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Author: American Society of Civil Engineers
Author: E. D. Hardy

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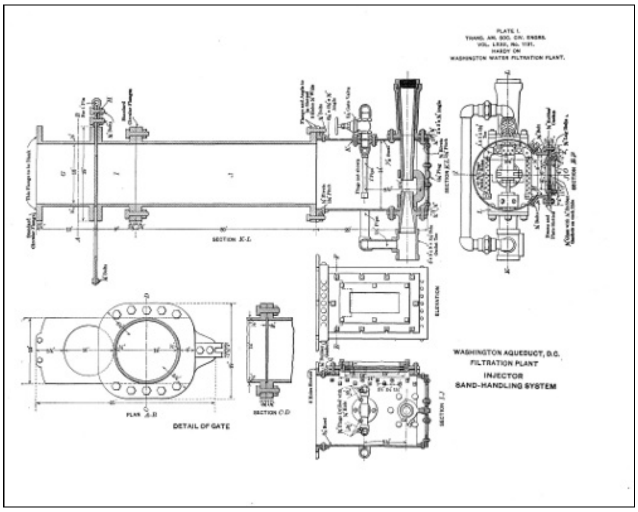

Plate 1: Washington Aqueduct, D. C. Filtration Plant Injector Sand-Handling System

AMERICAN SOCIETY OF CIVIL ENGINEERS

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TRANSACTIONS

Paper No. 1191

WATER PURIFICATION PLANT, WASHINGTON, D. C. RESULTS OF OPERATION.[1]

By E. D. Hardy, M. Am. Soc. C. E.

With Discussion by Messrs. Allen Hazen, George A. Johnson, Morris Knowles, George C. Whipple, F. F. Longley, and E. D. Hardy.

The Washington filtration plant has already been fully described.[2] At the time that paper was written (November, 1906), the filtration plant had been in operation for only about 1 year. It has now been in continuous operation for 5 years, and many data on the cost, efficiency, and methods of operation, have accumulated in the various records and books which have been kept. It is thought that a brief review of the results, and a summary of the records in tabular form, will be of interest to the members of the Society, and it is also hoped that the discussion of this paper will bring out the comparative results of operation of other filter plants. As a matter of convenience, the following general description of the plant is given.

Description of the Filtration Plant.—The Washington filtration plant was completed and put in operation in October, 1905. It consists of a pumping station for raising the water from the McMillan Park Reservoir to the filter beds; 29 filters of the slow sand type, having an effective area of 1 acre each; the filtered-water reservoir, having a capacity of about 15,000,000 gal.; and the necessary piping and valves for carrying water, controlling rates of filtration, etc.

[1] Presented at the meeting of February 15th, 1911.

[2] "Works for the Purification of the Water Supply of Washington, D. C.," by Allen Hazen and E. D. Hardy, Members, Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. LVII, p. 307.

In the pumping station, there are three centrifugal pumps, which are directly connected to tandem compound engines; two sand-washer pumps; three small electric generating sets for furnishing electric light; and four 200-h.p., water-tube boilers.

Each of the centrifugal pumps has a nominal capacity of 40,000,000 gal. per day when pumping against a head of 21 ft., and each sand-washer pump has a capacity of 2,500,000 gal. when pumping against a head of 250 ft. The electric light engines and generators supply the current for lighting the pumping station, the office and laboratory and other buildings, and also the courts and interior of the filter beds, and for operating a machine-shop.

The filters and filtered-water reservoir are built entirely of concrete masonry. The floors are of inverted groined arches on which rest the piers for supporting the groined arch vaulting. All this concrete work is similar to that in the Albany, Philadelphia, and Pittsburg filters.

The filters contain, on an average, 40 in. of filter sand and 12 in. of filter gravel. The gravel is graded from coarse to fine; the lower and coarser part acts as part of the under-drain system, and the upper and finest layer supports the filter sand. The raw water from the pumps is carried to the filters through riveted steel rising mains which have 20-in. cast-iron branches for supplying the individual filters. The filtered water is collected in the under-drainage system of the several filter beds, and is carried through 20-in., cast-iron pipes to the regulator-houses. These regulator-houses contain the necessary valves, registering apparatus, etc., for regulating the rate of filtration, showing the loss of head, shutting down a filter, filling a filter with filtered water from the under-drains, and for turning the water back into the raw-water reservoir, or wasting it into the sewer. From the regulator-houses, the filtered water flows directly to thefiltered-water reservoir. Generally, five filters are controlled from one house, but there are two cases where the regulator-houses are smaller, and only two filters are controlled from each.

The dirty sand removed from the filters is carried by a portable ejector through one or more lengths of 3-in. hose and a fixed line of 4-in. pipe, to the sand washers. From the sand washers, the washed sand is carried to the reinforced concrete storage bins, each of which has a capacity of 250 cu. yd., and is at such an elevation that carts may be driven under it and loaded through a gate.

Until April, 1909, the sand was replaced in the filters by carts which were filled through the gates in the sand bins. It was then hauled to the top of the filter beds and dumped through the manholes on the chutes, which could be revolved in any direction. These chutes were used to prevent the sand from being unduly compacted in the vicinity of the manholes, and to facilitate spreading it in the filters. Since April, 1909, all the sand has been replaced by the hydraulic method. An ejector is placed under the gate in the sand bin, and the sand is carried in a reverse direction from the bin through the 4-in. piping and one or more lengths of hose to the filter bed. This process has lowered the cost of re-sanding considerably, and present indications are that it will prove entirely satisfactory in every way.

The average effective size and uniformity coefficient of the filters are shown in Table 1.

Table 1—Filter Sand as Originally Placed.

Filter No.	Average effective size, in millimeters.	Average uniformity coefficient.	Depth of sand, in inches.	Average turbidity.
1	0.32	1.88	35.3	2,600
2	0.30	1.78	37.7	2,200
3	0.32	1.77	40.2	3,000
4	0.29	1.80	42.5	1,800
5	0.34	1.74	44.9	2,700
6	0.31	1.78	37.7	2,300
7	0.29	1.72	40.1	2,300
8	0.32	1.75	40.2	2,800
9	0.32	1.78	42.5	2,900
10	0.30	1.69	39.5	2,500
11	0.34	1.93	37.1	2,600
12	0.29	1.66	34.7	2,100
13	0.32	1.83	33.6	3,500
14	0.29	1.66	33.6	2,600
15	0.33	1.75	39.0	2,400
16	0.33	1.78	42.3	3,000
17	0.33	1.86	45.5	3,300
18	0.34	1.80	48.7	3,100
19	0.34	1.80	52.0	...
20	0.34	1.87	39.0	2,700
21	0.32	1.82	42.3	2,400
22	0.33	1.74	45.5	2,200
23	0.33	1.81	48.7	2,300
24	0.35	1.80	52.0	2,600
25	0.29	1.64	39.5	2,400
26	0.31	1.71	37.1	2,100

27	0.31	1.71	34.7	1,900
28	0.33	1.93	33.6	2,300
29	0.34	1.93	33.6	3,000
Maximum	0.36	1.93	52.0	3,300
Minimum	0.29	1.64	33.6	1,800
Average	0.32	1.77	40.4	2,600

Description of Washington Aqueduct.—The water supply of Washington is taken from the Potomac River, at Great Falls, about 16 miles above the city. At that place, a dam has been built across the river, which holds the water at an elevation of 150.5 ft. above mean tide at Washington. From Great Falls the water flows by gravity for a distance of 16 miles through a 9-ft. conduit, three reservoirs, and a tunnel. From McMillan Park Reservoir, the last of the three, the water is lifted by centrifugal pumps about 21 ft. to the filters. After passing through the filters, it flows to the filtered-water reservoir, and later to the city mains. In its passage from Great Falls to the filters, the water flows through three settling reservoirs, which have already been referred to. These reservoirs are known as the Dalecarlia, the Georgetown, and the McMillan Park Reservoirs, and have available capacities of 141,000,000, 140,000,000, and 180,000,000 gal., respectively.

Turbidity.—The Potomac River water is rather turbid, the turbidity being caused by very fine particles of clay. The river is subject to sudden fluctuations, it being no uncommon thing to have a turbidity of 100 one day, and 1,000 the next. The high turbidity usually disappears about as rapidly as it comes, and is seldom higher than 500 for more than 5 days at a time. It is frequently the case, however, that a succession of waves of high turbidity will appear so close together that the effect of one has not disappeared before that of another is felt.

The clarification of the water supply begins at the dam at Great Falls. Here it is a clarification by exclusion, for when an excessive quantity of mud appears in the river water, the gates are closed, and the muddy water is allowed to flow over the dam and form mud-bars in the Lower Potomac, while the city is supplied from the water stored in the three settling reservoirs. Until a comparatively recent date, the excessively muddy water was never excluded, having been taken, like other decrees of Providence, as it came.

During the summer of 1907, the practice of shutting out water with a turbidity of 500 or more was established for the warm months. This practice was discontinued during the cold months, as it was feared that a very high consumption of water might occur at the time of low water in the reservoirs, and so cause a partial famine. During the winter of 1909-10, however, the gates were closed, as was the practice throughout the summer months.

When the reservoirs are well filled, and the consumption of water is less than 70,000,000 gal. per day, it is safe to close the gates at Great Falls for a period of about 4 days.

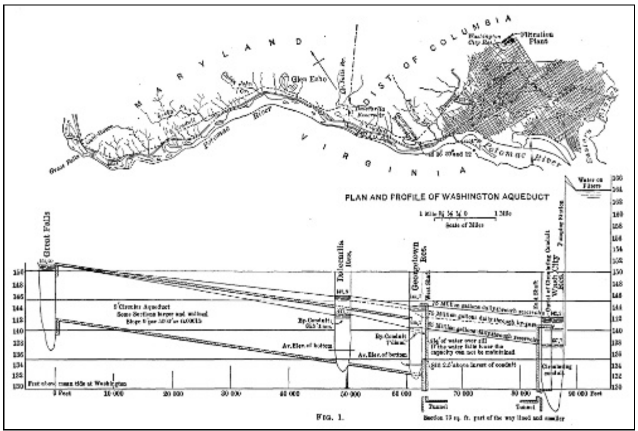

Figure 1—Plan and Profile of Washington Aqueduct.

While a considerable reduction in turbidity is effected in each of the reservoirs, the bulk of the mud is deposited at the upper end of Dalecarlia Reservoir. This reservoir had become so completely filled, that, in 1905, it was necessary to dredge a channel through the deposit, in order to allow the water to pass it. During the summers of 1907 and 1908, a 10-in. hydraulic dredge removed more than 100,000 cu. yd. of mud which had been deposited in this reservoir. The mud deposited in Georgetown and McMillan Park Reservoirs is so fine that the accumulation of many years is not very noticeable in its effect on the depth of water.

The particles of clay which remain in the water after its passage through the three reservoirs, are so exceedingly small that they do not settle out in any reasonable length of time. Even the filtration of the water through one or more slow sand filters occasionally fails to remove the last trace of turbidity. This is especially true in the colder months, and not a winter has passed when the water supply has not been noticeably turbid at some time.

A general idea of the quantity of mud contained in the river water, the quantity excluded by closing the gates at Great Falls, and that removed by sedimentation and filtration, may be gained from Table 2, which is, of course, only a rough approximation.

Table 2 also shows that the gates were closed 10.50% of the time, thereby excluding 40.06% of the total suspended matter which otherwise would have entered the system.

The turbidities, bacterial counts, and chemical analyses of numerous samples of water are shown in Tables 3, 4, 5, and 6. The amount of work done in the pumping station, average consumption of water, death rate from typhoid fever, and filter runs are shown in Tables 7, 8, 9, and 10.

Raking.—At the time the filters were first put in service, the sand bins had not been completed, and, consequently, the work of cleaning the filters was carried on in the old-fashioned way of scraping by hand and wheeling out the sand in barrows. This method of cleaning was used from October, 1905, to April, 1906; then the regular sand-handling system was commenced.

At times, during the first two summers the filters were in operation, considerable difficulty was experienced in keeping them cleaned as fast as was necessary to provide an ample supply of filtered water. For a short period in each summer it was found necessary to organize night shifts, and keep the work of cleaning in progress for from 16 to 24 hours per day.

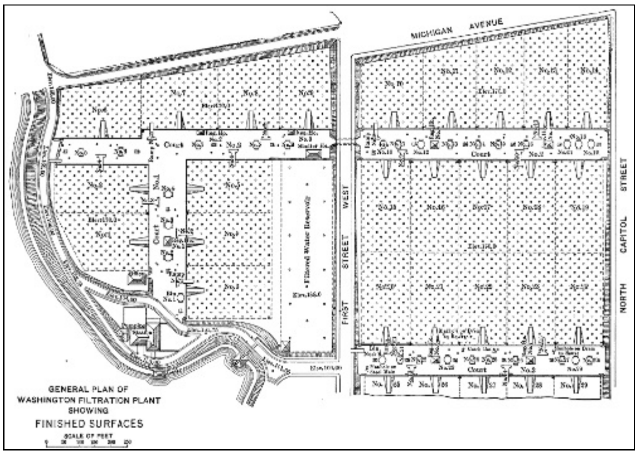

Figure 2—General Plan of Washington Filtration Plant Showing Finished Surfaces.

Table 2—Tons of Suspended Matter Entering System, Etc.

Month.	Amount that would have entered the system if the gates had been left continuously open.	Number of hours gates were closed.	Amount shut out.	Amount deposited in Dalecarlia Reservoir.	Amount deposited in Georgetown Reservoir.	Amount deposited in McMillan Park Reservoir.	Amount entering filtration plant.	Total.
1909.								
July	318	32.0	3	0	125	74	116	318
August	146	47.0	1	0	78	38	29	146
September	97	57.0	7	21	13	38	18	97
October	61	90.5	8	7	9	25	12	61
November	50	60.0	4	13	5	17	11	50
December	370	99.0	126	108	33	59	44	370
1910.								
January	2,410	136.0	1,109	1,020	67	117	97	2,410
February	839	117.5	481	126	56	75	101	839
March	208	7.5	13	43	15	13	124	208
April	321	65.0	17	195	43	43	23	321
May	197	84.5	58	54	22	24	39	197
June	1,505	124.0	786	535	49	88	47	1,505
Total	6,522	920.0	2,613	2,212	515	611	661	6,522

In order to relieve the situation at such times, the expedient of raking was tried. This was first attempted with the filters filled with water; the effluent was first shut off in order to prevent a downward flow of water, and the filter was then raked or harrowed from boats. This method was not satisfactory, however, as the work was neither as uniform nor as thorough as necessary. Later, the filters were drained to the necessary depth, and the surface of the sand was thoroughly stirred with iron garden rakes. The filters were then filled with filtered water through the under-drains and put in service.

This latter method proved so satisfactory that it has been resorted to at all times when the work was at all pressing. When the runs were of short duration, and the depth to which the mud had penetrated the filter sand was slight, a raking seemed to be nearly as effective in restoring the filter capacity as a scraping; it could be done in 8 hours by 3 laborers, and there seemed to be no ill effects from lowered efficiency.

Table 3—Turbidities.
Average by Months.
(United States Geological Survey Standard.)

Month.	Great Falls.		Reservoirs:							
			Dalecarlia Outlet.		Gerogetown Outlet.		McMillan Park Outlet.		Filtered water.	
	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.
1905.										
October	100	36	40	21	32	18	20	11	4	1
November	35	19	34	19	22	14	14	11	3	1
December	1,500	199	250	84	150	74	95	39	14	6
1906.										
January	700	94	180	60	120	60	85	52	20	12
February	120	45	85	41	55	29	35	22	5	3
March	1,750	272	350	181	120	56	90	46	8	6
April	1,270	167	180	72	95	58	75	46	12	7
May	600	56	50	20	45	16	34	10	3	2
June	1,700	303	500	125	450	94	180	41	13	2

July	1,000	130	180	54	150	47	250	43	13	3
August	1,530	375	250	112	95	66	65	45	5	2
September	120	33	180	34	95	28	75	25	7	2
October	1,025	127	110	37	60	24	55	21	1	1
November	160	27	75	20	45	16	24	13	1	1
December	600	69	110	31	80	28	80	26	8	2
1907.										
January	400	135	150	70	110	75	70	53	11	7
February	55	26	26	15	36	16	40	17	5	2
March	950	248	180	77	130	70	90	57	7	4
April	200	47	80	33	60	30	45	24	4	2
May	130	29	40	18	26	15	14	9	1	1
June	400	104	160	48	75	32	40	18	1	1
July	600	114	130	61	78	47	45	31	1	1
August	800	73	130	35	85	26	30	14	1	0
September	600	129	[1]	[1]	150	51	70	28	1	0
October	75	32	[1]	[1]	65	28	75	26	4	0
November	300	97	[1]	[1]	100	45	45	23	2	1
December	680	135	[1]	[1]	180	61	100	46	10	4
1908.										
January	2,100	202	340	73	250	82	160	65	20	7
February	3,000	302	300	52	150	52	75	32	7	4
March	300	91	150	78	100	68	65	42	5	4
April	75	23	65	41	37	27	26	20	3	2
May	2,000	172	130	48	85	37	50	20	1	1
June	400	40	70	29	40	24	30	18	1	1
July	1,500	149	...	74	170	44	75	15	0	0
August	900	129	200	[1]	150	56	85	39	2	1
September	75	24	[1]	[1]	50	19	35	18	0	0
October	95	20	[1]	[1]	55	18	28	15	0	0
November	24	11	[1]	[1]	20	11	19	10	0	0
December	20	9	17	11	14	9	10	7	0	0
1909.										
January	400	72	95	32	60	23	25	16	4	1
February	650	194	120	64	90	51	55	35	4	3
March	250	51	[1]	[1]	90	44	60	37	8	4
April	750	98	[1]	[1]	130	42	76	31	2	1
May	480	57	[1]	[1]	30	19	30	12	2	1
June	650	141	[1]	[1]	120	51	80	30	1	0
July	400	48	[1]	[1]	215	46	120	35	2	1
August	180	23	[1]	[1]	50	17	18	9	0	0
September	26	16	24	14	[1]	[1]	25	6	0	0
October	14	10	15	10	11	9	8	4	0	0
November	11	9	11	8	10	8	6	4	0	0
December	600	63	110	31	80	28	50	15	3	0
1910.										
January	3,000	357	200	58	150	53	115	30	5	2
February	3,000	143	150	55	120	50	100	36	7	4
March	210	36	100	35	95	38	100	43	9	5
April	350	55	100	25	55	18	25	8	1	0[2]
May	300	33	55	19	50	17	28	13	1	0[2]
June	1,500	246	180	42	110	37	50	16	1	0[2]
Fiscal years.										
1905-06[2]	1,750	133	500	70	450	47	180	31	20	5
1906-07	1,530	114	250	46	150	37	250	29	13	2
1907-08	3,000	117	340	53	250	45	160	31	20	2
1908-09	1,500	79	200	50	170	32	85	22	8	1
1909-10	2,100	86	200	30	215	29	120	18	9	1

[1] Reservoirs out of service.

[2] October to June 30th.

TABLE 4—BACTERIA.
Averages by Months.

