[*Reprinted from "The Journal of the American Chemical Society," Vol. VIII., No. 1.*]

SOME CONTRIBUTIONS TO THE STUDY OF THE NEW YORK WATER SUPPLY.

By A. A. Breneman, S.B.

The Croton water system, by which the city of New York is supplied, is well known as an engineering work, but has attracted little attention in proportion to its importance among the sanitary questions which have arisen over the water supply of other large cities.

The Croton water shed occupies a region which was when first chosen, and still is, comparatively free from the dangers of dense population or abundant manufactures, and such changes as may have occurred in the water from the influence of human habitation upon its gathering ground since it was first used in the city have been too minute, or have occurred too slowly to attract public attention. While the quality of this water has never been entirely unobjectionable, it has never been subject to such violent or sudden changes as have caused complaint in other cities. New York, deriving its supply through a subterranean conduit from a remote country district, has obvious advantages over a city which is supplied from an open river receiving sewage and manufacturing refuse from large towns and suburban districts. Nevertheless, there are variations in the quality of Croton water perceptible to the unaided senses which are sufficiently marked and sudden to attract attention with respect to the future character of the water, and to the present character as well, if any scientific standard of purity is to be regarded.

Although much valuable work in the analysis of Croton water has been done in recent years by the City Board of Health, the subject, involving, as it does, the interests of a million and a half of people, is of such importance that it cannot be too closely or minutely examined. The purity of the city water will, doubtless be controlled in future, as is done elsewhere, by a system of inspection and scientific oversight, in which chemical methods of investigation will play an important part. The nature and sources of all forms of contamination which characterize this water must be minutely studied, and their variations in quantity or quality must be accounted for, and all investigation which contributes to such a knowledge of the water will add to the efficiency of the Croton system.

For these reasons I venture to offer here the results of a series of analyses of Croton water, made during the summer and autumn of 1885, which were intended especially to show the variation in quantity of organic matter from day to day during the season, and the relation of these variations to the conditions of temperature and rainfall.*

Analyses were made of samples taken daily (Sundays excepted), from April 28 to September 10, and weekly thereafter to the end of the year. The samples were taken in the lower part of the city, from a faucet which communicated, through 60 feet of one-inch pipe, with the street main, and the water was in all cases allowed to run for five minutes before collecting the sample. To guard against any possible difference in composition, from sediment in the pipe, duplicate samples were occasionally taken from a street fountain near by, from which the water was constantly running.

The volume of the work, and the pressure of other duties, compelled me to limit the number of determinations as far as possible, and on this account the analyses include only the four factors of free and albuminoid ammonia, chlorine and solid matter. Putting aside the question of the absolute value of the ammonia method, it will be admitted that results obtained by the same method upon a number of samples from the same source, in the hands of the same analyst, and by means of specified procedure in manipulation, will be comparable among themselves, and this was, in the case under consideration, the principal end to be attained. For the rest, the ammonia method offers a better measure of the putrescible or nitrogenous matter in water than any method at present attainable, when rapidity of work is to be considered. The estimations of chlorine and solid residue were added simply for the purpose of studying the influence of the above-mentioned conditions upon these factors.

---

* For the records of rainfall and mean daily temperature, I am indebted to the officers of the United States Signal Service Station in New York city.

TABLE I. ANALYSES OF CROTON WATER.

(Parts per 100,000.)

