to a deterioration of the interior surface, the formation of organic growths, possible errors of observation, etc., cannot now be determined; and the facts are therefore submitted as they stand without further comment, except to call attention to the circumstance that the originally assumed value of the coefficient (c) was little different from that which was actually found by the two gaugings.

TABLE NO. I,

SHOWING DATA RELATING TO GAUGINGS NOS. 1 AND 5 OF THE NEW CONDUIT. SECTION FROM HEMLOCK LAKE TO RUSH RESERVOIR.

No.	ITEMS.	Gauging No. 1, Oct. 4, 1895.	Gauging No. 5, Dec. 23, 1895.
1	Duration of gauging or experiment, in hours...	4.9625	5.0167
2	Duration of gauging or experiment, in seconds	17,865	18,060
3	Observed rise of water surface in reservoir, feet	0.78796	0.79670
4	Mean area of water surface in reservoir for said rise and the given elevations, square feet....	580,068.23	579,879.72
5	Net volume added to reservoir, reduced to cubic feet per second.......	25.5847	25.5809
6	Observed evaporation from water surface, reduced to cubic feet per second (to be added).	0.1485	none
7	Observed rainfall upon water surface, reduced to cubic feet per second (to be subtracted)..	none	0.1818
8	Observed percolation of reservoir, reduced to cubic feet per second (to be added)....... ...	0.0464	0.0464
9	Gross discharge of conduit in cubic feet per second.	25.7796	25.4455
10	Standard diameter of conduit, being diameter of the "inside" courses, in inches............	38.00	38.00
11	Standard sectional area of conduit in square feet......................	7.8758	7.8758
12	Mean velocity (v) in conduit in feet per second, being quotient of No. 9 divided by No. 11. ..	3.2733	3.2308
13	Mean topographical elevation of water surface in chamber at head of conduit, feet.......	371.890	372.120
14	Computed mean topographical elevation of water surface in piezometer at end of conduit at reservoir, feet.........................	280.740	279.102
15	Total observed loss of head (h) in the conduit, in feet, being difference between Nos. 13 and 14	91.50	93.018
16	Total length of conduit (l) in feet from head to piezometer at reservoir..........	91,640.83	91,640.83
17	Hydraulic grade $s = \frac{h}{l} = \frac{\text{loss of head}}{\text{length}}$	0.00099464	0.0010150
18	Mean hydraulic radius $r = \frac{d}{4}$ in feet	$\frac{19}{24}$	$\frac{19}{24}$
19	Coefficient (c) in $v = c\sqrt{rs}$......	116.648	113.974
20	Mean temperature of water in pipe, in degrees F	60	40
21	Mean temperature of air in shade, in degrees F.	62	51
22	Mean height of barometer at both ends of conduit in inches of mercury....	....	29.044
23	Average age of conduit in service, in years ...	1.88	2.10
24	Gross discharge of conduit in gallons per day through temporary 16-inch inlet pipe at Rush Reservoir.	16,661,800	16,445,800

It should also be noted that in the section of conduit referred to in Table No. 1, there are eleven 36-inch stop-valves, and five 36-inch cast-iron

T-branches for future lateral connections. These castings are joined to the 38-inch riveted steel pipe by means of tapering courses, the total number of such courses being twenty. At the gate house of Rush reservoir, there is also a short length of 36-inch cast-iron pipe in this line. The aggregate length of 91,640.83 ft. given in said table consists of the following parts: 65,010.90 ft. of 38-inch pipe made of plates ¼-inch thick; 21,892.76 ft. of similar pipe made of plates 5-16-inch thick; 4,649.95 ft. of similar pipe made of plates ⅜-inch thick; and 87.22 ft. of 36-inch cast-iron pipe and special castings. Of said aggregate length, 71,935.86 ft. was laid and filled with water during the period from June 8 to Dec. 21, 1893, while the remainder was laid and filled during the interval from April 6 to May 23, 1894. Attention is also called to the fact that in computing the value of the coefficient (c) in the above table, no account was taken of the small losses of head due to the various 36-inch castings and tapering courses aforesaid.