Month.	Reservoirs:				
	Dalecarlia Inlet.	Dalecarlia Outlet.	Georgetown Outlet.	McMillan Park Outlet.	Filtered water.
1905.					
October	...	...	...	210	80
November	...	...	...	150	27
December	...	15,500	...	3,800	60
1906.					
January	...	2,800	...	1,500	39
February	2,900	4,100	1,800	550	16
March	1,800	1,100	900	650	19
April	3,300	1,700	700	400	22
May	425	210	95	65	17
June	7,900	4,600	325	220	17
July	13,500	600	475	160	26
August	8,700	1,100	1,200	190	14
September	425	250	140	135	14
October	2,300	950	650	270	16
November	1,800	1,100	1,200	220	12
December	6,900	3,800	3,600	700	45
1907.					
January	4,400	2,400	2,200	950	70
February	1,000	950	1,000	700	45
March	11,500	8,300	7,200	3,600	65
April	3,700	2,100	1,400	475	21
May	750	350	325	130	26
June	2,300	1,000	600	100	18
July	2,700	575	350	160	17
August	3,000	275	425	80	17
September	6,200	[1]	1,900	230	32
October	1,400	[1]	950	275	27
November	8,900	[1]	6,600	1,500	27
December	16,000	[1]	9,600	4,300	190
1908.					
January	11,000	8,700	9,400	3,700	190
February	11,500	6,000	5,000	2,800	75
March	4,600	4,000	2,900	1,300	30
April	700	450	250	120	13
May	9,500	1,100	650	325	17
June	750	120	110	95	12
July	4,900	...	400	150	8
August	1,600	325	300	100	12
September	325	[1]	200	80	11
October	375	[1]	325	140	8
November	550	[1]	300	200	12
December	800	750	375	170	23
1909.					
January	11,000	2,700	1,600	700	31
February	8,000	3,500	2,400	1,300	60
March	3,800	[1]	2,600	1,000	39
April	2,200	[1]	1,400	550	12
May	900	[1]	350	140	16
June	3,400	[1]	1,200	170	21
July	550	[1]	500	250	33
August	400	[1]	325	55	18
September	325	240	[1]	70	18
October	350	275	250	130	20
November	600	500	500	180	13
December	21,000	9,100	5,900	4,500	250
1910.					

January	76,000	78,000	88,000	52,000	800
February	45,000	35,500	31,000	17,500	350
March	9,900	7,600	7,400	4,800	80
April	7,900	4,100	3,500	650	29
May	1,230	810	830	448	28
June	3,660	930	800	324	27
Fiscal years:					
1905-06	3,300[2]	4,300[3]	750[4]	850[2]	33[2]
1906-07	4,900	1,900	1,700	650	31
1907-08	6,360	2,700	2,900	1,300	55
1908-09	3,400	2,000	950	400	21
1909-10	14,300	13,900	10,900	6,890	143

[1] Reservoirs out of service.

[2] October to June 30th.

[3] December to June 30th.

[4] February to June 30th.

Table 5—Results of Tests for *Bacillus Coli.* Percentage Positive.

Month.	Great Falls, or Dalecarlia Reservoir Inlet.			Dalecarlia Reservoir Outlet.			Georgetown Reservoir.			McMillan Park Reservoir (applied water).			Filtered water reservoir.		Tap water from various parts of cit	
	10 c.c.	1 c.c.	0.1 c.c.	10 c.c.	1 c.c.	0.1 c.c.	10 c.c.	1 c.c.	0.1 c.c.	10 c.c.	1 c.c.	0.1 c.c.	10 c.c.	1 c.c.	10 c.c.	1 c.
1906.																
January[1]	55.6	38.9	22.2	69.2	23.1	7.7	56.0	40.0	8.0	55.6	22.2	0	7.2	0	...	
February	33.3	26.7	6.7	26.1	17.4	8.7	30.4	13.0	4.4	8.3	4.2	0	0	0	...	
March	50.0	12.5	0	45.5	18.2	0	20.8	8.3	0	18.5	7.4	3.7	0	0	0	
April	72.2	33.3	16.7	95.5	50.0	4.6	59.1	22.7	4.6	32.0	8.0	0	4.0	0	0	
May	20.0	8.0	4.0	20.0	12.0	0	7.8	0	0	0	0	0	0	0	0	
June	57.7	38.5	19.2	40.0	32.0	8.0	50.0	34.6	0	23.1	7.7	3.8	0	0	3.1	
July	65.0	50.0	5.0	60.0	25.0	10.0	15.0	5.0	5.0	9.5	0	0	4.8	0	...	
August	84.6	69.2	61.5	88.5	65.4	34.6	80.0	57.7	23.1	63.0	33.3	0	7.4	3.7	11.9	5
September	50.0	10.0	0	30.0	10.0	10.0	40.0	10.0	0	32.0	12.0	0	8.0	0	3.1	
October	60.0	30.0	10.0	55.5	33.3	0	80.0	60.0	20.0	48.1	22.2	3.7	3.7	0	13.0	3
November	37.5	0	0	25.0	12.5	12.5	37.5	25.0	0	20.0	12.0	0	8.0	0	0	
December	55.5	44.5	0	66.7	44.5	22.2	66.7	22.2	0	20.8	8.3	4.2	16.7	8.3	7.5	
1907.																
January	77.8	33.3	22.2	66.7	33.3	0	55.5	55.5	22.2	69.3	34.6	3.8	19.2	11.5	14.0	
February	37.5	25.0	0	12.5	0	0	37.5	12.5	0	17.4	4.4	0	0	0	2.9	
March	87.5	50.0	0	75.0	37.5	0	50.0	25.0	0	30.8	7.7	0	0	0	2.1	
April	44.5	11.1	11.1	66.7	22.2	11.1	77.8	11.1	11.1	46.1	19.2	3.8	3.8	0	3.2	
May	91.3	65.2	17.4	88.9	33.3	0	87.5	50.0	12.5	23.1	0	0	0	0	1.4	
June	80.0	68.0	24.0	87.5	62.5	0	66.7	44.5	11.1	40.0	8.0	0	0	0	0	
July	42.3	30.8	19.2	25.0	12.5	0	22.2	22.2	0	3.8	0	0	0	0	1.4	1
August	48.1	29.6	3.7	33.3	16.7	16.7	36.4	18.2	0	14.8	3.7	0	0	0	0	
September	62.5	54.1	25.0	...	...	...	41.7	33.3	16.7	16.0	4.0	0	4.0	0	1.7	
October	51.9	40.8	7.4	...	...	...	53.3	40.0	6.7	38.7	25.8	9.7	6.5	0	12.5	2
November	80.0	64.0	24.0	...	...	...	72.7	54.5	0	58.6	17.3	3.5	0	0	4.9	
December	56.0	48.0	16.0	...	...	...	46.2	38.5	7.7	45.2	29.0	0	19.3	3.2	12.9	4
1908.																
January	46.2	30.8	15.4	50.0	12.5	0	33.3	0	0	22.6	9.7	3.2	3.2	0	1.9	1
February	12.5	0	0	25.0	0	0	12.5	0	0	0	0	0	0	0	0	
March	38.5	19.2	7.7	44.4	11.1	0	11.1	0	0	9.7	0	0	0	0	0	
April	15.4	7.7	0	0	0	0	0	0	0	6.7	3.3	0	0	0	0	
May	76.0	52.0	40.0	87.5	50.0	12.5	33.3	22.2	0	45.1	16.2	0	0	0	0	
June	7.7	0	0	0	0	0	11.1	0	0	0	0	0	0	0	0	
July	26.9	15.4	11.5	22.2	22.2	0	11.1	0	0	6.4	6.4	0	0	0	0	
August	46.2	26.9	3.9	44.4	33.3	0	62.5	25.0	12.5	12.9	3.2	0	0	0	1.6	
September	20.0	8.0	4.0	42.9	28.6	1.4	22.2	11.1	0	16.7	10.0	0	0	0	4.3	
October	18.4	3.7	0	0	0	0	9.1	0	0	9.7	6.4	3.2	0	0	0	
November	13.0	0	0	28.6	0	0	11.1	0	0	6.6	0	0	0	0	0	
December	11.5	7.7	3.8	0	0	0	12.5	0	0	3.2	0	0	0	0	0	
1909.																
January	12.0	8.0	0	30.0	10.0	0	0	0	0	3.2	3.2	0	3.2	0	0	

February	52.1	47.8	47.8	28.6	14.3	0	37.5	0	0	7.1	3.6	3.6	0	0	3.4	3
March	69.4	34.6	3.8	50.0	25.0	0	44.5	11.1	0	32.3	19.4	3.2	6.5	0	2.8	1
April	42.3	15.4	3.9	33.3	22.2	11.1	44.4	22.2	11.1	36.6	10.0	0	0	0	0	
May	88.4	26.1	4.3	50.0	12.5	0	33.3	0	0	12.9	3.2	0	0	0	0	
June	85.0	60.0	25.0	60.0	40.0	10.0	44.4	33.3	11.1	53.3	20.0	0	0	0	1.4	
July	34.8	8.7	4.4	...	...	...	33.3	11.1	0	25.8	12.9	0	0	0	0	
August	50.0	15.4	7.7	...	...	...	40.0	10.0	0	22.6	6.5	3.2	0	0	0	
September	43.5	21.8	8.7	25.0	25.0	12.5	0	0	0	13.3	3.3	0	0	0	0	
October	36.4	13.6	0	18.2	0	0	0	0	0	3.2	0	0	0	0	0	
November	4.5	0	0	10.0	0	0	0	0	0	0	0	0	0	0	0	
December	38.5	23.1	7.7	36.4	36.4	18.2	33.3	22.2	11.1	29.0	22.6	0	9.7	6.5	7.3	1
1910.																
January	72.0	48.0	24.0	44.5	33.3	11.1	75.0	25.0	0	61.3	35.5	9.7	5.8	3.2	15.9	3
February	47.8	43.5	17.4	63.2	21.1	5.3	40.0	30.0	5.0	32.2	7.1	0	3.6	0	0	
March	33.3	14.8	0	30.8	11.1	3.7	29.6	22.2	7.4	12.9	3.2	0	0	0	0	
April	41.7	33.3	20.8	40.0	32.0	16.0	38.5	23.1	15.4	23.3	13.3	0	0	0	0	
May	47.8	17.4	0	52.0	20.0	0	36.0	16.0	4.0	16.1	12.9	0	0	0	0	
June	95.5	86.4	31.8	80.8	46.2	19.2	64.0	28.0	8.0	43.3	6.7	0	0	0	1.4	
Fiscal years:																
1905-06	35.2	19.4	9.3	0.0	3.2	5.2	6.4	4.9	1.7	4.3	8.3	.8	.3	1.8	1.3	
1906-07	61.5	43.6	9.2	7.7	9.2	2.3	1.1	9.8	0.7	2.5	3.0	.4	.5	2.1	5.4	1
1907-08	44.6	31.3	3.0	2.3	2.3	3.1	4.4	2.1	4.1	2.2	9.4	.4	.8	0.3	3.1	0
1908-09	38.9	20.3	8.4	0.0	5.0	0	7.4	8.5	2.8	6.7	7.1	.8	.8	0	1.2	0
1909-10	45.5	26.9	0.1	5.3	4.0	8.8	7.9	9.8	6.2	3.6	0.4	.1	.3	0.8	2.2	0

[1] Presumptive tests.

Table 6—Summary of Sanitary Chemicals Analyses of Weekly Samples, July 1st, 1909, to June 30th, 1910.
(Results in Parts per Million.)
(*A*) Maximum.

Reservoirs.	Turbidity[1]	Ammonia.			Nitrogen as:		Hardness	Alkalinity	Chlorine
		Free	Albuminoid	Total	Nitrites	Nitrates			
Dalecarlia inlet	2,100	0.034	0.264	0.280	0.0070	0.45	120.0	106.0	5.4
Dalecarlia outlet[2]	200	0.034	0.180	0.206	0.0050	0.70	115.0	105.8	5.7
Georgetown outlet[3]	215	0.030	0.182	0.182	0.0060	0.60	115.0	105.0	4.9
McMillan Park outlet	120	0.028	0.126	0.154	0.0060	0.65	118.0	104.4	4.2
Filtered water	9	0.016	0.078	0.086	0.0010	0.70	119.5	106.3	4.5

Table 6—(*Continued.*)
(*B*) Minimum.

Reservoirs.	Turbidity[1]	Ammonia.			Nitrogen as:		Hardness	Alkalinity	Chlorine
		Free	Albuminoid	Total	Nitrites	Nitrates			
Dalecarlia inlet	7	0.000	0.016	0.016	0.0000	0.00	52.9	39.5	1.0
Dalecarlia outlet[2]	7	0.000	0.040	0.040	0.0000	0.00	54.3	38.2	0.9
Georgetown outlet[3]	7	0.000	0.044	0.044	0.0000	0.00	51.4	40.6	0.7
McMillan Park outlet	2	0.000	0.010	0.010	0.0010	0.00	51.4	38.5	0.2
Filtered water	0	0.000	0.000	0.000	0.0000	0.00	52.9	40.3	0.4

Table 6—(*Continued.*)
(*C*) Average.

Reservoirs.	Turbidity[1]	Ammonia.			Nitrogen as:		Hardness	Alkalinity	Chlorine
		Free	Albuminoid	Total	Nitrites	Nitrates			
Dalecarlia inlet	86	0.006	0.167	0.113	0.0027	0.19	93.2	81.4	2.9
Dalecarlia outlet[2]	30	0.008	0.106	0.114	0.0023	0.18	95.5	79.5	3.4
Georgetown outlet[3]	29	0.005	0.101	0.106	0.0027	0.18	93.4	80.9	2.9
McMillan Park outlet	18	0.004	0.077	0.081	0.0027	0.17	94.0	83.0	2.7
Filtered water	1	0.002	0.027	0.029	0.0000	0.19	94.9	84.0	2.8

[1] Summary of daily samples of water.

[2] Reservoir out of service from July 1st to September 13th, 1909.

[3] Reservoir out of service from September 10th to October 4th, 1909.

No chemical determinations were made during February, March, April, and May, 1910, on account of the rearrangement of the laboratory and equipment.

Table 7—Daily Results at Pumping Station.

(*A*)

Month.	Million gallons pumped:						Lift to filters.	Pressure at sandwasher pumps, per square inche.	Coal consumed per day in tons.			Station duty, per 100 lb. of coal consumed.		
	To filters.			To sand washers.										
	Max.	Min.	Ave.	Max.	Min.	Ave.			Max.	Min.	Ave.	Max.	Min.	Ave.
1909.														
July	76.16	57.65	64.05	1.140	0.298	0.730	24.18	110.0	13.4	8.4	10.8	67.8	52.3	61.4
August	69.31	54.44	61.42	0.629	0.157	0.441	22.18	110.0	12.4	8.0	10.1	64.2	49.5	56.6
September	66.02	52.82	69.32	0.831	0.207	0.572	22.26	110.0	12.7	8.7	10.5	61.0	48.9	55.1
October	78.50	48.12	59.18	0.761	0.060	0.467	21.84	110.0	13.4	8.0	10.3	59.6	49.1	53.6
November	64.92	49.83	55.25	0.468	0.141	0.272	20.49	110.0	11.3	7.9	9.2	55.6	45.7	51.1
December	67.83	48.32	56.77	0.307	0.039	0.174	20.54	110.0	10.3	8.5	9.5	61.0	45.4	50.4
1910.														
January	70.04	51.02	62.49	0.499	0.008	0.156	22.43	110.0	12.7	9.1	10.4	59.6	49.8	54.9
February	70.79	55.19	60.28	0.284	0.041	0.173	21.44	112.3	12.3	8.7	10.2	57.4	44.8	51.5
March	59.11	51.64	56.04	0.409	0.063	0.171	19.76	120.0	10.5	7.8	9.2	53.2	45.2	49.8
April	66.53	53.79	58.32	0.715	0.167	0.474	20.78	120.0	11.1	8.1	9.7	58.7	47.2	53.7
May	61.93	54.55	57.76	0.525	0.059	0.251	20.30	120.0	10.1	7.4	8.8	60.7	48.1	54.9
June	70.49	50.42	58.37	0.281	0.124	0.207	21.19	117.3	12.3	7.4	9.1	60.1	49.9	54.4
Fiscal years:														
1909-10	78.50	48.12	59.19	1.140	0.008	0.373	21.45	113.3	13.4	7.4	9.8	67.8	44.8	54.0
1905-06[1]	80.59	57.18	66.07	2.062	0.089	0.747	21.71	107.4	14.8	6.4	8.9	79.6	48.2	62.8
1906-07	80.29	57.44	66.89	2.120	0.023	0.580	21.60	120.8	15.0	7.0	10.0	71.6	46.5	58.6
1907-08	80.38	54.35	64.91	0.735	0.017	0.347	22.20	125.0	12.0	7.2	9.6	70.7	51.3	60.3
1908-09	78.93	47.83	61.47	0.875	0.060	0.453	22.52	122.3	13.2	7.0	10.0	74.0	45.7	57.7

Table 7—(*Continued.*)

(*B*)

Fiscal Year.	Name of coal used.	Cost per ton.	Duty per 100 lb. of coal consumed.	Cost of coal per 1,000,000 ft-lb. of work performed.
1905-06	George's Creek Big Vein	$3.34	62.8	$0.00238
1906-07	George's Creek Big Vein	3.43	58.6	0.00261
1907-08	George's Creek Big Vein	3.75	60.3	0.00278
1908-09	Orenda	3.47	57.7	0.00268
1909-10	Orenda	3.15[2]	54.0	0.00255

[1] Raw water shut off from city supply on October 5th.

[2] Corrected for increase or decrease in ash and British thermal units, as determined by United States Geological Survey.

Table 8.—Average Consumption of Water for Twenty-Four Hours, Per Million Gallons.

Month.	Fiscal years.							
	1903.	1904.	1905.	1906.	1907.	1908.	1909.	1910.
July	59.80	61.50	63.20	69.80	69.18	68.64	71.08	64.05
August	59.00	59.70	67.70	71.40	68.03	67.74	68.14	61.42
September	56.50	61.10	67.90	71.30	69.82	68.93	65.83	60.32
October	58.70	59.10	63.90	68.40	69.14	66.46	65.89	59.18
November	54.70	58.60	62.10	66.10	65.51	61.54	60.06	55.25
December	60.70	60.10	70.30	67.20	65.71	62.29	57.99	56.77
January	60.10	65.30	75.10	65.30	67.62	63.36	57.72	62.49
February	59.30	67.80	86.00	68.70	74.68	68.17	55.42	60.28
March	55.30	60.00	67.60	64.30	64.23	59.63	55.31	56.04
April	55.10	57.20	63.10	62.70	63.45	61.51	58.19	58.32
May	57.70	60.80	66.30	65.60	62.47	62.96	59.25	57.76
June	59.50	62.30	70.60	67.80	63.53	67.96	60.12	58.37
Average	58.03	61.10	68.70	67.40	66.90	64.91	61.47	59.19

The length of runs, depth of scraping, etc., after the scraping or raking, are shown in Tables 10 and 11.

Sand Handling.—For the first three years of operation, the sand was carried from the sand bins in carts and dumped through the numerous manholes of the filters on chutes which could be revolved in various directions, in order to facilitate the spreading of the sand evenly over the surface of the filter.

About a year ago, however, this method was changed, by substituting sand ejectors for the carts. By this method, an ejector is either attached to, or placed directly under, the outlet gate of the sand bin, the gate is opened, and the ejector is started. From this ejector, the sand is carried back through the line of 4-in. fixed pipe, and one or more lengths of 3-in. hose, to the point of discharge in the filter bed which is being re-sanded.

Table 9.

(*A*) Number of Deaths from Typhoid Fever, by Months, in the District of Columbia for the Last Fourteen Fiscal Years.