	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Solid Matter.	Daily Rainfall.	Mean daily Temperature.
April 27	.0029	.0210	.343	5.659	.38	57.1
" 28	.0032	.0233	.514	7.546	.92	48.7
" 29	.0031	.0164	.514	8.756	....	45.6
" 30	.0026	.0212	.514	9.775	....	58.1
May 1	.0017	.0209	.514	8.232	.65	46.0
" 2	.0016	.0209	......	8.063	.09	48.4
" 4	.0023	.0205	.514	6.856	....	47.8
" 5	.0016	.0192	.514	5.652	....	45.5
" 6	.0037	.0217	.514	5.827	.04	50.1
" 7	.0014	.0195	.514	6.856	.62	48.6
" 8	.0037	.0200	.428	5.142	.23	48.2
" 9	.0043	.0184	.428	7.370	.02	48.2
" 11	†.0035	.0189	......	....	....	49.3
" 11	.0055	.0222	.343	7.370	....	49.3
" 12	.0045	.0248	.343	8.227	....	51.3
" 13	.0039	.0240	.343	6.634	....	51.9
" 13	*.0028	.0179	.343	6.341	....	51.9
" 14	.0023	.0194	.343	8.227	.02	56.1
" 15	.0025	.0182	.343	8.398	....	70.6
" 16	.0033	.0172	.343	7.021	....	63.1
" 18	*.0039	.0176	.343	5.656	....	60.3
" 19	*.0032	.0185	.343	7.713	....	69.5
" 20	.0021	.0162	.343	6.170	....	64.7
" 21	.0022	.0145	.343	8.398	....	57.0
" 22	.0017	.0224	.343	7.370	....	56.9
" 23	*.0022	.0127	.343	8.227	.40	58.1
" 25	.0013	.0268	.343	8.227	....	58.3
" 26	*.0025	.0173	.343	6.341	....	72.7
" 26	.0043	.0192	.343	6.341	....	72.7
" 27	.0027	.0238	.343	8.398	....	70.5
" 28	.0030	.0208	.343	6.634	....	60.3
" 29	.0037	.0205	.343	7.546	.01	58.1
" 30	*.0032	.0175	.343	5.485	.02	58.6
June 1	.0031	.0186	.343	6.513	....	68.0
" 2	.0033	.0183	.343	7.892	....	62.7
" 4	.0029	.0176	.343	6.856	....	63.7
" 5	.0026	.0190	.343	7.892	.03	65.1
" 6	.0027	.0147	.343	7.713	....	65.0
" 6	*.0042	.0166	.343	7.198	....	65.0
" 8	.0038	.0175	.343	6.513	.69	68.0
" 9	.0048	.0204	.343	7.548	....	59.5
" 10	.0023	.0164	.428	6.174	....	62.3
" 11	.0025	.0193	.343	7.027	....	63.4
" 12	.0034	.0216	.428	7.370	....	65.3
" 13	.0031	.0190	.428	8.398	....	65.7
" 15	.0038	.0175	.428	8.198	.20	70.6
" 16	‡.0037	.0197	.514	7.198	.02	75.6
" 17	.0044	.0190	.514	5.656	.32	65.6
" 18	.0026	.0177	.427	6.341	....	68.7
" 19	.0021	.0189	.514	7.027	....	70.6
" 20	*.0027	.0171	.428	7.546	....	70.1
" 22	.0026	.0195	.428	6.513	....	72.3
" 23	.0029	.0221	.343	5.827	....	63.1
" 25	.0055	.0204	.343	7.546	....	69.4
" 26	.0050	.0212	.428	6.856	....	69.2
" 27	.0056	.0166	.343	7.198	28/.58	69.8
" 29	.0037	.0250	.343	7.892	.02	69.3
" 30	.0044	.0213	.428	9.255	....	64.8
July 1	.0028	.0260	.428	7.370	....	....
" 2	.0033	.0266	.428	8.063	....	....
" 3	.0026	.0245	.343	8.227	....	....
" 3	*.0028	.0233	.428	8.227	5/.16	....
" 6	.0028	.0208	.343	7.546	....	71.1
" 7	.0028	.0236	.428	7.546	.61	70.7
" 8	.0066	.0320	.428	7.892	.0	75.9

* From drinking fountain at Wall and South streets.
† " " " Burl. slip and South street.
‡ " faucet at 18th street and 3d avenue.

TABLE I. ANALYSES OF CROTON WATER.—*Continued.*

(Parts per 100,000.)