With reference to the coating of the steel pipe in said section, it may be mentioned that three different asphaltic mixtures were used. On the first six miles the coating consisted of the best obtainable preparation of California asphalt or maltha; but as this did not prove satisfactory, a mixture of refined Trinidad asphalt and coal-tar pitch was substituted for the next seven miles. Both of these coatings were applied by immersing the pipe in hot baths of said materials, and for about 71.5 per cent. of the distance the pipes were thus treated. In the remaining length, the japan coating devised by Prof. A. H. Sabin was used. Most of the pipes were very smooth and glossy, but at times the dipped coatings presented slight corrugations when cooled too quickly, or when caused to flow by long exposure to the sun in warm weather. It may also be stated that 71.01 per cent. of the pipe was made of 0.25-inch plate, 23.91 per cent. of 0.3125-inch plate and 5.08 per cent. of 0.375-inch plate, thus giving an average plate thickness of 0.2713-inch.

The accuracy of the discharge measurements given in gauging No. 5, Table No. 1, was furthermore verified by an independent measurement with a sharp-crested weir placed in the new gate house at Hemlock Lake. Somewhat more water than the pipe could carry was admitted into the 6-foot brick conduit, which extends northerly for a distance of about 12,000 feet from the lake to the head of the steel pipe, the entire flow passing over said weir and its depth being carefully measured; it then flowed through the brick conduit, and the surplus escaped over another sharp-crested weir on the spill-way of the overflow chamber, the depth being here again carefully measured. The difference between the discharge over the two weirs, plus the slight infiltration into the masonry conduit, was obviously the quantity which flowed into the steel pipe and was delivered into Rush reservoir. It is greatly regretted that no means of directly measuring the said infiltration were available at the time; but as previous observations showed that the volume thus coming into the conduit was insignificant, and since the gauging was made during a period of unusual drought, the conclusion is fair that this addition to the flow was not large enough to greatly affect the results. All of the data relating to the flow over the two weirs were taken with the utmost accuracy, and are submitted in the following Table No. 2.

For computing the discharge over the two weirs mentioned, the standard general formula: $Q = mlh\sqrt{2gh}$ was adopted, in which the value of the coefficient (m) was taken from the results of the recent elaborate experiments made by Bazin, inasmuch as the conditions attending said experiments corresponded very closely to those which prevailed in the case under consideration. A comparison of the results obtained by using the values of (m) derived from the classic experiments of Fteley & Stearns and Francis, is also given in said table, and it will be seen therefrom that the differences are quite small. With Bazin's values of (m), the weir in the gate house showed a uniform flow of 26.0350 cubic ft. per second, while the weir on the spill-way of the overflow chamber gave 0.8467 cub. ft. per second, thus leaving a difference of 25.1883 cub. ft. per second to be carried off by the steel pipe. To this latter quantity, however, we must add the volume of water gained by infiltration into the masonry conduit, as aforesaid. From previous observations in ordinary seasons, this infiltration was estimated at about 0.35 cubic ft. per second; but as a severe drought prevailed in this locality last December, it is reasonable to infer that the infiltration was somewhat less at the time when gauging No. 5 was made. Now according to the observations at the reservoir, the discharge of the steel pipe was 25.4454 cubic ft. per second, while according to the weir observations it was 25.1883 cubic ft. per second, plus the infiltration; the difference of 0.2571 cubic ft. per second between these measured quantities may therefore be regarded as a fair estimate of the infiltration, thus causing a substantial agreement between the two results.

TABLE NO. 2,

SHOWING DATA RELATING TO WEIR MEASUREMENTS OF THE WATER FLOWING INTO THE STEEL PIPE CONDUIT DURING GAUGING NO. 5, ON DEC. 23, 1895.

No.	ITEMS.	Weir in Gate House.	Weir in Overflow Chamber.
1	Length of weirs, no end contractions, (l) in feet........	9.900	6.997
2	Depth of water above crest of weir, (h) in feet	0.8425	0.1030
3	Value of ($2g$) from Pierce's formula......	64.328	64.328
4	Value of coefficient (m), as per Bazin......................	*0.4240	*0.4564
5	Value of coefficient (m), as per Fteley & Stearns, 1877....	*0.4274	*0.4365
6	Value of coefficient (m), as per Francis..	0.4169	....
7	Discharge (Q) in cub. ft. per sec., as per Bazin...........	26.0350	0.8467
8	Discharge (Q) in cub. ft. per sec., as per Fteley & Stearns 1877	26.2437	0.8098
9	Discharge (Q) in cub. ft. per sec., as per Francis.........	25.5990	....
10	Approximate elevation in feet of weirs above sea level	900	900
11	Approximate latitude of weirs, in degrees	43.807	43.807
12	Temperature of water, in degrees F..................	40	40
13	Height of weir crest above bottom of channel, in feet..	5.40	5.00

*The values of (m) here given are interpolations made in the original tables corresponding to the given values of (h).