Fiscal year.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Total.
1896-97	8	15	25	25	18	16	13	4	4	4	6	9	147
1897-98	10	16	18	10	9	18	8	4	2	9	6	20	130
1898-99	24	22	22	28	21	16	10	4	7	6	3	6	169
1899-1900	9	38	30	28	27	26	17	6	8	10	5	12	193
1901-02	16	33	28	21	22	16	19	8	12	9	13	9	206
1902-03	21	39	25	32	19	20	9	5	9	6	6	3	194
1903-04	17	26	18	19	8	14	5	5	6	10	8	8	144
1904-05	16	22	25	14	11	9	11	1	5	7	1	3	125
1905-06[1]	15	30	23	26	14	6	6	4	5	4	10	9	152
1906-07	21	32	21	25	17	4	7	6	4	6	7	2	152
1907-08	10	18	17	19	11	7	4	1	1	8	8	3	107
1908-09	15	13	23	17	16	13	16	8	3	8	7	7	146
1909-10	12	12	17	12	12	2	3	4	7	5	5	4	95
Average	15.3	25.5	22.9	21.5	16.6	13.1	9.6	4.4	5.8	6.7	6.4	7.5	155.4

Table 9—(*Continued.*)

(*B*) Number of Deaths from Typhoid Fever Reduced to Death Rates per 100,000 Inhabitants per Year.

Fiscal year.	July.	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	Annua death rate.
1896-97	35	65	109	109	78	70	56	17	17	17	26	39	5
1897-98	43	69	78	43	39	78	31	17	8	38	25	85	4
1898-99	102	93	93	119	89	68	42	17	29	25	12	26	5
1899-1900	37	158	125	116	112	108	69	24	33	41	20	49	7
1900-01	82	167	118	102	114	69	28	8	32	8	16	40	6
1901-02	64	132	112	84	88	64	75	31	47	35	51	35	6
1902-03	83	153	98	126	75	79	35	19	35	23	23	12	6
1903-04	66	100	69	73	31	54	19	19	23	38	30	30	4
1904-05	61	83	95	53	42	34	41	4	19	26	4	11	3
1905-06	56	111	85	97	52	22	22	15	18	15	36	33	4
1906-07	69	105	69	82	56	13	24	20	13	20	24	7	4
1907-08	35	64	60	67	39	25	14	4	4	28	28	11	3
1908-09	53	45	80	60	56	45	56	28	10	28	24	24	4
1909-10	42	42	60	42	42	7	11	14	24	17	17	14	2
Average monthly death rate.	59	99	89	84	65	53	38	24	22	26	24	30	.

[1] Filtered water supplied since October, 1905.

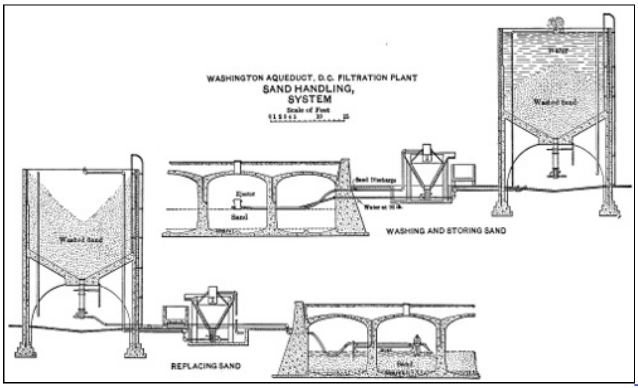

Figure 3—Washington Aqueduct, D. C., Filtration Plant. Sand Handling, System.

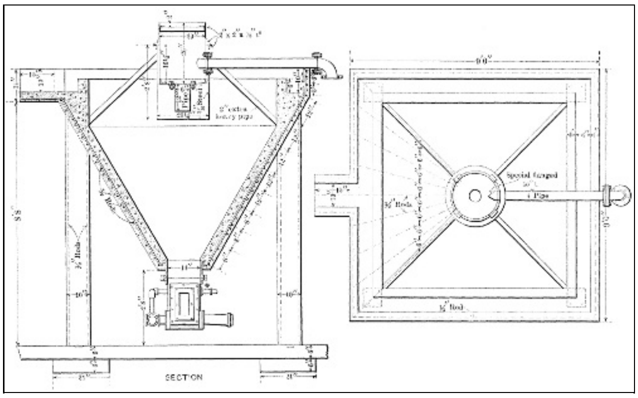

Figure 4—Washington Aqueduct, D. C., Filtration Plant. Washer Sand-Handling, System.

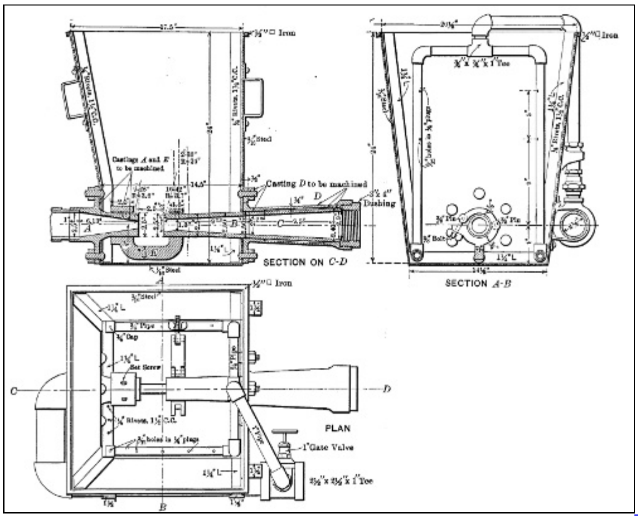

Figure 5—Washington Aqueduct, D. C., Filtration Plan. Ejector Sand-Handling, System.

Table 10—Periods of Operation, and Quantities Filtered.

Month.	Number of filter runs ended after:		Number of days since previous:						Million gallons filtered since previous:					
			Scraping.			Raking			Scraping.			Raking		
	Scraping.	Raking.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
1909.														
July	14	0	89	44	67.4	0	0	0	229.01	106.27	163.289	0	0	0
August	8	0	74	51	60.4	0	0	0	175.54	124.94	152.581	0	0	0
September	13	0	98	53	68.3	0	0	0	237.52	114.37	161.702	0	0	0
October	18	5	81	32	59.9	43	33	39.4	206.09	78.78	132.359	96.50	71.51	82.708
November	8	2	79	44	53.4	47	37	42.0	168.19	82.32	112.603	99.00	90.23	94.615
December	3	4	62	61	61.3	63	50	57.3	135.77	128.33	132.647	144.35	106.11	125.940
1910.														
January	9	4	95	79	88.0	88	72	77.0	204.38	146.58	178.461	189.48	152.33	170.735
February	1	4	99	99	99.0	93	51	71.0	205.73	205.73	205.730	192.98	118.85	158.890
March	3	4	120	110	113.7	108	101	104.3	275.96	257.36	265.493	249.68	224.49	238.993
April	10	12	126	62	84.8	129	21	65.3	295.96	104.13	181.972	307.57	45.22	142.448
May	3	2	86	38	69.7	55	32	43.5	186.64	81.66	150.230	102.15	69.79	85.978
June	13	2	100	61	79.7	129	78	103.5	213.70	130.85	171.059	181.25	167.84	174.540
Year 1909-10	103	39	126	32	71.1	129	21	66.6	295.96	81.66	159.151	307.57	45.22	143.832
Fiscal years:														
1905-06	71	0	195	38	91.1	0	0	0	497.45	116.66	240.379	0	0	0
1906-07	101	4	199	24	77.0	32	14	21.7	466.12	69.76	220.693	103.28	32.13	76.870
1907-08	143	77	180	11	54.9	63	7	28.6	477.19	28.20	146.912	165.25	17.08	75.775
1908-09	128	50	135	11	49.9	93	13	34.2	298.08	39.26	125.617	244.19	41.41	88.439

In re-sanding a filter, it is first filled with water to the proposed depth of the sand layer. The outlet end of the hose is connected to a 3-in. pipe which is supported on a boat, and the sand is discharged through this pipe at the point required. Work is first begun at the far end of the filter, and it is gradually filled by swinging the boat from side to side and backing it by degrees to the front end.

At first it was feared that a small quantity of mud would be deposited on the surface of the old sand, and that this mud would ultimately cause subsurface clogging. For this reason, when this method was first adopted, a man was required to rake the sand very thoroughly in front of the discharge. Later, it was found that by giving the end of the discharge pipe a slope of about 45° downward from the horizontal, the force of the current of sand and water could be depended on to cut the old surface of sand to any required depth, and move it ahead together with the new sand, thus completely breaking up the possible mud layer between the old and new sand layers. After having used this method almost exclusively for 15 months, in which time eleven filters have been re-sanded, and 24,531 cu. yd. of sand have been replaced, there seems to be no indication of an increased initial loss of head. The sand is very compact, and has no apparent tendency to separate into different sizes. The general appearance is similar to that of very fine sand on the seashore. The filters re-sanded in this way have been considerably more efficient than those in which the sand was replaced with carts, and as yet, no harmful results have been noted. The rate at which the sand is replaced is shown in Table 12, and the cost of labor for sand handling is given in detail in Table 14, which shows that quite a perceptible saving has been effected by the hydraulic method.

The figures showing the cost for sand handling do not include any charge for the quantity of water used, that item having been carried on the pumping-station account.

TABLE 11—QUANTITIES OF SAND REMOVED.

Month.	No. of filters scraped when last treatment was:		Cubic yards when last treatment was:						Depth, in inches, when last treatment was:					
	Scraping.	Raking.	Scraping.			Raking.			Scraping.			Raking.		
			Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
1909.														
July	14	0	338	121	190.6	0	0	0	2.51	0.90	1.415	0	0	0
August	8	0	356	149	218.5	0	0	0	2.65	1.11	1.631	0	0	0
September	8	0	524	97	178.6	0	0	0	3.90	0.72	1.330	0	0	0
October	9	5	150	93	115.8	301	121	169.0	1.12	0.69	0.862	2.24	0.90	1.256
November	2	2	134	88	111.0	132	81	106.5	1.00	0.65	0.825	0.98	0.60	0.790
December	0	2	0	0	0	133	126	129.5	0	0	0	0.99	0.94	0.965
1910.														
January	2	4	155	112	133.5	195	121	147.8	1.15	0.83	0.990	1.45	0.90	1.100
February	0	4	0	0	0	390	160	225.8	0	0	0	2.90	1.19	1.678
March	1	4	489	489	489.0	262	179	214.3	3.64	3.64	3.640	1.95	1.33	1.593
April	4	12	172	84	119.3	230	146	178.8	1.28	0.62	0.885	1.71	1.09	1.331
May	1	2	320	320	320.0	249	241	245.0	2.38	2.38	2.380	1.85	1.79	1.820
June	0	2	0	0	0	203	190	196.5	0	0	0	1.51	1.41	1.460
Year 1909-10	49	37	524	84	176.7	390	81	181.0	3.90	0.62	1.314	2.90	0.60	1.373
Fiscal Years:														
1905-06	71	0	600	71	250.0	0	0	0	4.47	0.53	1.799	0	0	0
1906-07	94	2	536	52	259.0	398	276	337.0	4.00	0.56	1.931	2.95	2.05	2.500
1907-08	81	53	527	46	190.2	411	35	118.4	3.92	0.21	1.507	3.06	0.21	0.881
1908-09	92	50	580	55	169.5	472	81	177.5	4.31	0.41	1.259	3.51	0.60	1.317

TABLE 12—RATES OF SAND HANDLING.

Date	Sand removed from filters.			Sand replaced in filters.		
	Ejector hours.	Cubic yards of sand removed	Average rate in cubic yards per hour	Ejector hours.	Cubic yards of sand removed	Average rate in cubic yards per hour
1906.						
April	49	253	5.2	...	...	...
May	380	2,511	6.6	...	...	...
June	567	3,280	5.8	...	...	...
July	931	5,376	5.8	...	...	...
August	105	533	5.1	...	...	...
September	315	1,892	6.0	...	...	...
October	1,067	5,173	5.8	...	...	...
November	168	935	5.6	...	...	...
December	203	1,073	5.3	...	...	...
1907.						
January	399	2,974	7.3	...	...	...
February	140	1,139	8.1	...	...	...
March	115	878	7.6	...	...	...
April	427	3,103	7.3	...	...	...
May	133	939	7.0	...	...	...
June	105	674	6.4	...	...	...
July	7	46	6.6	...	...	...
August	90	574	6.4	...	...	...
September	306	1,396	6.5	...	...	...
October	273	1,701	6.2	...	...	...
November	202	1,258	6.8	...	...	...

December	304	2,138	5.9	...	...	...
1908.						
January	546	3,708	6.8	...	...	...
February	98	776	7.9	...	...	...
March	315	2,832	9.0	...	...	...
April	469	3,775	8.1	...	...	...
May	182	1,414	7.8	...	...	...
June	280	2,057	7.4	...	...	...
July	280-1/2	2,683	9.6	...	...	...
August	327-1/2	2,808	8.6	...	...	...
September	402	3,371	8.4	...	...	...
October	308	2,696	8.7	...	...	...
November	47-1/2	333	7.0	...	...	...
December	153-3/4	1,268	8.3	...	...	...
1909.						
January	119-1/2	1,055	8.8	...	...	...
February	161-1/2	1,479	9.2	...	...	...
March	144	1,465	10.2	...	...	...
April	214-3/4	2,260	10.5	188	2,405	12.8
May	219-3/4	2,223	10.1	190	2,196	11.5
June	355	3,096	8.7	243	3,054	12.6
July	312-1/4	2,707	8.7	425-1/2	4,050	9.5
August	218-3/4	1,955	9.0	64-1/2	620	9.6
September	172-1/2	1,360	7.9	408	2,842	7.0
October	203	1,870	9.2	261-1/4	2,350	9.0
November	54	397	7.4	0	0	...
December	62	382	6.2	0	0	...
1910.						
January	104	703	6.8	0	0	...
February	106-1/2	1,058	9.9	28-1/4	371	13.1
March	98	985	10.0	72	1,008	14.0
April	268-3/4	2,852	10.7	134-1/4	2,159	16.1
May	58-3/4	693	11.8	171-3/4	3,042	17.7
June	58-3/4	642	10.9	9-3/4	166	17.0

The cost for pumping water for sand handling, including all labor, materials, and repairs, amounts to $0.06 per cu. yd. of sand ejected and washed, and $0.03 per cu. yd. for replacing.

In addition to the water used for carrying the sand which is being replaced, it is customary to keep a slight upward flow in the filter, thus using about 500,000 gal. of filtered water per day for this purpose. Assuming the value of this water to be the total cost for pumping, filtering, etc., or $3.80 per 1,000,000 gal., the cost per cubic yard of sand replaced would be about $0.02 when one ejector is used, and $0.01 when two are in operation.

It is not considered absolutely necessary to have an upward flow of water in the filter which is being re-sanded, and it is not always done. It was used, however, as an additional safeguard against the formation of a stratum of mud between the old and new layers of sand while the hydraulic method was in an experimental stage.

The quantities of sand removed from the filters per scraping and the rates of sand handling are shown in Tables 11 and 12.

Cost of Operation.—It is frequently difficult to compare the relative cost of corresponding items for different plants, because of the different methods of dividing the cost and the varying opinions of the officials as to what should properly be charged to each item.

In order that the data may be in sufficient detail to permit it to be rearranged to compare with other plants, a list of employees and charges for supplies is given in Table 13. This list accounts for the entire appropriation for the care and maintenance of the filtration plant, including pumping the water to the filters, parking and caring for the grounds, buildings, roads, sidewalks, etc. The cost for the various items per million gallons pumped to the filters is shown in Table 14, and the cost per cubic yard of sand handled in Table 15.

Preliminary Treatment.—Before the present filtration plant was designed, Rudolph Hering, George W. Fuller, and Allen Hazen, Members, Am. Soc. C. E., made an investigation and report. This report was dated February 18th, 1901, and contained the following paragraph:

> "In consideration of the full evidence, we recommend the construction of a complete system of slow or sand filters, with such auxiliary works as may be necessary for preliminary sedimentation, and the use of a coagulant for part of the time. There is no reason to believe that the use of this coagulant will in any degree affect the wholesomeness of the water."

Notwithstanding this opinion, considerable prejudice existed among the citizens of Washington against the use of a coagulant, and, as finally passed, the bill providing for the construction of the filters did not include an appropriation for the coagulant.

Table 13—List of Employees, Rates of Pay, and Approximate Cost for Supplies.

1 Superintendent	$3,000.00
1 Chief Chemist and Assistant Superintendent	2,100.00
1 First Assistant Chemist	1,500.00
1 Second Assistant Chemist	1,000.00
1 Stenographer and Clerk	1,200.00
1 Surveyor	1,200.00
1 Laboratory Helper	720.00
1 Janitor	600.00
1 Chief Steam Engineer	1,800.00
1 First Assistant Steam Engineer	1,440.00
1 Second Assistant Steam Engineer	1,080.00
3 Oilers, at $900 each	2,700.00
3 Firemen, at $900 each	2,700.00
3 Laborers, at $540 each	1,620.00
1 Filter Foreman	1,200.00
2 Foremen, at $900 each	1,800.00
1 Timekeeper	900.00
3 Watchmen and Gauge Tenders, at $900 each	2,700.00
1 Machinist	1,140.00
1 Blacksmith	900.00
1 Storekeeper	900.00
1 Painter	900.00
1 Mechanic	900.00
1 Electrician	900.00
4 Skilled Laborers at $600 each	2,400.00
1 Watchman and Special Officer	900.00
1 Recorder	720.00
27 Laborers, at $1.50 per day for 300 days	12,150.00
3 Teams, at $2.00 per day for 200 days	1,200.00
Laboratory and office supplies	2,700.00
Filter supplies, tools, hose, repair of roads, parks, shrubs, etc.	8,820.00
Pumping station supplies, oil, waste, packing, repairs, etc.	3,570.00
3,600 tons of coal, at $3.15 per ton	11,340.00
Charges in U. S. Engineer Office, labor	2,900.00
Charges in U. S. Engineer Office, materials	400.00
Total	$82,000.00

The results obtained from operating the filters being such as to justify the conclusions in the report referred to, an experimental plant was constructed for the purpose of studying the efficiency of various methods of preliminary treatment of the water. This plant consisted of three cylindrical concrete filter tanks, each 10 ft. in diameter. These tanks were filled with the layers of gravel and sand necessary to make them represent as accurately as possible the large slow sand units of the main filtration plant. Means were also provided for giving a preliminary treatment to the water supplying each of these experimental slow sand filters. In two cases, the preliminary treatment was rapid filtration, while the third consisted of sedimentation and coagulation. The sedimentation tank was of sufficient size, when compared with the area of the experimental slow sand filter, to represent the Georgetown and McMillan Park Reservoirs when used in connection with the large filters. The first preliminary filter was very similar in construction and operation to a mechanical filter. The sand for this filter was taken from the main filters, and, consequently, was finer than is generally used in mechanical filters. The second preliminary filter was a Maignen scrubber. It consisted of a cylindrical concrete tank, 4 ft. in diameter and 8-1/2 ft. deep, which contained 12 in. of cobble-stones on the bottom, then, successively, 12 in. of egg-size coke, 12 in. of stove-size coke, 24 in. of nut-size coke, and 24 in. of sponge clippings as the final or top layer.

Table 14—Cost Per Million Gallons Filtered.
(*A*) Labor.