		Ammonia.		Chlorine.	Solid Matter.	Daily Rainfall.	Mean daily Temperature.
		Free.	Albuminoid.				
July 9		.0047	.0206	.428	6.634	.96	76.7
“ 10		.0056	.0215	.514	6.713	.03	75.5
“ 11		.0065	.0243	.428	6.713	....	74.4
“ 13		.0075	.0221	.428	7.713	....	68.5
“ 14		.0089	.0227	.428	7.021	1.06†	68.3
“ 15		.0090	.0246	.428	8.741	....	71.9
“ 16		.0074	.0270	.428	8.063	....	76.8
“ 17		.0061	.0227	.343	7.713	....	81.6
“ 18		*.0050	.0208	.343	7.370	....	83.5
“ 20		.0028	.0200	.428	7.892	....	78.9
“ 21		.0015	.0191	.428	7.713	....	81.5
“ 23		.0056	.0178	.428	8.227	....	77.4
“ 24		*.0020	.0214	.428	8.063	....	76.1
“ 25		*.0022	.0240	.514	7.713	26/.18	80.8
“ 27		*.0040	.0203	.428	7.546	....	73.0
“ 30		.0034	.0211	.428	7.546	29/.04	75.0
“ 31		.0035	.0193	.428	6.856	....	72.0
Aug. 1		.0042	.0190	.514	6.341	2/2.08	74.9
“ 3		.0013	.0191	.343	7.198	2.06	70.1
“ 4		.0026	.0222	......	....	.24	73.3
“ 5		.0027	.0229	.428	6.513	.21	74.0
“ 6		.0033	.0248	.428	8.063	....	69.1
“ 10		.0046	.0254	.428	8.063	....	71.5
“ 11		.0051	.0232	.428	7.198	....	74.1
“ 12		.0049	.0202	.514	6.846	....	76.4
“ 13		.0024	.0266	.514	7.599	.70	78.4
“ 14		.0042	.0274	.514	7.370	.02	76.7
“ 15		*.0038	.0242	.514	6.856	....	70.9
“ 17		.0054	.0249	.599	6.535	....	70.2
“ 18		.0042	.0219	.514	6.341	....	74.3
“ 19		.0028	.0228	.514	8.741	.24	71.8
“ 20		.0024	.0284	.599	7.546	....	70.5
“ 21		.0044	.0259	.599	7.546	....	71.6
“ 24		.0041	.0297	.428	7.713	23/.61	76.8
“ 25		.0048	.0266	.428	7.021	....	68.1
“ 26		.0040	.0268	.428	8.063	.16	60.4
“ 27		.0042	.0336	.343	8.063	....	58.9
“ 28		.0039	.0288	.343	8.063	....	60.9
“ 29		*.0040	.0246	.343	7.892	....	64.2
“ 29		.0030	.0280	.428	8.398	30/.38	67.5
“ 31		.0043	.0222	.428	7.370	....	71.6
Sept. 1		.0041	.0273	.428	7.546	....	68.9
“ 2		.0043	.0277	.428	8.393	....	60.7
“ 3		.0037	.0278	.428	8.570	....	62.4
“ 4		.0050	.0262	.514	8.398	.02	69.7
“ 5		.0020	.0290	.514	7.021	.10	65.2
“ 7		.0043	.0244	.428	7.021	8/.10	61.8
“ 10		.0054	.0332	.428	8.570	.05	59.6
“ 16		*.0040	.0284	.342	7.370	9/.14 15/.25	67.6
“ 21		.0037	.0259	.342	7.198	....	60.7
“ 26		.0028	.0191	.428	....	....	61.9
Oct. 6		.0026	.0197	.514	8.912	14.50	49.6
“ 10		*.0022	.0159	.428	7.198	....	55.8
“ 10		.0022	.0138	.514	8.912	....	....
“ 17		.0029	.0159	.514	7.198	....	58.1
“ 24		.0033	.0184	.600	8.227	....	52.5
“ 31		.0024	.0135	.600	9.426	....	41.6
Nov. 7		.0029	.0176	.565	8.603	.13	63.7
“ 14		.0017	.0152	.514	8.570	8/1.09	45.9
“ 21		.0014	.0152	.514	9.426	9/.13	39.8
Dec. 6		.0017	.0146	.514	6.856	5/.13	28.4
“ 12		.0022	.0128	.428	7.892	13/1.13	30.8
“ 19		.0026	.0142	.428	7.546	14/.25	39.3
“ 26		.0044	.0231	.428	7.021	18/.08	24.5

* From drinking fountain at Wall and South streets.

† To 3.00 P. M.