III. Gaugings between Rush and Mt. Hope Reservoirs.—In addition to the foregoing, three gaugings were also made of the capacity of the steel conduit from Rush reservoir to Mt. Hope reservoir, said gaugings being numbered 2, 3 and 4. This section of the conduit is about 8.75 miles long, and consists of 13,079.01 feet of 38-inch pipe made of plates ¼-inch thick; 12,922.19 feet of similar pipe made of plates 5-16-inch thick; 19,392.73 feet of similar pipe made of plates ⅜-inch thick, and 1,151.92 feet of 36-inch cast-iron pipe, special castings and stop-valves. As in the preceding section, tapering courses were used in passing from the 36-inch to the 38-inch pipe, eight such courses being required at the several points. All of the pipe was laid in 1894, and was filled with water at different times between June 20 and August 25, 1894, so that the average age of the pipe in service was about 1.3 years before the gaugings were made. It should also be noted that near Mt. Hope reservoir the conduit makes an abrupt turn of 90 degrees by means of a square-shouldered T-branch, as the general plan of the work contemplates the future continuation of the main line to a new distributing reservoir.

Particular interest attaches to these gaugings from the fact that the section embraces a long line of 36-inch pipe at Rush reservoir, in which the loss of head was separately measured. In anticipation of this circumstance, special care was taken to ascertain the actual mean interior diameter by exact measurements of two such diameters at right angles to each other at both ends of every pipe. Furthermore, as considerable variations were thus discovered, the pipes were then arranged in the line in such sequence as to present the most uniform gradation of diameter practicable. To exhibit these variations, it may be mentioned that in 78 such pipes the maximum difference found was 0.594 inch, and that the average diameter at the spigot ends was 3.0292 feet, while the average diameter at the bell ends was 3.0521 feet, thus giving an average difference of 0.0229 feet, or somewhat more than one-fourth inch. For the following computation of the coefficient (c), the mean diameter of the entire series was taken at 3.0406 feet. These pipes were all coated with a coal-tar pitch varnish in the usual manner, but in many cases both the coating and the surface of the iron were somewhat rough and granular.

The riveted steel pipe on the other hand, was coated with a comparatively smooth japan varnish, applied according to Prof. A. H. Sabin's process, and the diameter of the inside courses was uniformly 38 inches. It will also be observed by reference to the respective lengths formed of the different thicknesses of plate, that 42.72 per cent. was made of plates 0.375 inch thick, and 28.47 per cent. consisted of 0.3125-inch plates, while the remaining 28.81 per cent. was made of 0.25-inch plates. The average plate thickness was thus 0.3212-inch, while in the preceding section of the conduit it was 0.2713-inch; and as the losses of head referred to above appear to increase rapidly with the plate thickness, it is reasonable to expect a somewhat smaller value for the coefficient (c) in the section of the conduit now under consideration than in the preceding section.

The gaugings were made by carefully measuring the depth of the stratum of water which was drawn in a known period of time from Rush reservoir to Mt. Hope reservoir through the new conduit. In the first experiment, all inflow to the former reservoir from both conduits was temporarily cut off ; but in the two following ones, the discharge from the old conduit was allowed to continue, in consequence of which the depth of the stratum of water removed was less than in the first case. This discharge was computed for the particular elevations of the water surface in Rush reservoir from the coefficient (c) derived from a separate gauging of the old conduit on Oct. 18, 1895, when the water stood at a different elevation. Due allowance was also made in each case for evaporation and leakage of said reservoir. The total loss in the entire section of the new conduit, as well as that which occurred in a length of 889.57 ft. of the 36-inch cast-iron pipe, was obtained from careful piezometer measurements. In one experiment this latter loss was determined by a properly calibrated mercury gauge giving directly the difference in the water-pressures at each end of said length, and in another case, it was found from measurements in two open piezometers placed side by side, and connected with ¾-inch iron pipe to said ends. In both cases, special care was taken to give these connecting pipes a continuously ascending grade for their entire length to the gauge and the open piezometer vessels. At Mt. Hope reservoir, the elevation of the hydraulic grade was likewise determined from observations of a similar open piezometer ; and after plotting the two curves representing the elevations of said grade at the terminal points of the section, the difference between these curves or elevations at the middle of the duration of the gauging was taken as the total loss of head.