Month.	Office and laboratory.	Pumping station.	Filter Operations:		Parking (care of grounds).	Experimental filters.	Main office.	Total.
			Sand handling.	Repairs, etc.				
1909.								
July	$0.73	$0.57	$0.86	...	$0.31	...	$0.15	$2.62
August	0.75	0.64	0.59	...	0.71	...	0.14	2.83
September	0.83	0.67	0.80	...	0.51	...	0.17	2.98
October	0.72	0.66	0.73	...	0.34	...	0.08	2.53
November	0.87	0.76	0.42	...	0.38	...	0.18	2.61
December	0.90	0.69	0.27	...	0.40	...	0.12	2.38
1910.								
January	0.81	0.63	0.33	...	0.14	...	0.10	2.01
February	0.94	0.74	0.35	$0.07	0.11	...	0.16	2.37

March	0.92	0.81	0.30	0.07	0.18	...	0.13	2.41
April	0.93	0.83	0.49	0.03	0.36	...	0.13	2.77
May	0.86	0.72	0.36	0.03	0.55	...	0.18	2.70
June	0.88	0.67	0.38	...	0.38	...	0.12	2.43
Average	0.84	0.70	0.27	[1]0.25	0.36	...	0.14	2.56
Fiscal years:								
1905-1906	0.45	0.45	0.47	0.02	0.01	...	0.09	1.49
1906-1907	0.57	0.57	0.58	0.21	0.07	$0.03	0.04	2.07
1907-1908	0.70	0.56	0.42	0.32	0.15	0.09	0.09	2.36
1908-1909	0.72	0.61	0.41	0.34	0.22	0.01	0.13	2.44

Table 14—(*Continued.*)
(*B*) Materials.

Month.	Office and laboratory.	Pumping station.	Filter Operations:		Parking (care of grounds).	Experimental filters.	Main office.	Total.
			Sand handling.	Repairs, etc.				
1909.								
July	...	...	$0.01	...	...	...	...	$0.01
August	$0.01	...	...	...	$0.07	...	$0.01	0.09
September	0.05	$0.31	0.04	...	0.01	...	0.03	0.44
October	0.08	0.11	0.13	...	0.46	...	0.02	0.80
November	0.13	0.78	0.10	...	0.34	...	0.02	1.37
December	0.03	0.17	0.05	...	0.01	...	0.05	0.31
1910.								
January	0.12	0.74	0.14	...	0.01	...	...	1.01
February	0.07	1.88	0.18	...	0.01	...	0.01	2.15
March	0.26	0.28	0.01	...	...	...	...	0.55
April	0.18	1.22	0.10	...	0.29	...	0.02	1.81
May	0.06	0.72	0.02	...	0.11	...	0.02	0.98
June	0.54	2.23	...	[2]$2.16	0.46	...	0.04	5.43
Average	0.13	0.69	0.02	[3]0.21	0.17	...	0.02	1.24
Fiscal years.								
1905-1906	0.04	0.59	0.02	...	...	...	...	0.65
1906-1907	0.03	0.67	0.08	0.20	0.02	...	...	1.00
1907-1908	0.05	0.54	0.04	0.07	0.06	...	0.01	0.77
1908-1909	0.10	0.69	0.05	0.18	0.18	...	0.02	1.22

[1] $0.02 for new sand-handling system.
[2] $2.02 for new sand-handling system.
[3] $0.16 for new sand-handling system.

Table 14—(*Continued.*)
(*C*) Totals.

Month.	Office and laboratory.	Pumping station.	Filter Operations:		Parking (care of grounds).	Experimental filters.	Main office.	Total.
			Sand handling.	Repairs, etc.				
1909.								
July	$0.73	$0.57	$0.87	...	$0.31	...	$0.15	$2.63
August	0.76	0.64	0.59	...	0.78	...	0.15	2.92
September	0.88	0.98	0.84	...	0.52	...	0.20	3.42
October	0.80	0.77	0.86	...	0.80	...	0.10	3.33
November	1.00	1.54	0.52	...	0.72	...	0.20	3.98
December	0.93	0.86	0.32	...	0.41	...	0.17	2.69
1910.								
January	0.93	1.37	0.47	...	0.15	...	0.10	3.02
February	1.01	2.62	0.53	$0.07	0.12	...	0.17	4.52
March	1.18	1.09	0.31	0.07	0.18	...	0.13	2.96
April	1.11	2.05	0.59	0.03	0.65	...	0.15	4.58
May	0.92	1.44	0.38	0.03	0.66	...	0.20	3.63
June	1.42	2.90	0.38	2.16	0.84	...	0.16	7.86
Average.	0.97	1.39	0.29	0.46	0.58	...	0.16	3.80
Fiscal years:								
1905-1906	0.49	1.04	0.49	0.02	0.01	...	0.09	2.14

1906-1907	0.60	1.24	0.66	0.41	0.09	$0.03	0.04	3.07
1907-1908	0.75	1.13	0.46	0.39	0.21	0.09	0.10	3.13
1908-1909	0.82	1.30	0.46	0.52	0.40	0.01	0.15	3.66

The two preliminary filters were operated at a rate of about 50,000,000 gal. per acre per day, and the three slow sand filters at rates of from 3,000,000 to 4,000,000 gal. per day.

This plant was put in service during the early part of February, 1907, and was kept in practically continuous operation until the end of July, 1908.

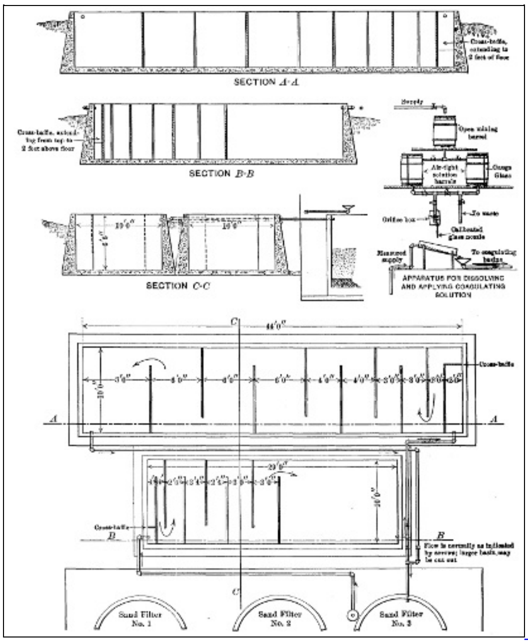

Figure 6—Washington Aqueduct, D. C.
Experimental Filters Below Dalecarlia Reservoir Coagulating Basins and Apparatus.

Table 15—Average Cost for Labor for Sand Handling.
(*A*) Per Million Gallons Pumped To Filter.

Month.	Scraping.	Ejecting.	Washing.	Smoothing.	Raking.	Re-Sanding.	Total.
1909.							
July	$0.10	$0.21	$0.03	$0.02	...	$0.21	$0.57
August	0.07	0.16	0.03	0.01	...	0.04	0.31
September	0.05	0.13	0.02	0.01	$0.01	0.27	0.49
October	0.06	0.15	0.03	0.01	0.02	0.12	0.39
November	0.02	0.06	...	...	0.02	...	0.70
December	0.02	0.04	0.01	...	0.01	0.01	0.09
1910.							
January	0.04	0.07	...	0.01	0.02	...	0.14
February	0.04	0.10	...	0.01	...	0.02	0.17
March	0.04	0.06	...	0.01	0.01	0.05	0.17
April	0.10	0.15	0.04	0.01	0.02	0.06	0.38
May	0.02	0.03	0.01	...	0.01	0.11	0.18
June	0.02	0.04	...	...	0.02	0.01	0.09
Average	0.05	0.10	0.01	0.01	0.01	0.08	0.26
Fiscal years:							
1905-06	0.06	0.29	0.02	0.06	...	0.04	0.47
1906-07	0.07	0.20	0.05	0.02	...	0.24	0.58
1907-08	0.09	0.14	0.03	0.01	0.02	0.13	0.42
1908-09	0.07	0.15	0.03	0.01	0.01	0.14	0.41

Table 15—(*Continued.*)
(*B*) Per Cubic Yard of Sand.

Month.	Scraping.	Ejecting.	Washing.	Smoothing.	Raking.	Re-Sanding.	Total.
1909.							
July	$0.08	$0.15	$0.03	$0.01	...	$0.10	$0.37
August	0.07	0.15	0.03	0.01	...	0.11	0.37
September	0.07	0.17	0.03	0.01	...	0.17	0.45
October	0.06	0.15	0.03	0.01	...	0.09	0.34
November	0.10	0.23	0.02	0.02	...	...	0.37

December	0.12	0.25	0.04	0.02	...	0.08	0.51
1910.							
January	0.10	0.19	...	0.02	...	...	0.31
February	0.07	0.15	...	0.01	...	0.09	0.32
March	0.06	0.11	...	0.02	...	0.08	0.27
April	0.07	0.09	0.03	0.01	...	0.05	0.25
May	0.06	0.09	0.03	0.01	...	0.06	0.25
June	0.06	0.12	...	0.01	...	0.10	0.29
Average	0.07	0.14	0.02	0.01	...	0.10	0.34
Fiscal years:							
1905‘06	0.07	0.35	0.04	0.07	...	0.14	0.67
1906-07	0.06	0.19	0.03	0.02	...	0.17	0.47
1907-08	0.09	0.15	0.03	0.01	...	0.14	0.42
1908-09	0.06	0.14	0.03	0.01	...	0.13	0.37

For convenience in referring to the different systems, the combined rapid and slow sand filter will be designated as Filter Plant No. 1, the combined Maignen scrubber and slow sand filter as Filter Plant No. 2, and the combined coagulating basin and slow sand basin as Filter Plant No. 3.

The length of run of Filter Plant No. 1 was relatively long at first. The rapid rate of filtration, however, tended to carry the clay, which was suspended in the applied water, to a considerable depth in the filtering material, so that the runs gradually decreased in length until they were reduced to about three days. Unfortunately, it was necessary to use unfiltered water for washing, which, together with the great penetration from the applied water, finally made it necessary to remove all the filtering materials, and wash them.

Although this preliminary filter was operated at a high rate, its efficiency was quite satisfactory. In fact, at times when the applied water was comparatively good, very little work was left for the slow sand filter. At times of high turbidity, however, some of the exceedingly fine mud in the applied water passed through this filter, as well as the slow sand filter connected with it, and it proved to be absolutely impossible to produce a clear effluent at all times with this combination.

Filter Plant No. 2 proved more economical and convenient in operation, but somewhat less efficient than Filter Plant No. 1. Neither filter could be depended on to give a clear effluent when the applied water was turbid.

In the operation of Filter Plant No. 3, sulphate of alumina was used when the applied water contained too much turbidity to be treated satisfactorily by slow sand filters.

When the water was comparatively clear, either one of the three systems, or slow sand filtration alone, was entirely satisfactory. At times of high turbidity, however, Filter Plant No. 3 was the only one which could be depended on to produce a clear effluent.

A fair comparison between the results of the three systems when treating turbid water in January, 1908, is given in Table 16.

Table 16 shows very clearly that neither Filter Plant No. 1 nor No. 2 would prove at all satisfactory when treating turbid water, while No. 3 could be depended on under all conditions. The results of operation are shown in detail in Tables 17, 18, and 19. It will be noticed in Table 17, that on March 10th, 1908, Filter Plant No. 1 was put out of service and a Puech system of preliminary filters was substituted for it.

The Puech preliminary filters consisted of five units containing gravel of varying sizes through which the water was filtered successively before it was finally applied to the final slow sand filter. A general idea of this system may be obtained by referring to Figure 8.

Table 16—Turbidity Results with Experimental Filters, During Period of High Turbidity, January, 1908.

Date.	Raw water.	Filter No. 1		Filter No. 2		Filter No. 3	
		Effluent preliminary filter.	Effluent sand filter.	Effluent preliminary filter.	Effluent sand filter.	Effluent coagulant basin.	Effluent sand filter.
January 12th	40	10	1	12	1	2	0
January 13th	110	45	2	51	2	2	0
January 14th	210	95	3	113	4	2	0
January 15th	325	190	12	222	15	3	0
January 16th	360	210	37	247	42	5	0
January 17th	242	122	24	147	26	6	0
January 18th	137	...	...	73	7	6	0
January 19th	117	40	12	cleaning	...	5	0
January 20th	72	31	6	sand filter	...	cleaning	0
January 21st	55	20	4	25	4	sand filter	...
January 22d	49	17	3	21	4	sand filter	...
January 23d	40	12	3	15	3	3	0
January 24th	40	11	3	13	3	3	0

It is unfortunate that this system was not in operation in January, 1908, when the water was cold and turbid. The results, however, indicate that it would be no more successful than either Filter Plant No. 1 or No. 2.

Experimental Rate Studies.—In September, 1908, an experimental plant consisting of six small filters was put in operation. The object of these experiments was to study the relative efficiencies and cost for the operation of slow sand filters when operated at different rates.

The units of the plant consisted of cylindrical galvanized-iron tanks 4 ft. in diameter and 9 ft. high. The filter sand in these tanks was taken from the supply for the main filters. It was supported on gravel layers and supplied with under-drains of suitable sizes for the proposed rate of flow in each case.

The units of the experimental plant were designated as Nos. 1, 2, 3, 4, 5, and 6, and it was the original intention to operate them at rates of 1,000,000, 3,000,000, 6,000,000, 10,000,000, 30,000,000, and 100,000,000 gal. per acre daily, respectively.

This schedule of rates was carried out in a general way with all the filters, with the exception of Nos. 5 and 6. For these, the rates were found to be higher than could be maintained for any great length of time, owing to the deeper penetration of the mud in the filter sand, which caused high initial losses of head, short runs, and deep scrapings. A rate of about 30,000,000 gal. was maintained in the case of Filter No. 5 from the time it was started on September 9th, 1908, until November 8th, 1909, when it was reduced to about 17,000,000 gal., which rate was maintained thereafter until the filter was shut down in February, 1910.

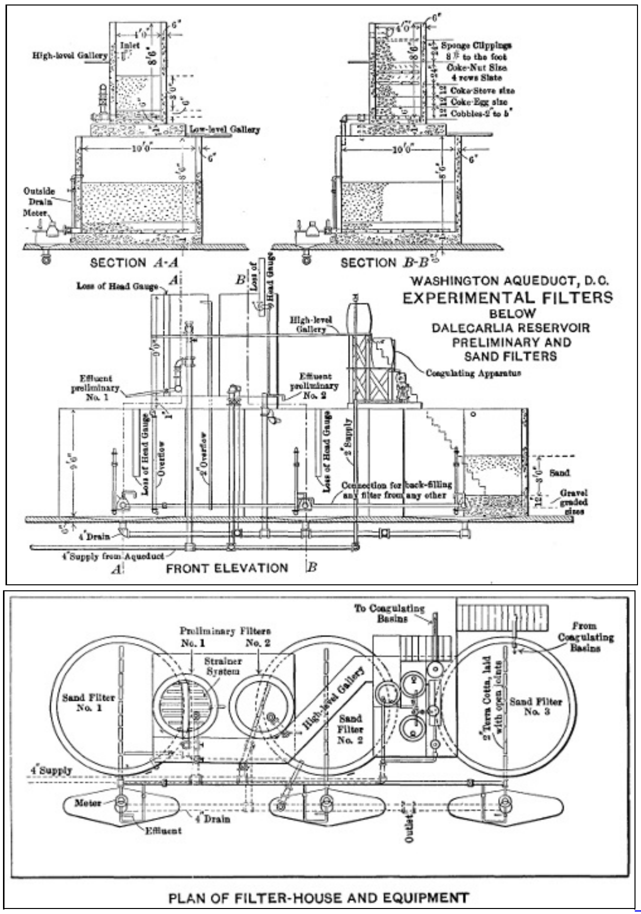

Figure 7—Plan of Filter-House and Equipment.

In the case of Filter No. 6, it was found impossible to maintain a rate of 100,000,000 gal. for more than a very few days at a time. It was started at about this rate, however, at the beginning of each run, and kept as high as possible for the remainder of the time during the first seven runs. At the end of the seventh run, on October 17th, 1908, the filter was given a very deep scraping and re-sanded.

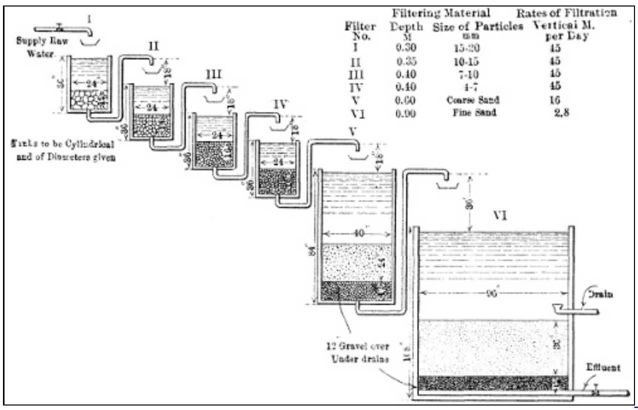

Figure 8—Diagrammatic Sketch Showing Arrangements for Testing "Puech" System of Water Filtration at Washington D. C., U. S. A.

The layer of clean sand restored the original capacity, and the filter was operated as before, but with gradually decreasing rates until December, 1908, when the rate was reduced to about 40,000,000 gal. Even this lower rate was too high to be maintained without removing and replacing a large part of the sand. The rates, therefore, gradually decreased to about 23,000,000 gal. on March 13th, 1909, when the filter was again re-sanded. After this re-sanding the rate was reduced to about 20,000,000 gal., and the filter was operated at approximately that rate until it was again re-sanded on November 13th, 1909, when the rate was again reduced to about 14,000,000 gal., which was maintained until the filter was put out of service on February 28th, 1910.

This experimental plant was in service from September, 1908, to the latter part of February, 1910, or for about 1-1/2 years, and the leading results are summarized in Table 20.

TABLE 17—RECORD OF EXPERIMENTAL FILTER PLANT NO. 1.