In the distillation for albuminoid aminonia the process was not stopped after the third distillation had been taken off, as Wanklyn directs, but was continued to near dryness leaving only 3–5 c.c. of liquid in the retort. In this way a much better opportunity is given to study the rate at which the albuminoid matter decomposes, each distillate being separately nesslerized. The concentration of the last portions of the reagent and the high boiling point of the liquid are both favorable to the elimination of the maxium of albuminoid nitrogen and the results must approximate the true quantity of nitrogen thus held unless there are subordinate reactions in which nitrogen escapes, a matter which has never, so far as I am aware, been fully determined. That the third distillate is an arbitrary limit is evident when it is considered that different samples of water are known to differ widely in the rate at which they give off ammonia under the action of alkaline permanganate. Even with water from the same source, as in this case, the proportions of the total ammonia obtained after the third distillation differ greatly in successive operations. In twenty-four consecutive analyses of Croton water this proportion averaged about one-fourth of the whole, but there were many wide variations from this mean. *To render the above results comparable, therefore, with those obtained by the ordinary method the figure for albuminoid ammonia should be reduced one-fourth.* On the other hand a direct experiment in which the exhausted retort received a fresh quantity of ammonia-free water showed only traces of ammonia and yielded none after a second renewal of the pure water. This is a point, however, upon which I hope to make further experiments.

In distilling to near dryness there is a very marked increase in the yield of ammonia, as the end is approached. The rate of distillation has an important influence upon the manner in which ammonia is given off, and probably to some extent upon the total quantity, but this source of error is evidently of less importance when the process is carried nearly to dryness. As a rule at least ten minutes were given to each separate distillate.

Free ammonia was taken off in four separate distillates; the fourth distillate rarely showed a perceptible tinge with Nessler reagent.

Chlorine was titrated with neutral chromate in a miniature U. S. gallon (58.3 c.c.), and solid residue was determined by evaporating the same volume in platinum and drying at 100° C.

The results, as shown by the table, indicate, what was, on general grounds, to be expected, viz., a close dependence of organic matter upon rainfall, and an equally marked but more slowly exerted effect of temperature.

The short interval of one to two days between the occurrence of any considerable fall of rain and the rise in the proportion of albuminoid ammonia shows that the passage of water from the gathering ground to the consumer is very rapid, and indicates the need of a better system of storage and settling, so that storm water may be retained long enough to allow the coarser suspended matter to subside. This increase of organic matter is due to loose material torn by the violence of rushing water from the banks of streams and water courses, and to sediment stirred up from shallow pools. The turbidity is largely due to light organic matter, as is shown by the slight influence which it exerts upon the solid residue; any important increase in mineral matter would readily show itself in the weight of dry matter obtained.

The nature of this organic matter requires further investigation. To the eye it seems to be made up of minute, light and floculent particles of a greenish-brown color, almost transparent, and visible only in certain lights. It remains suspended for an indefinite time. Analyses made of the water of August 21, after standing in perfect quiet for three days, showed .0208 and .0198 of albuminoid ammonia in duplicate samples, while the same water shaken up before analysis yielded only .0225. It must be said, in strictness, that this persistent suspended matter belongs rather to late summer, and is less abundant earlier in the season; a sample taken May 25th showed, before settling, .0268 albuminoid ammonia; after settling, .0191. However, it is questionable, whether any process of subsidence alone will be satisfactory as a means of purifying Croton water; filtration, either in the household or on a large scale, is probably the only method by which it can be satisfactorily freed from the suspended matter which is its greatest defect. Along with the abundance of suspended organic matter, there are living bodies of visible size, among which, the familiar crustacean *Cyclops* and minute, brownish worms are most abundant. This abundance of visible, living forms points, unquestionably, to a much greater abundance of microscopic germs and organisms. I expect, during the coming season, to apply to Croton water the new biological methods for detection of these microscopic forms.

Free ammonia, as shown by the above table, rarely reaches a high figure and is more difficult to connect with rainfall, except in the remarkable increase exhibited from July 7 to 13; otherwise the fluctuations between drought and times of heavy rains do not seem regular or proportionate to the precipitation. The reason of this is, probably, to be found in the rapidity with which ammonia is taken up by water plants and low vegetable organisms.

As to chlorine, the proportion is too low to be of much significance and its minute variations, if they have any meaning, can only be interpreted by a more delicate method of determination than the one employed.

Solid matter is remarkably constant. The water is eminently a "soft" water, and the only effect of rainfall is to lower its proportion slightly, by dilution. The highest proportions are shown during prolonged drought.

WATER SUPPLY OF OTHER AMERICAN CITIES.