It may also be remarked that noticeable fluctuations occurred in the several piezometers, but as the observations were made simultaneously and at frequent intervals, it is fair to presume that the mean of the observed differences represents very closely the actual loss of head in each case. Having thus determined separately the losses of head in the whole section and in the straight 36-inch pipe, their difference is obviously the sum of the losses in the 38-inch steel pipe and the several valves and special castings mentioned above. For the latter, only approximate estimates can now be given, as no direct experiments with objects of the size here considered are yet available ; their aggregate, however, is comparatively small, and will probably not exceed 0.50 ft. while the castings are free from accretions of rust, but to avoid any over-estimation, this aggregate loss, including that which results from the aforesaid square turn, was taken at only 1.5 times the head due to the velocity in the pipe. The other data pertaining to these gaugings are given in the following table :

TABLE NO. 3, SHOWING DATA RELATING TO GAUGINGS NOS. 2, 3 AND 4 OF THE NEW CONDUIT.—SECTION FROM RUSH RESERVOIR TO MT. HOPE RESERVOIR.

No.	ITEMS.	Gauging No. 2, Oct. 17, 1895.	Gauging No. 3, Oct. 26, 1895.	Gauging No. 4, Nov. 7, 1895.
1	Duration of gauging, in hours	5.3500	5.2167	6.3833
2	Duration of gauging, in seconds	19,260	18,780	22,980
3	Observed fall of water surface in reservoir, in feet	1.02373	0.65815	0.80516
4	Mean area of water surface in reservoir for said fall and the given elevations, in square feet	577,717.64	589,400 47	587,565.61
5	Net volume taken from reservoir, reduced to cubic feet per second	30.7075	20.6557	20.5869
6	Observed evaporation from water surface, reduced to cubic feet per second, (to be subtracted)	0.1348	0.0603	0.0289
7	Observed percolation of reservoir, reduced to cubic feet per second, (to be subtracted)	0.0464	0.0464	0.0464
8	Computed gross delivery of old conduit into Rush reservoir during gauging, in cubic feet per second, (to be added)	0.0000	10.2287	10.2322
9	Discharge of new conduit in cubic feet per second	30.5263	30.7777	30.7438
10	Standard diameter of 38-inch steel pipe, in feet	3.1667	3.1667	3.1667
11	Actual mean diameter of 36-inch cast-iron pipe in feet	3.0406	3.0406	3.0406
12	Standard sectional area of 38-inch steel pipe in square feet	7.8758	7.8758	7.8758
13	Mean sectional area of 36-inch cast-iron pipe, in square feet	7.2612	7.2612	7.2612
14	Mean velocity (v) in 38-inch steel pipe, in feet per second	3.8756	3.9079	3.9036
15	Mean velocity (v') in 36-inch cast-iron pipe, in feet per second	4.2040	4.2386	4.2340
16	Mean topographical elevation of water surface in piezometer vessel at Rush reservoir, in feet, (above city datum)	477.188	478.684	478.970
17	Mean topographical elevation of water surface in piezometer vessel at Mt. Hope reservoir, in feet (above city datum)	403.157	403.303	403.400
18	Total observed loss of head (H) in the conduit between end piezometers, in feet	74.031	75.381	75.570
19	Computed loss of head (h') in 36-inch cast-iron pipe, based on observed loss in a length of 889.57 feet of said pipe, in feet	1.5863	*1.7019	1.6981
20	Estimated loss of head in 36-inch stop-valves, special castings, and square turn in direction, in feet	0.4117	0.4185	0.4175
21	Net loss of head (h) in 38-inch steel pipe alone, in feet	72.033	73.2606	73.4544
22	Total length (l) of 38-inch steel pipe alone, in feet	45,400.00	45,400.00	45,400.00
23	Hydraulic grade $s=\frac{h}{l}$ in 38-inch steel pipe alone	.0015864	0.0016137	0.0016179
24	Coefficient (c) in $v=c\sqrt{rs}$ for 38-inch steel pipe alone	109.35	109.34	109.07
25	Total length (l') of 36-inch cast-iron pipe between end piezometers, in feet	1,145.85	1,129.52	1,129.52
26	Hydraulic grade $s'=\frac{h'}{l'}$ in 36-inch cast-iron pipe alone	0.0013876	*0.0015067	0.0015034
27	Coefficient (c') in $v'=c'\sqrt{r's'}$ for 36-inch cast-iron pipe alone	129.45	*125.25	125.25
28	Mean temperature of water in pipe, in degrees F.	51	46	50
29	Mean temperature of air in shade, in degrees F.	46	50	64
30	Average age of conduit in service, in years	1.265	1.290	1.320
31	Discharge of entire section of conduit in gallons per day, through temporary 16-inch inlet pipe at Mt. Hope reservoir	19,729,700	19,892,100	19,870,200