Date.	Preliminary Filter.		Final Filter.		Turbidity.			Bacteria.		
	Rate, millions of gallons per acre daily.	Loss of head.	Rate, millions of gallons per acre daily.	Loss of head.	Applied water.	Effluent preliminary filter.	Effluent final filter.	Applied water.	Effluent preliminary filter.	Effluent final filter.
1907.										
Feb. 8	19.40	0.71	3.10	0.17	...	...	...	1,100	2,000	2,500
Feb. 9	21.50	0.81	3.11	0.16	...	...	...	200	950	500
Feb. 10	20.60	0.95	3.04	0.14	...	...	...	...	...	...
Feb. 11	20.10	1.08	3.03	0.12	12	3	2	600	900	1,300
Feb. 12	19.80	1.23	3.02	0.13	14	4	2	650	650	650
Feb. 13	19.50	1.38	2.96	0.12	15	6	2	600	600	950
Feb. 14	21.20	1.67	3.21	0.11	15	4	2	650	700	800
Feb. 15	25.40	2.03	3.90	0.13	12	4	2	600	550	800
Feb. 16	25.00	2.23	3.89	0.12	14	3	2	850	550	500
Feb. 17	Shut down for changes in size of meter and piping.									
Feb. 18	...	...	...	...	...	...	...	1,200	...	650
Feb. 21	38.60	1.59	3.93	0.18	20	4	2	1,800	1,100	700
Feb. 22	38.00	1.84	3.92	0.15	15	3	2	Holiday.		
Feb. 23	42.10	2.36	3.95	0.14	20	5	2	1,600	600	220
Feb. 24	47.90	3.04	3.93	0.13	20	6	3	Sunday.		
Feb. 25	Shut down change meter from outlet to inlet.							1,400	800	450
Feb. 27	...	2.24	...	0.13	17	6	3	700	550	280
Feb. 28	49.80	2.55	3.90	0.13	15	6	3	800	470	230
Mar. 1	50.00	2.90	3.93	0.13	15	5	3	650	450	140
Mar. 2	50.20	3.21	3.93	0.13	15	5	3	1,000	650	200
Mar. 3	38.80	3.09	3.89	0.13	31	8	3	Sunday.		
Mar. 4	50.00	3.54	3.93	0.12	35	10	5	1,200	...	...
Mar. 5	50.00	4.01	3.90	0.13	135	39	8	13,000	3,700	600
Mar. 6	50.00	4.82	3.90	0.13	135	39	8	18,000	4,500	...
Mar. 7	50.00	5.89	3.90	0.13	102	34	6	24,000	5,000	2,000
Mar. 8	50.00	6.58	3.90	0.13	100	25	4	22,000	5,000	1,400
Mar. 9	50.00	7.21	3.93	0.13	90	25	4	24,000	4,000	650
Mar. 10	50.00	7.52	3.90	0.13	82	22	5	Sunday.		
	Washed.									
Mar. 11	50.00	0.84	3.90	0.13	68	19	6	18,000	2,100	350
Mar. 12	50.00	0.95	3.96	0.13	46	19	4	11,000	6,000	310
Mar. 13	50.00	1.17	3.99	0.13	40	19	4	9,000	4,900	300
Mar. 14	50.00	1.53	4.01	0.13	39	17	4	5,500	1,300	130
Mar. 15	50.00	2.27	4.05	0.13	35	15	4	6,500	1,500	60
Mar. 16	50.00	3.08	4.03	0.13	60	20	4	5,000	1,200	100
Mar. 17	50.00	4.26	4.03	0.13	135	35	4	Sunday.		
Mar. 18	50.00	5.65	4.00	0.13	170	49	7	9,000	1,200	95
Mar. 19	50.00	7.02	4.01	0.13	125	37	6	7,000	600	100
	Washed.									
Mar. 20	50.00	1.08	3.98	0.13	102	30	5	4,800	300	75
Mar. 21	50.00	1.23	3.98	0.12	125	32	4	8,500	1,000	85
Mar. 22	50.00	1.46	4.00	0.13	190	65	4	7,500	1,100	45
Mar. 23	50.00	1.76	3.99	0.13	180	65	6	7,500	600	55
Mar. 24	50.00	2.11	3.99	0.12	140	52	7	Sunday.		
Mar. 25	50.00	2.46	4.00	0.11	88	30	5	4,400	500	85
Mar. 26	50.00	2.75	4.00	0.12	62	22	4	3,600	300	65
Mar. 27	50.00	3.04	4.08	0.13	47	18	4	2,200	160	60
Mar. 28	50.00	3.38	3.94	0.11	35	10	3	1,300	100	55
Mar. 29	50.00	3.70	4.00	0.11	26	8	3	700	80	29
Mar. 30	50.00	4.42	4.00	0.11	25	6	3	310	70	35
Mar. 31	50.00	5.25	3.99	0.11	21	5	2	Sunday.		
Apr. 1	50.00	6.14	4.00	0.12	20	5	2	600	25	30

	Washed.									
Apr. 2	50.00	2.10	4.00	0.12	24	5	2	270	28	32
Apr. 3	50.00	3.00	4.00	0.12	24	5	2	460	26	43
Apr. 4	50.00	4.01	4.00	0.12	20	5	2	280	20	26
Apr. 5	50.00	5.15	4.00	0.12	20	4	2	450	37	41
	Washed.									
Apr. 6	50.00	O.76	3.59	0.12	20	4	2	320	6	34
Apr. 7	50.00	O.99	3.47	0.12	20	4	2	Sunday.		
Apr. 8	50.00	1.39	4.03	0.14	18	3	2	330	10	20
Apr. 9	50.00	2.04	4.01	0.13	18	3	2	140	9	35
Apr. 10	50.00	3.03	4.02	0.13	30	2	1	750	43	29
Apr. 11	50.00	4.45	4.02	0.14	66	1	1	4,000	900	26
Apr. 12	50.00	6.14	4.01	0.13	72	11	2	14,000	1700	41
	Washed.									
Apr. 13	50.00	0.95	4.00	0.14	80	21	2	13,000	1300	70
Apr. 14	50.00	1.18	4.00	0.13	77	25	3	Sunday.		
Apr. 15	50.00	1.57	4.00	0.14	62	21	3	7,000	380	55
Apr. 16	50.00	2.33	4.00	0.15	47	20	3	3,600	160	33
Apr. 17	50.00	3.33	4.00	0.15	39	15	2	1,600	70	39
Apr. 18	50.00	4.81	4.00	0.16	30	10	2	1,810	130	34
Apr. 19	50.00	6.29	3.99	0.16	25	7	2	790	50	32
	Washed.									
Apr. 20	50.00	0.93	4.01	0.16	20	5	2	540	24	28
Apr. 21	50.00	1.36	3.97	0.16	20	3	2	Sunday.		
Apr. 22	50.00	2.22	4.02	0.16	18	2	1	235	15	28
Apr. 23	50.00	3.33	3.99	0.14	15	2	1	170	14	16
Apr. 24	50.00	4.78	3.97	0.15	19	1	1	150	32	14
Apr. 25	50.00	6.43	3.90	0.15	34	1	1	700	20	18
	Washed.									
Apr. 26	50.00	O.97	3.97	0.14	46	2	1	1,200	16	16
Apr. 27	50.00	2.37	4.00	0.14	52	3	1	1,700	25	17
Apr. 28	50.00	5.33	3.99	0.14	45	4	1	Sunday.		
	Washed.									
Apr. 29	50.00	0.81	3.99	0.14	44	5	1	600	16	17
Apr. 30	50.00	1.75	3.99	0.14	39	6	1	550	27	12
May 1	50.00	0.80	3.99	0.14	31	5	1	500	24	11
	Washed.									
May 2	50.00	1.13	4.00	0.14	24	4	1	500	12	16
May 3	50.00	2.09	4.00	0.14	19	3	1	280	30	25
May 4	50.00	3.80	4.00	0.14	16	2	1	400	20	12
May 5	50.00	5.38	4.00	0.14	15	1	1	Sunday.		
	Washed.									
May 6	50.00	0.91	3.90	0.14	13	1	1	390	50	40
May 7	50.00	1.56	3.90	0.14	12	1	1	190	19	80
May 8	50.00	2.25	3.99	0.14	10	1	1	...	...	...
May 9	50.00	3.37	4.00	0.14	10	1	1	390	21	38
May 10	50.00	5.16	4.00	0.14	10	1	1	300	14	13
	Washed.									
May 11	50.00	1.03	4.00	0.14	12	1	1	390	13	12
May 12	50.00	1.89	4.00	0.14	17	1	1	Sunday.		
May 13	50.00	3.82	4.00	0.14	35	2	1	600	33	15
May 14	50.00	6.31	4.00	0.14	39	3	1	500	27	7
	Washed.									
May 15	50.00	0.85	4.00	0.14	17	2	1	500	20	29
May 16	50.00	1.42	3.99	0.14	24	2	1	290	19	40
May 17	50.00	2.47	3.99	0.14	18	2	1	260	19	16
May 18	50.00	4.31	4.00	0.13	15	1	1	190	16	20
	Washed.									
May 19	50.00	0.83	3.99	0.13	12	1	1	Sunday.		
May 20	50.00	1.66	4.00	0.13	12	1	1	260	17	41
May 21	50.00	3.83	4.00	0.13	16	1	1	260	26	25
	Washed.									
May 22	50.00	0.82	3.99	0.13	20	1	1	280	16	19
May 23	50.00	1.64	4.00	0.13	15	1	1	130	20	22

May 24	50.00	3.85	4.00	0.13	15	1	1	170	17	32
	Washed.									
May 25	50.00	0.84	4.00	0.13	15	1	1	340	25	55
May 26	50.00	1.67	3.99	0.13	18	1	1	Sunday.		
May 27	50.00	3.03	4.00	0.13	13	1	1	210	10	40
	Washed.									
May 28	50.00	0.87	4.01	0.13	16	1	1	260	26	55
May 29	50.00	1.43	4.01	0.13	16	1	1	500	19	50
May 30	50.00	2.55	4.00	0.13	14	1	1	Holiday.		
May 31	50.00	4.19	4.00	0.13	17	1	1	380	22	50
June 1	50.00	6.26	3.99	0.13	15	1	1	900	27	50
	Washed.									
June 2	50.00	0.78	3.98	0.13	17	1	1	Sunday.		
June 3	50.00	1.19	4.00	0.13	24	1	1	550	41	50
June 4	50.00	2.15	4.00	0.13	37	2	1	6,500	150	60
June 5	50.00	3.67	4.01	0.13	65	4	1	3,200	150	46
June 6	50.00	6.06	4.00	0.14	77	12	1	1,500	60	27
	Washed.									
June 7	50.00	0.86	4.00	0.14	64	19	1	2,100	68	45
June 8	50.00	1.41	4.00	0.14	46	16	1	600	35	44
June 9	50.00	2.62	4.01	0.14	44	12	1	Sunday.		
June 10	50.00	4.79	4.00	0.14	36	8	1	240	31	35
	Washed.									
June 11	50.00	0.77	4.00	0.14	30	6	1	280	47	47
June 12	50.00	1.20	4.01	0.14	34	6	1	330	70	55
June 13	50.00	2.42	4.00	0.14	35	8	1	480	43	75
June 14	50.00	4.44	4.00	0.15	31	7	1	440	55	45
	Washed.									
June 15	50.00	0.80	3.99	0.15	32	6	1	420	17	34
June 16	50.00	1.15	4.00	0.15	26	5	1	Sunday.		
June 17	50.00	2.15	3.99	0.14	26	5	1	340	55	37
June 18	50.00	4.36	4.00	0.14	31	6	1	440	14	140
	Washed.									
June 19	50.00	0.79	4.01	0.15	37	8	1	500	70	24
June 20	50.00	1.19	4.00	0.15	30	7	1	330	49	27
June 21	50.00	2.65	3.98	0.14	25	5	1	170	30	18
June 22	50.00	5.58	4.00	0.14	20	4	1	100	18	13
	Washed.									
June 23	50.00	0.85	3.62	0.13	26	3	1	Sunday.		
June 24	50.00	2.02	3.99	0.13	140	11	1	1,700	27	36
June 25	50.00	4.77	3.99	0.13	130	26	1	400	70	23
	Washed.									
June 26	50.00	0.73	4.01	0.13	82	27	1	750	200	41
June 27	50.00	1.17	4.01	0.13	65	18	1	...	...	...
June 28	50.00	3.10	3.99	0.13	47	16	1	...	20	...
	Washed.									
June 29	50.00	0.67	3.99	0.13	37	7	1	220	35	29
June 30	50.00	1.02	4.00	0.13	30	6	1	Sunday.		
July 1	50.00	2.70	3.99	0.13	30	6	1	400	46	3
	Washed.									
July 2	50.00	0.69	4.00	0.13	32	7	1	180	80	38
July 3	50.00	1.21	3.99	0.13	36	8	1	350	70	90
July 4	50.00	3.40	3.99	0.13	44	10	1	Holiday.		
	Washed.									
July 5	50.00	0.77	3.99	0.13	44	11	1	550	180	34
July 6	50.00	1.19	4.01	0.13	39	10	1	250	60	26
July 7	50.00	3.72	3.99	0.13	34	8	1	Sunday.		
	Washed.									
July 8	50.00	0.78	3.97	0.13	25	5	1	220	31	21
July 9	50.00	1.27	3.98	0.13	22	4	1	50	10	9
July 10	50.00	3.11	4.09	0.13	47	9	1	Lost.		
	Washed.									
July 11	50.00	0.83	3.99	0.13	90	19	1	150	19	8

July 12	50.00	1.47	3.99	0.13	97	25	1	300	40	23
July 13	50.00	3.61	4.00	0.13	96	29	1	220	47	16
	Washed.									
July 14	50.00	0.84	3.99	0.13	90	30	1	Sunday.		
July 15	50.00	1.30	4.00	0.13	95	30	1	375	55	21
July 16	50.00	2.72	3.99	0.14	120	35	1	Lost.	90	13
July 17	50.00	5.08	3.99	0.14	85	32	1	270	2	11
	Washed.									
July 18	50.00	0.85	3.99	0.14	56	22	1	1,675	70	50
July 19	50.00	1.43	4.00	0.14	41	12	1	450	95	22
July 20	50.00	3.23	3.99	0.14	62	19	1	300	38	11
	Washed.									
July 21	50.00	0.80	3.99	0.14	62	21	1	Sunday.		
July 22	50.00	1.06	3.98	0.14	80	26	1	1,400	150	7
July 23	50.00	2.18	3.99	0.14	105	30	1	3,700	Lost.	11
July 24	50.00	4.95	3.98	0.15	95	30	1	770	Lost.	22
	Washed.									
July 25	50.00	0.84	3.98	0.15	77	22	1	250	33	11
July 26	50.00	1.22	3.98	0.15	67	19	1	140	100	4
July 27	50.00	2.36	4.00	0.16	54	15	1	300	95	7
July 28	50.00	4.74	3.98	0.16	46	12	1	Sunday.		
	Washed.									
July 29	50.00	0.83	3.99	0.17	36	10	1	470	110	18
July 30	50.00	1.02	4.00	0.17	29	7	1	Plates lost.		
July 31	50.00	1.66	4.00	0.17	21	5	1	Plates lost.		
Aug. 1	48.20	2.95	4.00	0.17	16	4	1	Plateslost.		
Aug. 2	46.40	4.96	4.00	0.17	15	2	1	130	42	13
	Washed.									
Aug. 3	42.60	0.79	4.00	0.17	16	1	1	120	4	16
Aug. 4	49.10	0.91	4.00	0.17	21	1	1	Sunday.		
Aug. 5	49.10	1.59	4.00	0.17	29	1	1	230	160	11
Aug. 6	48.20	3.16	4.00	0.17	34	2	1	85	200	12
Aug. 7	45.60	5.65	3.99	0.17	21	2	1	200	Lost	4
	Washed.									
Aug. 8	50.00	0.80	3.99	0.17	19	2	1	100	70	11
Aug. 9	49.10	0.94	4.00	0.17	16	1	1	75	44	9
Aug. 10	48.20	1.51	4.00	0.17	24	1	1	60	13	6
Aug. 11	48.20	3.32	4.00	0.17	62	3	1	Sunday.		
	Washed.									
Aug. 12	41.90	0.83	3.99	0.17	120	14	1	620	110	5
Aug. 13	49.10	1.14	3.99	0.17	107	29	1	820	53	36
Aug. 14	49.10	1.72	4.00	0.18	82	30	1	850	160	110
Aug. 15	48.20	3.30	4.00	0.18	65	22	1	150	37	4
Aug. 16	46.40	0.84	4.00	0.19	45	15	1	270	110	13
Aug. 17	48.20	1.05	4.00	0.19	35	10	1	340	110	6
Aug. 18	50.00	1.54	4.00	0.19	21	5	1	Sunday.		
Aug. 19	49.10	2.29	4.00	0.19	18	4	1	180	85	13
Aug. 20	49.10	3.74	3.99	0.19	20	2	1	210	85	8
	Washed.									
Aug. 21	44.10	1.01	3.98	0.19	20	2	1	1300	115	9
Aug. 22	45.60	1.86	4.00	0.19	27	2	1	3800	265	1
Aug. 23	47.30	4.08	3.99	0.19	49	2	1	2500	70	13
	Washed.									
Aug. 24	41.30	1.29	3.97	0.19	36	6	1	3900	46	6
Aug. 25	44.10	2.11	3.98	0.20	34	7	1	Sunday.		
Aug. 26	48.20	3.42	3.99	0.20	21	5	1	700	140	0
Aug. 27	48.20	5.10	4.00	0.20	19	4	1	470	100	4
	Washed.									
Aug. 28	46.40	1.28	4.00	0.20	18	3	1	500	49	3
Aug. 29	41.90	1.90	4.02	0.20	17	2	1	360	80	0
Aug. 30	45.60	3.23	4.00	0.20	15	1	1	320	190	1
Aug. 31	46.40	4.57	4.00	0.20	13	1	1	200	20	3
Sept. 1	50.00	5.17	3.65	0.20	14	1	1	Sunday.		
Sept. 2	48.20	5.97	4.00	0.20	12	1	1	Holiday.		

	Washed.									
Sept. 3	47.30	1.13	4.00	0.20	12	1	1	300	9	1
Sept. 4	48.20	2.01	4.00	0.20	16	1	1	600	60	2
Sept. 5	46.40	5.41	3.67	0.20	34	1	0	360	72	...
	Washed.									
Sept. 6	40.60	1.42	3.98	0.20	160	12	0	15000	140	0
Sept. 7	42.60	5.19	3.99	0.20	64	18	1	2000	130	1
	Washed.									
Sept. 8	42.60	1.25	4.00	0.20	56	18	1	Sunday.		
Sept. 9	46.40	3.07	4.00	0.22	59	18	1	220	80	4
	Washed.									
Sept. 10	45.60	1.02	3.99	0.23	57	16	1	18000	57	8
Sept. 11	48.20	2.36	4.00	0.23	65	18	1	2700	90	1
	Washed.									
Sept. 12	44.10	1.14	3.99	0.24	72	18	1	1000	47	4
Sept. 13	46.40	3.61	3.99	0.25	87	20	1	2300	77	5
	Washed.									
Sept. 14	38.20	1.42	3.97	0.26	72	19	1	2400	80	5
Sept. 15	45.60	4.27	4.00	0.27	65	18	1	Sunday.		
	Washed.									
Sept. 16	40.00	1.06	3.99	0.28	65	18	1	Lost.	22	Lost.
Sept. 17	46.40	2.48	4.01	0.28	52	16	1	420	75	1
	Washed.									
Sept. 18	46.40	1.11	4.00	0.28	60	13	1	900	37	3
Sept. 19	46.40	2.76	4.00	0.28	85	16	1	2000	186	0
	Washed.									
Sept. 20	44.10	1.12	4.00	0.31	100	19	1	4200	110	7
Sept. 21	48.20	2.07	3.99	0.33	120	24	1	1100	110	3
	Washed.									
Sept. 22	44.10	1.30	3.67	0.34	137	29	1	Sunday.		
Sept. 23	45.60	3.79	3.99	0.39	112	25	1	2400	50	2
	Washed.									
Sept. 24	45.60	1.15	3.97	0.40	100	25	1	4000	69	4
Sept. 25	48.20	2.06	4.00	0.42	432	53	1	56000	680	0
Sept. 26	Stopped, unable to wash preliminary.									
Sept. 28	50.00	1.74	4.00	0.71	127	35	1	...	...	37
	Washed.									
Sept. 29	44.10	2.85	3.99	0.82	105	31	1	Sunday.		
Sept. 30	44.90	3.78	3.97	1.04	115	32	1	Lost.	Lost.	160
	Washed.									
Oct. 1	44.10	1.20	3.98	1.34	82	26	1	600	180	55
Oct. 2	49.10	3.22	3.97	1.54	65	19	1	4,400	120	5
	Washed.									
Oct. 3	44.10	1.31	3.97	1.56	59	17	1	900	55	10
Oct. 4	49.10	2.97	3.97	1.65	55	15	1	850	60	6
	Washed.									
Oct. 5	44.90	1.31	3.98	1.75	59	16	1	2,000	110	38
Oct. 6	46.40	3.65	3.99	1.89	59	17	1	Sunday.		
	Washed.									
Oct. 7	44.90	1.34	3.98	1.99	52	13	1	1,250	70	15
Oct. 8	49.10	3.49	3.98	2.17	54	13	1	11,000	65	6
	Washed.									
Oct. 9	44.10	1.20	3.97	2.33	51	13	1	2,000	85	4
Oct. 10	49.10	2.22	3.98	2.55	50	12	1	800	36	10
Oct. 11	46.40	4.59	4.00	2.51	47	11	1	2,000	57	10
Oct. 12	Shut off to remove sand in preliminary filter in order to clean out the under-drains.									
Nov. 5	50.00	1.38	3.97	3.49	185	50	1	...	...	...
Nov. 6	48.20	3.25	3.98	3.79	170	52	1	5,000	1,500	240
	Washed.									
Nov. 7	45.60	1.18	3.98	4.05	100	35	1	14,000	1,000	220
Nov. 8	48.20	4.08	3.99	4.37	95	32	1	1,900	270	160
Nov. 9	42.00	6.58	3.98	4.39	80	27	1	4,000	500	190
Nov. 10	Shut down for scraping. Removed 266,000 cu. cm. of sand.									