In connection with the above work I have made a number of analyses of water taken from other American cities, which are inserted here for comparison.* The samples were obtained through the kindness of many friends, and were all taken from faucets connecting directly with the mains supplying the respective cities, and were collected with the same precautions that have been observed in taking the Croton samples. They were taken principally during the autumn of 1885, and with two exceptions† were, so far as I am aware, perfectly normal samples, that is, they were not taken under any exceptional conditions of rainfall or accidental contamination of the water at the respective sources. In judging of the quality of the different waters as compared with Croton, samples taken at the same time should be compared.

Such comparisons have, of course, a very limited value, since even specimens, taken at the same moment over so wide an area, might be subject to the meteorological conditions, which would considerably alter their character for the time. However, no other mode of comparison is possible, and provided the samples are normal the

* See Table II.

† Philadelphia and San Francisco. See Table II.

relations brought out in this way have a certain value. The results as to albuminoid ammonia have been obtained by the method of distillation heretofore described.

TABLE II. WATER OF AMERICAN CITIES (PARTS PER 100,000).

Date. 1885.	City.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Solid Matter.
Oct. 25	Pitttsburgh, Pa.[1]	.0023	.0204	.771	9.084
" 26	Chicago	.0031	.0123	.600	16.540
" 28	Milwaukee	.0010	.0126	.514	18.168
" 28	Albany, N. Y	.0029	.0163	.514	10.798
" 29	St. Louis[2]	.0030	.0199	1.456	44.021
Nov. 4	Washington	.0018	.0131	.514	10.289
" 7	New York	.0029	.0176	.565	8.603
Dec. 3	Boston[3]	.0019	.0143	.857	5.827
" 28	San Francisco[4]	.0028	.0162	2.690	23.139
1886					
Jan. 6	Philadelphia[5]	.0103	.0565	.342	22.796
" 7	Brooklyn	.0004	.0083	.942	7.198

1. Quite turbid, with clay and flocculent matter.

2. Very turbid, with fine, reddish clay.

3. Cochituate water.

4. Slightly more turbid than usual, owing to very heavy rain shortly before the sample was taken.

5. Loaded with suspended clay and organic mud from a very heavy flood in the Schuylkill river. This specimen is entirely abnormal, and if taken as representative would do great injustice to Fairmount water.

The above table, representing the composition of the different waters after the close of the warm season, makes probably the most favorable exhibition of each. Exceptional causes of contamination occur in summer, especially in August and September. The accumulated effects of temperature in stimulating all processes of growth and decay and in reducing the volume of water by which debris resulting from these processes is carried off, had reached their limit and subsided greatly, as the larger table shows, before the period at which the samples of the smaller table were taken.

Comparing the figures for albuminoid ammonia among themselves in Table II., the most striking circumstance is the great purity of Brooklyn water as compared with that of other large cities.

Next to this in order of purity stand Chicago and Milwaukee, using the waters of Lake Michigan, although these cannot be regarded as waters of a high degree of purity. The contamination of Chicago water by admixture of sewage from the city, even as far distant as the crib, at which the water of the lake is taken in has been feared, and if this has already occurred, then the water of the lake opposite Milwaukee must be contaminated to an equal degree. The difference in chlorine, a very suggestive factor when sewage is considered, is too small here to be of much significance. The decrease in solid residue in the Chicago water probably indicates dilution with water from sources other than the lake.

The water of St. Louis is loaded with Missouri river mud, and leaves a residue of red clay on evaporation. This water, however uninviting in appearance, is commonly regarded as wholesome for drinking. Judging by the proportion of albuminoid ammonia, however, it is hardly to be commended.

Albany and Pittsburgh are supplied by their adjacent large rivers and can never expect from these sources water of any high degree of purity.

The water of Philadelphia is not to be considered in the list, as the sample, because of the exceptional conditions under which it was collected, is not representative. It is worthy of remark, however, that there is need of great improvement in a water system in which water of this character is permitted to enter into the city supply.

Taking the above list for what it is worth, and arranging the cities in the order of the figures indicating albuminoid ammonia for the purpose of a rough comparison, they would stand as follows:

1. Brooklyn,
2. Chicago,
3. Milwaukee,
4. Washington,
5. Boston,
6. San Francisco,
7. Albany,
8. New York,
9. St. Louis,
10. Pittsburgh.