*NOTE.—The loss of head (h′) in the 36-inch cast-iron pipe was not determined separately on Oct. 26, 1895, and the figures in the above table having the (*) prefixed are derived from computations made with the value of (c′) found in Gauging No. 4.

From the foregoing it will be noticed that the accuracy of all these gaugings depends upon the correctness of the volumetric measurements in Rush reservoir; and in relation thereto it may be stated that the area of the water surface, at a number of different elevations or depths, was determined from very careful measurements, while the thickness of the stratum of water added to or taken from said reservoir during each experiment, was ascertained by means of a finely graduated hook gauge dipping into a securely fixed piezometer vessel, the latter being used for the purpose of eliminating as far as possible the influence of waves and oscillations on the surface. A verification of the general accuracy of these measurements is afforded by the weir gaugings cited in Table No. 2. It may also be remarked that the actual duration of the gaugings was in each case considerably longer than the time given in the tables, so as to insure the establishment of a uniform flow in the conduit. The experiments are therefore regarded as being as correct as it is possible to make them with the means available.

IV. *Comparison of Results.*—A comparison of the results obtained from the above-described gaugings, with the initial assumptions relating to the discharge of the new conduit, shows that the values of the coefficient (c), in the fundamental formula $v=c\sqrt{rs}$, were taken somewhat too high in the preliminary calculations. Thus, for the 36-inch cast-iron and the 38-inch riveted steel pipes, the values of (c) were assumed at 135 and 117, respectively, for the same hydraulic grade and discharge while the pipes were new and smooth; from the gaugings, on the other hand, it is found that the actual values of (c) after the conduit had been in use from 1.3 to 2.1 years, were respectively: 125 for the 36-inch cast-iron pipe; 114 for the 38-inch riveted steel pipe having an average plate thickness of 0.2713 inch, and 109 for the same pipe with an average plate thickness of 0.3212 inch, Furthermore, by taking both sections of the conduit into account, the average plate thickness becomes 0.2878 inch, and the average value of (c) will be 112.34 for the 38-inch riveted pipe, of the aforesaid age. Probably these values of (c) would have been somewhat greater if the gaugings had been made very soon after the pipes were filled, as experiments have shown that a comparatively slight increase in the roughness of the interior surface of a pipe conduit causes a considerable reduction in the velocity or discharge.

With respect to the delivery of the new conduit after the completion of the permanent inlet connections at Rush and Mt. Hope reservoirs, it may be stated that by using the values of the coefficient (c) found above, and the full hydraulic grades from the beginning of the steel pipe near Hemlock Lake to high water level in said reservoirs, the discharges at the present time would be about 19,200,000 gallons per day at Rush, and about 21,200,000 gallons per day at Mt. Hope reservoir. The difference between these two quantities is due to the fact that the high water surface of Rush reservoir is about 34 feet above the hydraulic grade line drawn from the beginning of the pipe to the high water surface in Mt. Hope reservoir, as will be seen by reference to the profile. These discharges will gradually diminish from year to year, as the inner surface of the pipe becomes rougher from accretions of rust and organic growths, until after a period of twenty years the reduction will probably amount to 20 or 25 per cent. of the original capacity ; and if this loss be taken at the higher figure, the ultimate delivery at Mt. Hope reservoir will become about 16,000,000 gallons per day, as was assumed in the outset.