Nov. 12	50.00	0.98	3.99	0.25	40	10	1	...	...	...
Nov. 13	50.00	1.51	4.00	0.22	36	8	1	1,600	750	85
Nov. 14	48.20	2.60	4.00	0.21	42	11	1	2,700	700	210
Nov. 15	47.30	3.80	4.00	0.20	35	9	1	1,800	350	180
Nov. 16	47.30	4.87	4.00	0.19	26	5	1	1,100	200	34
Nov. 17	50.00	5.75	4.00	0.19	20	4	1	Sunday.		
Nov. 18	50.00	6.41	4.00	0.19	17	3	1	1,600	290	55
	Washed.									
Nov. 19	48.20	1.06	3.99	0.20	16	2	1	1,300	480	60
Nov. 20	48.20	2.05	3.99	0.20	45	3	1	6,500	3,700	800
Nov. 21	48.20	3.48	3.99	0.20	52	9	1	9,900	4,000	300
Nov. 22	47.30	4.85	3.99	0.20	65	17	1	10,000	1,000	380
Nov. 23	48.20	6.11	3.99	0.20	49	15	1	18,000	1,000	320
	Washed.									
Nov. 24	46.40	3.71	3.98	0.20	134	24	1	Sunday.		
Nov. 25	Shut down for fear of washing preliminary with such muddy water.									
Nov. 29	50.00	1.55	4.00	0.21	80	25	1	...	...	...
Nov. 30	47.30	3.14	3.98	0.22	54	16	1	3,800	950	160
Dec. 1	47.30	4.48	3.98	0.23	37	10	1	Sunday.		
Dec. 2	47.30	5.63	3.98	0.25	36	6	1	2,900	550	90
	Washed.									
Dec. 3	46.40	0.98	3.99	0.25	29	6	1	2,900	480	75
Dec. 4	50.00	1.15	3.99	0.26	20	4	1	2,000	270	70
Dec. 5	50.00	1.48	4.00	0.25	18	3	1	1,100	270	50
Dec. 6	48.20	2.04	3.63	0.25	16	2	1	3,000	...	...
Dec. 7	48.20	2.80	4.00	0.26	14	1	1	2,400	190	10
Dec. 8	50.00	3.40	3.72	0.27	12	1	1	Sunday.		
Dec. 9	49.10	3.93	4.00	0.27	11	1	1	1,200	170	7
Dec. 10	49.10	4.50	4.00	0.27	12	1	1	800	90	55
Dec. 11	48.20	5.52	4.00	0.27	255	44	1	6,500	---	---
Dec. 12	Shut down 12/11 at 6 P.M. turbidity too high to wash.									
Dec. 15	---	---	---	---	---	---	---	Sunday.		
Dec. 16	50.00	4.02	3.99	0.28	90	35	2	---	---	---
	Washed.									
Dec. 17	40.00	1.90	3.97	0.30	70	25	2	21,000	10,000	1,200
	Washed.									
Dec. 18	44.10	1.08	3.97	0.31	49	15	2	6,500	4,200	800
Dec. 19	48.20	1.88	3.98	0.31	39	10	1	Lost.	Lost.	Lost.
Dec. 20	46.40	4.77	3.99	0.31	42	13	1	Lost.	Lost.	Lost.
Dec. 21	46.40	6.68	3.99	0.32	26	6	1	Lost.	Lost.	Lost.
	Washed.									
Dec. 22	49.10	1.14	3.99	0.32	20	4	1	Sunday.		
Dec. 23	49.10	2.17	4.00	0.31	34	7	1	1,400	300	100
Dec. 24	49.10	3.76	4.00	0.31	195	56	1	9,000	950	70
Dec. 25	Shut down 12/24 at 9 P.M. turbidity too high to wash. Holiday.									
Dec. 30	50.00	2.61	3.97	0.33	56	19	2	---	---	---
Dec. 31	44.80	5.57	3.98	0.36	39	12	1	---	---	---
	Washed.									
1908.										
Jan. 1	46.40	1.30	3.98	0.36	31	6	1	Holiday.		
Jan. 2	48.20	3.36	4.00	0.36	39	9	1	---	---	---
Jan. 3	47.30	4.95	3.99	0.35	36	9	1	3,100	490	90
Jan. 4	50.00	5.28	3.99	0.35	32	7	1	2,400	240	43
Jan. 5	49.10	6.26	4.00	0.35	26	5	1	Sunday.		
	Washed.									
Jan. 6	49.10	0.99	3.98	0.35	20	4	1	600	200	37
Jan. 7	50.00	1.15	4.00	0.35	20	4	1	1,100	150	47
Jan. 8	50.00	1.41	4.00	0.35	22	4	1	1,900	160	30
Jan. 9	49.10	1.92	4.00	0.35	45	11	1	13,000	1,300	70
Jan. 10	49.10	2.56	4.00	0.36	70	25	1	10,000	3,500	170
Jan. 11	50.00	3.17	3.99	0.37	56	18	1	16,000	4,000	240
Jan. 12	49.10	3.73	4.00	0.37	40	10	1	Sunday.		
Jan. 13	50.00	4.14	4.00	0.37	110	45	2	8,500	1,200	840

Jan. 14	49.10	4.65	3.99	0.38	210	95	3	16,000	3,900	500
Jan. 15	49.10	5.23	3.99	0.41	325	190	12	24,000	7,000	550
Jan. 16	50.00	5.75	3.99	0.43	360	210	37	28,000	8,500	1,200
Jan. 17	49.10	6.34	4.00	0.45	242	122	24	65,000	15,000	1,700
Jan. 18	---	---	---	---	---	---	---	---	---	---
Jan. 19	50.00	1.17	4.00	0.46	117	40	12		Sunday.	
Jan. 20	50.00	1.38	4.00	0.46	72	31	6	1,600	1,800	320
Jan. 21	50.00	1.68	3.57	0.37	55	20	4	5,000	450	
Jan. 22	49.10	2.04	4.00	0.44	49	17	3	3,600	600	100
Jan. 23	50.00	2.47	3.24	0.33	40	12	3	1,800	290	130
Jan. 24	49.10	3.03	3.00	0.34	40	11	2	2,300	270	65
Jan. 25	50.00	3.61	3.00	0.35	39	10	2	1,100	180	60
Jan. 26	49.10	4.18	2.99	0.35	32	7	2		Sunday.	
Jan. 27	50.00	4.81	3.00	0.35	32	7	2	300	40	24
Jan. 28	48.20	5.45	2.99	0.35	45	12	2	1,200	90	31
Jan. 29	49.10	6.01	2.99	0.35	60	21	2	1,000	230	50
Jan. 30	49.10	6.62	2.99	0.36	57	22	2	1,400	170	48
	Washed.									
Jan. 31	50.00	1.30	2.99	0.36	42	15	2	1,100	190	23
Feb. 1	50.00	1.51	2.99	0.37	39	11	2	750	40	31
Feb. 2	50.00	1.78	3.00	0.37	27	7	2		Sunday.	
Feb. 3	49.10	2.13	3.00	0.37	29	6	2	1,300	200	7
Feb. 4	50.00	2.69	3.00	0.37	25	5	1	600	160	18
Feb. 5	49.10	3.31	2.99	0.37	24	5	1	750	140	41
Feb. 6	50.00	3.89	2.99	0.37	20	4	1	2,000	180	29
Feb. 7	48.20	4.50	2.99	0.37	17	3	1	...	38	15
Feb. 8	49.10	5.11	2.99	0.37	15	3	1	900	95	24
Feb. 9	49.10	5.65	3.00	0.38	14	3	1		Sunday.	
Feb. 10	49.10	6.43	2.99	0.38	11	3	1	850	85	21
Feb. 11	50.00	6.90	3.00	0.38	10	3	1	1,000	70	20
	Washed.									
Feb. 12	49.10	1.29	2.99	0.38	8	2	1	750	20	16
Feb. 13	50.00	1.50	2.99	0.39	9	2	1	700	40	11
Feb. 14	50.00	1.80	2.99	0.39	9	2	1	1,200	39	7
Feb. 15	49.10	2.35	3.00	0.39	61	13	1	5,500	600	7
Feb. 16	49.10	3.28	2.99	0.39	80	30	2		Sunday.	
Feb. 17	48.20	4.85	2.99	0.39	80	29	3	33,000	3,800	130
Feb. 18	47.30	6.39	2.99	0.39	130	44	3	---	2,600	160
Feb. 19	45.50	7.32	2.98	0.40	320	143	6	28,000	6,000	180
	Washed.									
Feb. 22	50.00	1.40	3.00	0.41	85	30	5		Holiday.	
Feb. 23	50.00	1.77	3.00	0.41	60	21	4		Sunday.	
Feb. 24	49.10	2.25	2.99	0.41	46	14	3	3,600	2,800	90
Feb. 25	50.00	2.61	3.00	0.41	31	7	2	2,300	140	47
Feb. 26	50.00	3.06	3.00	0.41	30	6	2	3,800	140	45
Feb. 27	48.20	3.65	2.99	0.41	30	5	1	1,300	100	22
Feb. 28	50.00	4.24	3.00	0.41	37	6	1	1,400	100	40
Feb. 29	48.20	5.28	2.99	0.41	123	52	2	13,500	420	40
	Washed.									
Mar. 1	44.60	1.56	2.99	0.42	97	39	5		Sunday.	
Mar. 2	48.20	2.90	2.99	0.42	82	30	4	8,000	320	60
Mar. 3	46.40	4.69	2.98	0.42	87	33	4	11,000	750	30
Mar. 4	47.30	6.13	2.99	0.42	67	24	3	6,000	290	34
Mar. 5	48.20	7.31	2.99	0.42	59	19	3	4,400	220	41
	Washed.									
Mar. 6	49.10	1.53	2.99	0.42	72	24	2	7,000	170	41
Mar. 7	50.00	1.95	3.00	0.43	82	30	2	9,500	210	34
Mar. 8	49.10	2.62	2.99	0.43	92	37	3		Sunday.	
Mar. 9	50.00	3.19	3.00	0.43	125	56	4	11,000	700	65
Mar. 10	Preliminary filter discontinued and the Puech system started.									

TABLE 17—RECORD OF EXPERIMENTAL FILTER, PUECH SYSTEM.—(*Continued.*)

	PUECH SYSTEM:	FINAL FILTER.		TURBIDITY.			BACTERIA.		

Date.	Rates, millions of gallons per acre daily.					Rate, millions of gallons per acre daily.	Loss of head.	Applied water.	Effluent, preliminary filter.	Effluent, final filter.	Applied water.	Effluent, preliminary filter.	Effluent, final filter.
1908.													
Mar. 11	265	170	90	53	18	2.99	0.53	155	80	7	6,500	8,500	490
Mar. 12	265	170	90	53	18	2.99	0.60	135	70	7	5,900	6,000	360
Mar. 13	265	170	90	53	18	3.00	0.60	122	52	6	1,900	1,700	140
Mar. 14	265	170	90	53	18	3.00	0.61	97	40	5	1,800	1,600	130
Mar. 15	265	170	90	53	18	2.99	0.64	77	31	4	Sunday.		
Mar. 16	265	170	90	53	18	3.00	0.69	65	26	3	1,400	1,200	50
Mar. 17	241	155	82	48	16	2.99	0.71	59	19	3	900	200	45
Mar. 18	252	162	86	50	17	2.99	0.75	67	22	2	1,000	700	33
Mar. 19	241	155	82	48	16	2.99	0.78	60	21	2	...	800	44
Mar. 20	294	189	100	59	20	2.99	0.85	57	18	2	1,300	650	37
Mar. 21	279	179	95	56	19	2.99	0.92	67	21	2	800	600	34
Mar. 22	265	170	90	53	18	2.99	0.99	80	27	2	Sunday.		
Mar. 23	265	170	90	53	18	2.99	1.06	90	32	2	4,600	1,300	33
Mar. 24	265	170	90	53	18	2.99	1.12	82	34	3	2,500	950	38
Mar. 25	265	170	90	53	18	2.99	1.18	67	27	3	1,600	...	30
Mar. 26	265	170	90	53	18	2.99	1.22	60	20	3	550	400	24
Mar. 27	265	170	90	53	18	3.00	1.23	59	18	2	950	360	28
Mar. 28	265	170	90	53	18	3.00	1.25	51	14	2	650	230	18
Mar. 29	265	170	90	53	18	2.99	1.28	31	6	2	Sunday.		
Mar. 30	265	170	90	53	18	2.99	1.36	30	5	1	500	160	25
Mar. 31	265	170	90	53	18	2.99	1.43	39	7	1	750	140	26
April 1	265	170	90	53	18	3.00	1.48	44	9	1	750	60	41
April 2	265	170	90	53	18	2.99	1.56	42	9	1	1,100	140	26
April 3	318	204	108	64	22	2.99	1.63	41	8	1	1,500	47	11
April 4	294	189	100	59	20	2.99	1.70	54	13	1	700	80	35
April 5	279	179	95	56	19	3.00	1.73	50	13	1	Sunday.		
April 6	279	179	95	56	19	2.99	1.76	41	9	1	440	65	17
April 7	265	170	90	53	18	3.00	1.78	35	6	1	650	65	34
April 8	265	170	90	53	18	3.00	1.79	39	6	1	550	44	10
April 9	265	170	90	53	18	3.00	1.79	40	6	1	390	30	25
April 10	265	170	90	53	18	3.00	1.77	40	6	1	500	27	16
April 11	265	170	90	53	18	3.00	1.78	45	7	1	430	28	28
April 12	265	170	90	53	18	2.99	1.80	52	11	1	Sunday.		
April 13	265	170	90	53	18	...	1.81	50	10	1	490	17	26
April 14	Shut down on account of losing water when aqueduct was drained; also cleaned coarse sand filter. Started April 22d.												
April 23	241	155	82	48	16	...	1.82	29	4	1	140	600	38
April 24	241	155	82	48	16	3.00	1.87	21	3	1	200	1,000	13
April 25	241	155	82	48	16	2.99	1.95	20	3	1	85	180	25
April 26	252	162	86	50	17	3.00	1.95	24	3	1	Sunday.		
April 27	241	155	82	48	16	3.00	1.93	18	2	1	95	35	23
April 28	241	155	82	48	16	3.00	1.96	20	2	1	70	24	18
April 29	241	155	82	48	16	2.99	1.97	24	3	1	110	21	24
April 30	241	155	82	48	16	2.99	2.03	21	2	1	70	25	6
May 1	241	155	82	48	16	3.00	2.07	32	4	1	130	20	18
May 2	241	155	82	48	16	2.99	2.12	26	3	1	140	16	12
May 3	241	155	82	48	16	2.99	2.17	22	3	1	Sunday.		
May 4	241	155	82	48	16	3.00	2.19	19	2	1	85	30	17
May 5	241	155	82	48	16	3.00	2.20	18	2	1	130	33	9
May 6	241	155	82	48	16	2.99	2.23	18	2	1	230	55	6
May 7	252	162	86	50	17	3.00	2.24	19	2	1	160	75	10
May 8	241	155	82	48	16	3.00	2.25	19	2	1	375	55	8
May 9	318	204	108	64	22	2.99	2.29	18	2	1	1,200	12	9
May 10	318	204	108	64	22	2.99	2.30	30	3	1	Sunday.		
May 11	265	170	90	53	18	2.99	2.33	60	10	1	2,800	130	11
May 12	252	162	86	50	17	2.99	2.39	70	15	1	2,900	135	9
May 13	241	155	82	48	16	3.00	2.41	66	14	1	1,800	110	16
May 14	265	170	90	53	18	3.00	2.38	45	7	1	2,700	65	18

May 15	252	162	86	50	17	3.00	2.41	39	5	1	950	45	14
May 16	241	155	82	48	16	3.00	2.41	49	7	1	800	32	10
May 17	241	155	82	48	16	3.01	2.34	46	7	1	Sunday.		
May 18	241	155	82	48	16	3.00	2.31	31	4	1	700	26	6
May 19	252	162	86	50	17	3.00	2.26	36	4	1	375	28	17
May 20	252	162	86	50	17	3.00	2.20	41	5	1	425	38	11
May 21	344	221	117	69	23	3.00	2.18	30	3	1	300	25	9
May 22	241	155	82	48	16	3.01	2.17	53	7	1	950	220	18
May 23	265	170	90	53	18	2.99	2.25	127	38	1	2,400	600	21
May 24	331	212	112	66	22	3.00	2.19	110	39	3	Sunday.		
May 25	318	204	108	64	22	3.01	2.02	90	25	3	600	300	40
May 26	279	179	95	56	19	3.02	1.87	135	45	3	3,200	110	34
May 27	265	170	90	53	18	3.01	1.63	110	39	3	14,500	320	45
May 28	252	162	86	50	17	3.01	1.41	90	27	3	1,000	95	28
May 29	252	162	86	50	17	3.01	1.24	70	17	3	1,100	150	26
May 30	252	162	86	50	17	3.01	1.07	50	9	2	Holiday.		
May 31	241	155	82	48	16	3.01	1.03	34	4	2	Sunday.		
June 1	252	162	86	50	17	3.00	0.83	35	4	1	...	...	...
June 2	241	155	82	48	16	3.00	0.74	39	5	1	...	...	...
June 3	252	162	86	50	17	3.00	0.68	35	4	1	...	...	...
June 4	241	155	82	48	16	3.00	0.63	30	3	1	...	...	...
June 5	252	162	86	50	17	2.99	0.60	30	3	1	...	...	...
June 6	241	155	82	48	16	3.00	0.56	27	3	1	...	...	...
June 7	241	155	82	48	16	2.99	0.53	22	2	1	...	...	...
June 8	241	155	82	48	16	3.00	0.49	20	1	1	...	...	...
June 9	241	155	82	48	16	2.99	0.46	20	1	1	...	...	...
June 10	241	155	82	48	16	3.00	0.44	17	1	1	...	...	...
June 11	331	212	112	66	22	2.98	0.42	12	1	1	...	...	...
June 12	318	204	108	64	22	2.98	0.42	11	1	1	...	...	...
June 13	265	170	90	53	18	3.00	0.40	36	3	1	...	...	...
June 14	252	162	86	50	17	2.99	0.40	39	5	1	...	...	...
June 15	241	155	82	48	16	2.99	0.39	25	3	1	...	...	...
June 16	241	155	82	48	16	2.99	0.40	34	3	1	...	...	...
June 17	252	162	86	50	17	2.99	0.41	64	11	1	...	...	...
June 18	241	155	82	48	16	2.99	0.42	57	11	1	...	...	...
June 19	241	155	82	48	16	2.99	0.42	46	8	1	...	...	...
June 20	241	155	82	48	16	2.99	0.42	40	5	1	...	...	...
June 21	241	155	82	48	16	3.00	0.43	28	4	1	...	...	...
June 22	241	155	82	48	16	2.99	0.43	25	3	1	...	...	...
June 23	241	155	82	48	16	2.99	0.43	25	3	1	...	...	...
June 24	241	155	82	48	16	2.99	0.43	29	4	1	...	...	...
June 25	241	155	82	48	16	2.99	0.43	18	2	1	...	...	...
June 26	241	155	82	48	16	2.80	0.42	15	1	1	...	...	...
June 27	241	155	82	48	16	2.99	0.44	12	1	1	...	...	...
June 28	241	155	82	48	16	2.99	0.44	9	1	1	...	...	...
June 29	241	155	82	48	16	2.99	0.44	8	1	1	...	...	...
June 30	241	155	82	48	16	2.99	0.44	10	1	1	...	...	...
July 1	241	155	82	48	16	3.00	0.45	8	1	1	80	10	4
July 2	241	155	82	48	16	3.00	0.46	8	1	0	290	24	5
July 3	241	155	82	48	16	3.00	0.47	8	1	0	350	45	6
July 4	241	155	82	48	16	2.99	0.49	9	1	0	...	...	...
July 5	305	195	103	61	21	3.00	0.51	10	1	0	...	...	...
July 6	241	155	82	48	16	3.00	0.51	9	1	0	300	36	7
July 7	241	155	82	48	16	2.99	0.53	8	1	0	110	10	3
July 8	252	162	86	50	17	3.00	0.53	9	1	0	85	22	2
July 9	241	155	82	48	16	3.00	0.54	8	1	0	85	26	2
July 10	...	...	...	...	...	...	...	...	...	...	200	3	5
July 11	305	195	103	61	21	3.00	0.56	12	1	0	145	7	3
July 12	241	155	82	48	16	2.99	0.58	11	1	0	...	...	...
July 13	241	155	82	48	16	3.00	0.60	10	1	0	115	34	55
July 14	241	155	82	48	16	2.99	0.62	16	1	0	300	55	30
July 15	241	155	82	48	16	2.99	0.64	17	1	0	180	32	23

July 16	241	155	82	48	16	3.00	0.67	13	1	0	100	115	3
July 17	241	155	82	48	16	2.99	0.71	10	1	0	65	275	5
July 18	241	155	82	48	16	2.99	0.73	11	1	0	38	425	10
July 19	241	155	82	48	16	3.00	0.76	12	1	0	...	...	...
July 20	241	155	82	48	16	2.99	0.79	10	1	0	95	90	70
July 21	252	162	86	50	17	2.99	0.83	10	1	1	70	17	4
July 22	241	155	82	48	16	2.99	0.87	13	1	1	440	8	5
July 23	305	195	103	61	21	2.99	0.92	54	4	1	650	26	5
July 24	331	212	111	66	22	2.98	0.99	305	61	1	1,650	...	...
July 25	265	170	90	53	18	2.98	1.08	330	85	1	2,600	115	15
July 26	252	162	86	50	17	2.98	1.21	290	77	2	...	...	...
July 27	305	195	103	61	21	2.98	1.40	335	87	2	35,000	250	...
July 28	252	162	86	50	17	2.98	1.68	170	52	2	1,200	1,350	15
July 29	252	162	86	50	17	2.97	2.14	180	52	2	2,000	600	13
July 30	252	162	86	50	17	2.97	2.65	237	56	2	800	1,300	12
July 31	241	155	82	48	16	2.95	3.01	250	60	2	1,000	310	7

TABLE 18—RECORD OF EXPERIMENTAL FILTER PLANT NO. 2.

Date.	PRELIMINARY FILTER.		FINAL FILTER.		TURBIDITY			BACTERIA		
	Rate, millions of gallons per acre daily.	Loss of head.	Rate, millions of gallons per acre daily.	Loss of head.	Applied water.	Effluent preliminary filter.	Effluent final filter.	Applied water.	Effluent preliminary filter.	Effluent final filter.
1907.										
Feb. 8	21.50	0.04	2.81	0.17	...	...	...	1,100	2,100	...
Feb. 9	21.60	0.04	1.09	0.06	...	...	...	200	550	2,100
Feb. 10	20.90	0.05	1.59	0.08	...	...	...	...	...	...
Feb. 11	19.80	0.05	3.01	0.15	12	6	2	600	1,160	1,100
Feb. 12	19.70	0.06	3.01	0.14	12	5	2	650	400	700
Feb. 13	19.60	0.06	3.01	0.12	15	5	2	660	900	700
Feb. 14	24.70	0.07	2.65	0.13	15	6	2	650	1,100	900
Feb. 15	37.20	...	3.40	0.12	12	5	2	600	800	850
Feb. 16	37.30	...	3.40	0.11	14	4	2	850	950	600
Feb. 17	Shut down for changes in meters and piping.									
Feb. 18	...	...	...	...	...	...	...	1,200	...	600
Feb. 21	44.50	...	4.36	0.19	20	6	2	1,800	1,400	800
Feb. 22	48.60	...	4.37	0.16	15	4	2	Holiday.		
Feb. 23	48.40	...	4.20	0.15	20	7	2	1,600	750	380
Feb. 24	48.30	...	4.02	0.13	20	10	3	Sunday.		
Feb. 25	Shut down several hours.			0.14	20	10	3	1,400	1,000	450
Feb. 26	48.60	0.04	4.12	0.14	20	10	3	700	800	260
Feb. 27	53.20	0.04	4.08	0.15	17	8	3	700	700	290
Feb. 28	52.80	0.04	4.09	0.15	15	8	3	800	650	500
Mar. 1	53.00	0.04	4.10	0.16	15	8	3	650	550	200
Mar. 2	53.30	0.04	4.11	0.16	15	7	3	1,000	800	300
Mar. 3	50.60	0.05	4.11	0.16	31	11	3	Sunday.		
Mar. 4	42.40	0.05	4.12	0.17	35	15	6	1,200	1,500	360
Mar. 5	42.70	0.05	4.11	0.17	135	52	10	13,000	850	...
Mar. 6	48.60	0.07	4.13	0.17	135	54	12	18,000	8,000	...
Mar. 7	50.50	0.08	4.12	0.18	102	46	8	24,000	6,500	1,800
Mar. 8	51.80	0.09	4.12	0.18	100	40	6	22,000	6,000	1,600
Mar. 9	53.00	0.10	4.12	0.18	90	40	5	24,000	6,000	800
Mar. 10	54.40	0.12	4.11	0.19	82	39	6	Sunday.		
Mar. 11	51.00	0.12	4.12	0.19	68	32	7	18,000	4,300	240
Mar. 12	51.20	0.12	4.07	0.19	46	25	5	11,000	4,600	210
Mar. 13	50.50	0.12	4.00	0.19	40	20	5	9,000	1,500	200
Mar. 14	46.50	0.12	...	0.20	39	20	4	5,500	1,200	90
Mar. 15	45.80	0.12	3.98	0.20	35	18	4	6,500	1,100	150
Mar. 16	42.50	0.12	3.97	0.19	60	24	4	5,000	800	160
Mar. 17	49.30	0.14	3.98	0.19	135	45	5	Sunday.		
Mar. 18	52.60	0.16	3.98	0.20	170	59	9	9,000	1,700	100

Mar. 19	53.50	0.17	4.01	0.19	125	51	8	7,000	1,000	120
Mar. 20	52.90	0.17	3.99	0.18	102	40	6	4,800	700	75
Mar. 21	48.20	0.16	4.00	0.19	125	42	5	8,500	1,100	90
Mar. 22	51.80	0.18	4.01	0.20	190	82	5	7,500	1,100	55
Mar. 23	51.60	0.19	4.01	0.20	180	75	6	7,500	1,300	90
Mar. 24	48.20	0.17	4.01	0.20	140	68	7	Sunday.		
Mar. 25	48.50	0.18	4.01	0.20	88	40	5	4,400	900	75
Mar. 26	45.90	0.18	3.98	0.20	62	32	4	3,600	750	90
Mar. 27	50.50	0.20	4.04	0.20	47	25	4	2,200	400	60
Mar. 28	49.60	0.20	3.92	0.19	35	16	3	1,300	350	55
Mar. 29	42.20	0.17	3.98	0.19	26	12	3	700	180	20
Mar. 30	48.00	0.22	4.01	0.19	25	7	3	310	220	39
Mar. 31	49.10	0.22	3.99	0.20	21	6	2	Sunday.		
April 1	49.10	0.24	4.00	0.20	20	6	2	600	110	38
April 2	49.70	0.25	4.00	0.20	24	6	2	270	110	29
April 3	51.40	0.27	4.00	0.21	24	6	2	460	85	31
April 4	48.70	0.27	4.00	0.22	20	6	2	280	60	22
April 5	48.10	0.27	4.00	0.22	20	5	2	450	70	40
April 6	Shut down awaiting Mr. Maiguen to apply bone-charcoal.									
April 7	Removed 1.06 in. of sand.							Sunday.		
April 8	52.20	0.33	4.05	0.27	18	4	3	330	...	...
April 9	46.90	0.29	4.02	0.29	18	4	2	140	60	32
April 10	47.60	0.31	4.03	0.28	30	4	1	750	120	28
April 11	46.00	0.30	4.04	0.28	66	7	2	4,000	...	32
April 12	45.40	0.31	4.03	0.29	72	20	3	14,000	2,900	85
April 13	45.10	0.32	3.99	0.32	80	30	3	13,000	2,500	95
April 14	49.00	0.34	4.00	0.32	77	35	4	Sunday.		
April 15	47.80	0.35	3.99	0.33	62	31	4	7,000	1,100	60
April 16	47.40	0.36	3.99	0.34	47	27	4	3,600	650	31
April 17	45.60	0.36	4.00	0.34	39	21	3	1,600	160	38
April 18	45.70	0.36	4.00	0.34	30	13	2	1,810	210	42
April 19	45.60	0.37	4.00	0.34	25	9	2	790	190	34
April 20	45.30	0.40	4.00	0.36	20	6	2	540	87	23
April 21	47.20	0.44	3.99	0.38	20	4	2	Sunday.		
April 22	45.20	0.42	3.99	0.38	18	3	1	235	55	22
April 23	44.90	0.44	4.05	0.40	15	3	1	170	45	16
April 24	40.50	0.41	4.02	0.44	19	2	1	150	14	14
April 25	39.60	0.41	4.03	0.45	34	3	1	700	12	23
April 26	40.70	0.44	4.05	0.45	46	4	1	1,200	80	16
April 27	39.30	0.44	4.00	0.44	52	4	1	1,700	160	23
April 28	34.70	0.43	4.05	0.44	45	5	1	Sunday.		
April 29	37.20	0.45	4.00	0.42	44	6	1	600	60	10
April 30	43.00	0.49	4.00	0.41	39	7	1	550	55	15
May 1	41.30	0.49	4.00	0.41	31	6	1	500	80	17
May 2	42.40	0.49	4.00	0.41	24	5	1	500	80	19
May 3	40.70	0.48	4.00	0.40	19	4	1	280	75	48
May 4	33.80	0.47	4.00	0.39	16	3	1	400	80	9
May 5	26.20	0.43	4.00	0.39	15	1	1	Sunday.		
May 6	29.00	0.38	3.99	0.37	13	2	1	390	100	65
May 7	27.60	0.36	...	0.37	12	2	1	190	60	19
May 8	24.70	0.31	3.99	0.37	10	2	1	...	...	...
	Washed.									
May 9	24.40	0.03	3.98	0.39	10	2	1	390	65	10
May 10	24.80	0.04	4.00	0.42	10	2	1	300	80	18
May 11	50.00	0.06	4.00	0.44	12	2	1	390	110	12
May 12	50.00	0.08	4.00	0.48	17	2	1	Sunday.		
May 13	50.00	0.09	4.00	0.47	35	3	1	600	100	18
May 14	50.00	0.10	4.00	0.46	39	4	1	500	65	15
May 15	48.50	0.15	4.00	0.45	17	3	1	500	70	16
May 16	47.00	0.16	4.00	0.46	24	3	1	290	70	16
May 17	47.00	0.16	3.99	0.47	18	3	1	260	40	9
May 18	47.00	0.19	4.00	0.48	15	2	1	190	...	17
May 19	47.00	0.21	3.99	0.51	12	2	1	Sunday.		

May 20	46.60	0.24	4.00	0.53	12	2	1	260	40	13
May 21	46.40	0.24	4.00	0.55	16	2	1	260	65	9
May 22	46.40	0.27	4.00	0.58	20	2	1	280	35	12
May 23	46.40	0.29	4.00	0.61	15	2	1	130	35	10
May 24	46.40	0.30	4.00	0.63	15	2	1	170	26	6
May 25	46.40	0.32	4.00	0.66	15	2	1	340	80	13
May 26	46.40	0.34	3.99	0.70	18	2	1	Sunday.		
May 27	46.40	0.86	3.99	0.74	13	2	1	210	80	7
May 28	46.40	0.38	3.15	0.76	16	2	1	260	70	10
May 29	46.00	0.44	3.88	0.78	16	2	1	500	55	12
May 30	45.60	0.46	3.99	0.86	14	2	1	Holiday.		
May 31	45.60	0.46	4.00	0.92	17	2	1	380	65	11
June 1	45.60	0.46	4.00	0.98	15	2	1	900	48	10
June 2	45.60	0.48	4.00	1.09	17	2	1	Sunday.		
June 3	45.60	0.51	4.00	1.20	24	2	1	550	75	16
June 4	45.60	0.54	4.00	1.32	37	3	1	6,500	...	22
June 5	45.60	0.55	4.00	1.48	65	5	1	3,200	140	19
June 6	45.60	0.56	4.01	3.66	77	16	1	1,500	210	14
June 7	45.00	0.57	4.00	1.80	64	27	1	2,100	230	20
June 8	45.00	0.57	4.00	1.90	46	22	1	600	240	33
June 9	45.00	0.55	4.01	2.00	44	18	1	Sunday.		
June 10	45.00	0.56	4.00	2.09	36	12	1	240	110	43
June 11	45.00	0.58	4.00	2.17	30	8	1	280	130	60
June 12	45.00	0.60	4.01	2.27	34	8	1	330	150	60
June 13	45.00	0.62	4.00	2.36	35	10	1	480	...	120
June 14	45.00	0.63	3.99	2.49	31	9	1	440	...	65
June 15	45.00	0.64	3.99	2.56	32	8	1	420	...	49
June 16	44.70	0.65	4.00	2.63	26	7	1	Sunday.		
June 17	44.40	0.64	4.00	2.67	26	6	1	340	270	55
June 18	45.00	0.63	3.98	2.69	31	7	1	440	140	65
June 19	45.00	0.63	4.00	2.73	37	10	1	500	110	24
June 20	45.00	0.62	4.01	2.72	30	9	1	330	70	34
June 21	45.00	0.61	4.01	2.68	25	7	1	170	130	60
June 22	Shut down to scrape and apply asbestos and coke; removed 0.79 in. of sand.									
June 23	Applied 8 lb. of asbestos and 10 lb. of bone-charcoal.									
June 25	50.00	0.54	4.00	0.27	130	45	1	400	...	...
June 26	50.00	0.57	4.01	0.46	82	37	1	750	550	35
June 27	50.00	0.63	4.01	0.55	65	26	1	...	1,200	140
June 28	50.00	0.65	3.99	0.63	47	21	1	...	1,200	26
June 29	50.00	0.70	4.00	0.73	37	9	1	220	800	22
June 30	50.00	0.77	3.99	0.82	30	8	1	Sunday.		
July 1	50.00	0.87	4.00	0.80	30	8	1	400	90	37
July 2	50.00	0.95	4.01	0.73	32	9	1	180	230	25
July 3	50.00	1.01	4.00	0.66	36	10	1	350	80	58
July 4	50.00	1.03	4.00	0.58	44	12	1	Holiday.		
July 5	50.00	1.07	3.99	0.54	24	14	1	550	130	47
July 6	50.00	1.10	4.00	0.52	39	12	1	250	110	33
July 7	50.00	1.14	4.00	0.50	34	10	1	Sunday.		
July 8	50.00	1.16	4.00	0.48	25	7	1	220	190	14
July 9	50.00	1.18	4.00	0.46	22	5	1	50	30	3
July 10	50.00	1.20	3.99	0.45	47	11	1	Lost.	Lost.	Lost.
July 11	50.00	1.20	3.99	0.45	90	30	1	150	140	12
July 12	50.00	1.20	4.01	0.44	97	35	1	300	110	20
July 13	50.00	1.15	4.00	0.47	90	39	1	220	120	14
July 14	50.00	1.15	4.00	0.48	90	40	1	Sunday.		
July 15	50.00	1.14	3.99	0.48	95	40	1	375	320	19
July 16	50.00	1.19	4.00	0.48	120	45	1	Lost.	150	12
July 17	50.00	1.21	4.00	0.48	85	42	1	270	60	5
July 18	50.00	1.19	3.99	0.50	56	32	1	1,675	23	39
July 19	50.00	1.16	3.99	0.52	41	20	1	450	200	13
July 20	50.00	1.16	3.99	0.56	62	29	1	300	220	8
July 21	50.00	1.19	3.99	0.63	62	31	1	Sunday.		
July 22	50.00	1.20	3.99	0.77	80	36	1	1,400	70	9

July 23	50.00	1.21	3.99	0.93	105	40	1	3,700	370	25
July 24	50.00	1.38	3.99	1.07	95	40	1	770	260	31
July 25	50.00	1.17	3.99	1.22	77	32	1	250	230	3
July 26	50.00	1.07	4.00	1.37	67	29	1	140	90	12
July 27	50.00	1.11	4.00		54	25	1	300	180	6
July 28	50.00	1.22	3.98	1.65	46	19	1	Sunday.		
July 29	50.00	1.21	4.00	1.82	36	16	1	470	230	18
July 30	50.00	1.20	3.99	1.98	29	11	1	Plates lost.		
July 31	50.00	1.20	3.99	2.11	21	9	1	Plates lost.		
Aug. 1	51.00	1.21	3.99	2.27	16	6	1	Plates lost.		
Aug. 2	51.00	1.21	3.99	2.43	15	4	1	130	130	4
Aug. 3	51.00	1.21	4.00	2.66	16	3	1	120	80	4
Aug. 4	50.00	1.21	3.99	2.95	21	3	1	Sunday.		
Aug. 5	50.00	1.21	3.98	3.22	29	3	1	230	210	4
Aug. 6	50.00	1.22	3.98	3.50	34	4	1	85	320	19
Aug. 7	50.00	1.21	3.99	3.74	21	4	1	200	Lost.	19
Aug. 8	48.20	1.20	...	4.09	19	4	1	100	150	17
Aug. 9	50.00	1.18	...	4.45	16	3	1	75	220	9
Aug. 10	47.30	1.16	...	4.67	24	3	1	60	250	10
Aug. 11	Shut down to drain and scrape sand filter; O.9 in. depth over all.									
Aug. 16	Out of service all the rest of month washing sponge and asbestos.									
Sept. 3	50.00	0.02	4.00	0.16	12	5	1	300	...	...
Sept. 4	50.00	0.02	3.99	0.14	16	6	1	600	260	370
Sept. 5	50.00	0.02	4.01	0.13	34	6	1	360	71	165
Sept. 6	46.40	0.02	4.00	0.12	160	52	1	15,000	1,900	120
Sept. 7	50.00	0.03	4.00	0.11	64	26	1	2,000	170	62
Sept. 8	46.40	0.04	3.99	0.11	56	25	1	Sunday.		
Sept. 9	50.00	0.05	4.90	0.11	59	25	1	220	13	19
Sept. 10	50.00	0.05	4.00	0.11	57	21	1	18,000	100	24
Sept. 11	50.00	0.06	4.00	0.11	65	25	1	2,700	150	25
Sept. 12	50.00	0.07	4.00	0.12	72	26	1	1,000	190	36
Sept. 13	50.00	0.08	4.00	0.12	87	30	1	2,300	...	35
Sept. 14	50.00	0.09	4.01	0.12	72	27	1	2,400	130	230
Sept. 15	48.20	0.11	4.00	0.12	65	25	1	Sunday.		
Sept. 16	51.00	0.13	4.00	0.12	65	25	1	Lost.	Lost.	27
Sept. 17	50.00	0.14	4.00	0.12	52	21	1	420	60	29
Sept. 18	49.10	0.14	4.00	0.13	60	18	1	900	80	41
Sept. 19	50.00	0.15	4.00	0.13	85	22	1	2,000	...	19
Sept. 20	49.10	0.17	4.00	0.13	100	29	1	4,200	300	28
Sept. 21	49.10	0.18	4.00	0.13	120	34	1	1,100	160	30
Sept. 22	48.20	0.20	4.00	0.13	137	41	1	Sunday.		
Sept. 23	49.10	0.19	4.00	0.13	112	37	1	2,400	90	34
Sept. 24	46.40	0.19	3.99	0.14	100	35	1	4,000	210	12
Sept. 25	46.40	0.20	4.00	0.14	432	80	1	56,000	510	27
Sept. 26	45.60	0.24	4.00	0.15	385	80	4	1,300	450	55
Sept. 27	44.80	0.27	4.00	0.16	245	70	3	4,000	240	41
Sept. 28	46.40	0.30	3.99	0.16	127	46	2	15,000	430	37
Sept. 29	46.40	0.31	3.99	0.16	105	41	2	Sunday.		
Sept. 30	46.40	0.31	4.00	0.17	115	42	1	Lost.	1,600	110
Oct. 1	48.20	0.33	4.00	0.18	82	36	1	600	600	120
Oct. 2	50.00	0.33	4.01	0.19	65	27	1	4,400	170	47
Oct. 3	48.20	0.33	4.00	0.19	59	34	1	900	210	44
Oct. 4	48.20	0.34	4.00	0.19	55	20	1	850	200	37
Oct. 5	50.00	0.38	4.00	0.19	9	21	1	2,000	150	34
Oct. 6	48.20	0.41	4.00	0.19	59	24	1	Sunday.		
Oct. 7	48.20	0.42	4.00	0.19	552	17	1	1,250	200	28
Oct. 8	50.00	0.42	4.00	0.19	54	16	1	11,000	210	28
Oct. 9	44.80	0.40	4.00	0.19	51	16	1	2,000	310	29
Oct. 10	48.20	0.42	4.00	0.19	50	15	1	800	220	16
Oct. 11	48.20	0.43	4.00	0.20	47	13	1	2,000	310	46
	Washed.									
Oct. 12	50.00	0.14	4.00	0.20	36	11	1	1,200	370	25
Oct. 13	47.30	0.15	4.00	0.21	40	15	1	Sunday.		

Oct. 14	50.00	0.18	4.00	0.22	47	19	1	1,200	390	22
Oct. 15	53.00	0.20	4.00	0.23	41	16	1	900	140	16
Oct. 16	50.00	0.20	4.00	0.24	35	12	1	Lost.	310	18
Oct. 17	50.00	0.21	4.00	0.25	30	8	1	550	180	7
Oct. 18	50.00	0.21	4.00	0.25	25	6	1	260	100	33
Oct. 19	50.00	0.21	4.00	0.25	25	6	1	750	220	15
Oct. 20	50.00	0.22	4.00	0.25	20	5	1	Sunday.		
Oct. 21	50.00	0.23	4.00	0.25	19	5	1	480	120	11
Oct. 22	50.00	0.24	4.00	0.26	18	4	1	230	70	7
Oct. 23	50.00	0.25	4.00	0.26	15	3	1	250	120	12
Oct. 24	50.00	0.26	4.00	0.26	15	3	1	300	80	12
Oct. 25	50.00	0.27	4.00	0.27	15	2	1	450	60	15
Oct. 26	50.00	0.28	4.00	0.27	15	2	1	450	Lost.	14
Oct. 27	50.00	0.29	4.00	0.27	13	2	0	Sunday.		
Oct. 28	50.00	0.30	4.00	0.27	13	2	0	190	110	9
Oct. 29	50.00	0.31	4.00	0.27	25	2	0	380	...	...
Oct. 30	50.00	0.32	4.00	0.27	21	3	0	...	...	...
Oct. 31	Out of commission. 4-in supply pipe stopped up.									
Nov. 4	50.00	0.16	4.00	0.28	125	11	1	...	...	...
Nov. 5	50.00	0.17	4.00	0.28	185	61	1	6,000	3,000	220
Nov. 6	50.00	0.18	4.00	0.29	170	66	1	5,000	1,100	150
Nov. 7	50.00	0.20	4.00	0.30	100	45	1	14,000	1,600	120
Nov. 8	50.00	0.21	4.00	0.32	95	42	1	1,900	2,000	29
Nov. 9	50.00	0.22	4.00	0.34	80	36	1	4,000	2,000	110
Nov. 10	50.00	0.23	4.00	0.36	67	29	1	Sunday.		
Nov. 11	50.00	0.24	3.46	0.38	52	20	1	1,900	460	160
Nov. 12	50.00	0.26	3.99	0.40	40	13	1	7,500	1,100	110
Nov. 13	50.00	0.27	4.00	0.44	36	10	1	1,600	550	50
Nov. 14	50.00	0.28	4.00	0.49	42	13	1	2,700	950	48
Nov. 15	50.00	0.29	4.00	0.55	35	11	1	1,800	900	49
Nov. 16	50.00	0.30	4.00	0.65	26	7	1	1,100	360	35
Nov. 17	50.00	0.31	3.98	0.80	20	5	1	Sunday.		
Nov. 18	50.00	0.32	3.99	0.98	17	4	1	1,600	200	35
Nov. 19	50.00	0.34	3.99	1.26	16	3	1	1,300	400	55
Nov. 20	50.00	0.35	3.98	1.64	45	4	1	6,500	3,500	200
Nov. 21	50.00	0.36	3.99	2.03	52	12	1	9,900	4,500	130
Nov. 22	50.00	0.37	3.98	2.33	65	24	1	10,000	5,500	220
Nov. 23	50.00	0.38	3.99	2.60	49	19	1	18,000	3,500	100
Nov. 24	50.00	0.40	3.98	2.85	134	32	1	Sunday.		
Nov. 25	48.20	0.45	3.98	3.10	225	87	2	50,000	19,000	340
Nov. 26	50.00	0.49	3.98	3.62	237	90	2	40,000	11,000	220
Nov. 27	50.00	0.51	3.99	4.15	185	77	2	16,000	7,500	310
Nov. 28	50.00	0.54	3.84	4.44	130	57	2	Holiday.		
Nov. 29	50.00	0.55	3.67	4.55	80	36	1	10,000	2,200	80
Nov. 30	50.00	0.56	3.44	4.65	54	25	1	3,800	2,200	55
Dec. 2	Shut down to scrape sand filter.									
Dec. 6	50.00	0.64	4.00	0.46	16	3	1	---	---	---
Dec. 7	50.00	0.64	4.00	0.39	14	3	1	2,400	1,200	490
Dec. 8	50.00	0.64	4.01	0.35	12	2	1	Sunday.		
Dec. 9	50.00	0.65	4.01	0.33	11	2	1	1,200	420	60
Dec. 10	50.00	0.65	4.00	0.33	12	2	1	800	950	66
Dec. 11	47.30	0.64	4.00	0.35	255	84	3	6,500	1,600	140
Dec. 12	46.40	0.70	3.98	0.39	212	100	6	48,000	15,000	1,800
Dec. 13	50.00	0.79	3.98	0.49	495	217	9	42,000	20,000	1,600
Dec. 14	52.00	0.84	3.97	0.65	357	167	9	49,000	9,500	1,200
Dec. 15	49.10	0.84	3.98	0.77	157	76	6	Sunday.		
Dec. 16	49.10	0.86	3.97	0.84	90	42	4	19,000	800	700
Dec. 17	49.10	0.88	3.98	0.91	70	31	2	21,000	18,000	1,600
Dec. 18	48.20	0.89	3.98	0.94	49	21	2	6,500	7,000	600
Dec. 19	50.00	0.91	3.98	0.97	39	13	1	Lost.	Lost.	Lost.
Dec. 20	49.10	0.92	3.98	1.03	42	16	1	"	"	"
Dec. 21	50.00	0.94	3.98	1.08	26	7	1	"	"	"
Dec. 22	50.00	0.97	3.98	1.13	20	5	1	Sunday.		

Dec. 23	50.00	0.95	3.98	1.19	34	9	1	1,400	500	160
Dec. 24	47.30	0.93	3.98	1.28	195	75	2	9,000	1,700	130
Dec. 25	44.10	0.91	3.97	1.47	445	210	9	Holiday.		
Dec. 26	46.40	1.01	3.97	1.63	370	172	7	51,000	8,000	250
Dec. 27	50.00	1.11	3.98	1.81	245	110	5	55,000	5,600	210
Dec. 28	48.20	1.12	3.99	1.87	102	46	3	10,000	4,500	140
Dec. 29	50.00	1.14	3.99	1.85	75	32	2	Sunday.		
Dec. 30	49.10	1.15	3.98	1.86	56	24	2	4,400	1,900	190
Dec. 31	50.00	1.17	4.00	1.87	39	15	1	14,000	1,300	60
1908.										
Jan. 1	50.00	1.18	3.98	1.90	31	8	1	...	...	...
Jan. 2	50.00	1.18	3.99	1.94	39	11	1	4,400	750	45
Jan. 3	50.00	1.19	3.98	1.98	36	11	1	3,100	1,600	70
	Washed.									
Jan. 4	50.00	0.17	3.97	2.09	32	9	1	2,400	1,200	43
Jan. 5	50.00	0.18	3.98	2.22	26	6	1	Sunday.		
Jan. 6	50.00	0.19	3.98	2.28	20	5	1	600	600	49
Jan. 7	50.00	0.20	3.98	2.37	20	5	1	1,100	330	49
Jan. 8	50.00	0.21	3.99	2.43	22	5	1	1,900	900	43
Jan. 9	50.00	0.23	3.98	2.52	45	13	1	13,000	3,400	50
Jan. 10	50.00	0.24	3.99	2.66	70	30	1	10,000	8,000	50
Jan. 11	50.00	0.27	3.98	2.74	56	22	1	16,000	220	200
Jan. 12	50.00	0.28	3.98	2.83	40	12	1	Sunday.		
Jan. 13	49.10	0.30	3.98	2.93	110	51	2	8,500	1,200	43
Jan. 14	48.20	0.33	3.99	3.04	210	113	4	16,000	6,000	280
Jan. 15	46.40	0.35	3.98	3.21	325	222	15	24,000	9,500	700
Jan. 16	50.00	0.40	3.98	3.49	360	247	42	28,000	14,000	900
Jan. 17	50.00	0.43	3.98	3.86	242	147	26	65,000	20,000	1,200
Jan. 18	50.00	0.46	3.91	3.99	137	73	7	7,000	6,500	400
Jan. 19	...	...	...	...	...	...	...	Sunday.		
Jan. 20	Scraped.									
Jan. 21	50.00	0.48	3.00	0.76	55	25	4	...	...	...
Jan. 22	50.00	0.48	3.01	0.60	49	21	4	3,600	1,900	150
Jan. 23	50.00	0.49	3.00	0.57	40	15	3	1,800	700	170
Jan. 24	50.00	0.49	2.99	0.60	40	13	3	2,300	950	90
Jan. 25	50.00	0.50	2.99	0.65	39	12	3	1,100	800	95
Jan. 26	50.00	0.50	2.98	0.69	32	9	2	Sunday.		
Jan. 27	50.00	0.51	2.99	0.76	32	9	2	300	700	70
Jan. 28	50.00	0.52	2.99	0.82	45	15	2	1,200	900	70
Jan. 29	50.00	0.55	2.99	0.90	60	26	2	1,000	1,400	95
Jan. 30	50.00	0.57	2.98	0.98	57	27	2	1,400	210	33
Jan. 31	50.00	0.58	2.98	1.08	42	18	2	1,100	750	45
Feb. 1	50.00	0.59	2.99	1.16	39	14	2	750	1,000	70
Feb. 2	49.10	0.60	2.99	1.22	27	9	2	Sunday.		
Feb. 3	49.10	0.61	2.98	1.30	29	8	2	1,300	750	20
Feb. 4	50.00	0.64	2.99	1.40	25	6	2	600	900	60
Feb. 5	50.00	0.66	2.99	1.50	24	6	2	750	200	75
Feb. 6	50.00	0.67	2.99	1.55	20	5	2	2,000	800	60
Feb. 7	50.00	0.68	3.00	1.56	17	4	1	...	600	34
Feb. 8	50.00	0.69	3.00	1.53	15	4	1	900	220	35
Feb. 9	50.00	0.71	3.00	1.54	14	4	1	Sunday.		
Feb. 10	50.00	0.72	2.99	1.60	11	4	1	850	500	28
Feb. 11	50.00	0.74	2.99	1.62	10	4	1	1,000	500	23
Feb. 12	50.00	0.75	2.98	1.68	8	4	1	750	290	18
Feb. 13	50.00	0.76	2.99	1.74	9	4	1	700	260	10
Feb. 14	48.20	0.76	2.99	1.77	9	4	1	1,200	250	27
Feb. 15	51.80	0.79	2.99	1.89	61	18	1	5,500	4,800	13
Feb. 16	48.20	0.79	2.99	2.08	80	40	2	Sunday.		
Feb. 17	48.20	0.81	2.99	2.24	80	40	3	33,000	1,300	60
Feb. 18	47.30	0.82	2.99	2.31	130	65	3	...	950	120
Feb. 19	51.80	0.92	2.99	2.45	320	200	7	28,000	22,000	360
Feb. 20	52.70	0.99	2.99	2.61	177	97	9	22,000	16,300	350
Feb. 21	51.80	1.03	2.99	2.68	105	52	6	10,600	3,800	270
Feb. 22	50.90	1.07	2.99	2.72	85	42	5	Holiday.		

Feb. 23	50.00	1.09	2.99	2.76	60	30	4		Sunday.	
Feb. 24	51.80	1.12	2.99	2.80	46	19	3	3,600	1,700	120
Feb. 25	50.00	1.14	2.99	2.84	31	9	2	2,300	1,300	60
Feb. 26	50.00	1.17	3.00	2.87	30	8	2	3,800	1,300	43
Feb. 27	48.20	1.18	2.99	2.90	30	7	1	1,300	900	42
Feb. 28	47.30	1.19	2.99	2.94	37	7	1	1,400	800	31
Feb. 29	51.80	1.23	2.99	3.01	123	49	2	13,500	750	35
Mar. 1	48.20	1.20	2.98	2.99	97	44	5		Sunday.	
Mar. 2	50.00	1.28	2.99	3.12	82	35	4	8,000	2,500	70
Mar. 3	50.90	1.32	2.98	3.22	87	38	4	11,000	6,000	55
Mar. 4	50.00	1.33	2.99	3.28	67	29	3	6,000	1,400	38
Mar. 5	50.00	1.35	2.99	3.32	59	23	3	4,400	2,500	37
Mar. 6	Discontinued; sand filter being used for sedimentation experiments.									

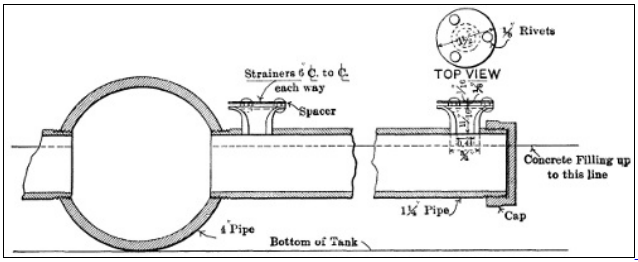

Figure 9—Detail of Strainer System.

Table 19—Record of Experimental Filter Plant. No. 3.

Date.	Sand Filter.		Turbidity.			Bacteria.			Coagulant.
	Rate.	Loss of head.	Applied water.	Effluent, coagulant.	Effluent, sand.	Applied water.	Effluent, coagulant.	Effluent, sand.	Grains, per gallon.
1907.									
Feb. 12	2.99	0.18	14	...	2	...	...	...	...
Feb. 13	3.00	0.17	15	...	2	600	...	...	...
Feb. 14	3.19	0.18	15	...	2	650	...	...	...
Feb. 15	3.86	0.22	12	...	2	600	...	2,500	...
Feb. 16	3.84	0.29	14	...	2	850	...	1,600	...
Feb. 17	...	...	...	...	...	...	...	...	...
Feb. 18	...	...	...	...	...	1,200	...	300	...
Feb. 21	3.91	0.32	20	...	2	1,800	...	550	...
Feb. 22	3.95	0.39	15	...	2	2		Holiday.	
Feb. 23	3.94	0.43	20	...	3	1,600	...	1,100	...
Feb. 24	3.89	0.47	20	...	3	3		Sunday.	
Feb. 25	4.19	0.52	20	...	3	1,400	...	600	...
Feb. 26	4.13	0.57	20	...	3	700	...	650	...
Feb. 27	3.32	0.62	17	...	3	700	...	2,300	...
Feb. 28	4.41	0.67	15	...	3	800	...	550	...
Mar. 1	3.91	0.72	15	...	3	650	...	300	...
Mar. 2	3.93	0.79	15	...	3	1,000	...	270	...
Mar. 3	3.90	0.82	31	...	3		Sunday.		
Mar. 4	3.92	0.80	35	...	3	1,200	...	140	1.45
Mar. 5	3.96	0.98	135	...	4	13,000	...	190	1.94
Mar. 6	4.05	1.25	135	29	2	18,000	2,100	160	2.03
Mar. 7	3.95	1.52	102	15	1	24,000	3,500	160	1.50
Mar. 8	3.90	1.67	100	15	1	22,000	1,800	130	1.38
Mar. 9	3.93	1.80	90	15	1	24,000	3,500	130	1.37
Mar. 10	3.95	1.91	82	16	1		Sunday.		1.26
Mar. 11	3.96	2.08	68	18	1	18,000	6,000	120	1.24
Mar. 12	4.02	2.19	46	18	1	11,000	9,000	140	1.08
Mar. 13	4.02	2.31	40	15	1	9,000	5,000	120	0.94
Mar. 14	3.96	2.44	39	16	1	5,500	3,600	90	0
Mar. 15	4.07	2.42	35	20	1	6,500	3,800	85	0
Mar. 16	3.85	2.20	60	29	1	5,000	3,500	100	1.26
Mar. 17	3.95	2.21	135	25	1		Sunday.		1.52

Mar. 18	3.88	2.86	170	25	1	9,000	1,900	85	1.75
Mar. 19	3.82	3.31	125	21	1	7,000	700	65	1.57
Mar. 20	3.78	3.47	102	20	1	4,800	1,500	60	1.31
Mar. 21	3.71	3.70	125	20	1	8,500	1,500	70	1.38
Mar. 22	3.64	3.81	190	25	1	7,500	1,100	35	1.57
Mar. 23	3.58	3.95	180	26	1	7,500	470	55	1.68
Mar. 24	3.46	4.18	140	19	1		Sunday.		1.52
Mar. 25	Scraped, 1.03 in. of sand removed.								
Mar. 27	4.06	0.22	47	8	1	2,200	480	60	1.08
Mar. 28	4.02	0.37	35	...	0	1,300	250	80	1.00
Mar. 29	4.02	0.46	26	...	...	700	240	65	0
Mar. 30	Shut down to fill coagulant basin.								
	...	...	25	...	...	310	...	...	0
Mar. 31	4.00	0.45	21	15	1		Sunday.		0
Apr. 1	3.39	0.42	20	15	1	600	1,000	43	0
Apr. 2	3.06	0.46	24	17	1	270	Lost.	35	0
Apr. 3	3.01	0.49	24	17	1	460	"	41	0
Apr. 4	2.95	0.50	20	15	1	280	550	27	0
Apr. 5	2.95	0.51	20	13	1	450	1,000	60	0
Apr. 6	2.96	0.49	20	12	1	320	50	35	0
Apr. 7	2.99	0.48	20	12	1	Sunday.	0		
Apr. 8	3.01	0.49	18	12	1	330	650	22	0
Apr. 9	3.01	0.55	18	12	1	140	750	21	0
Apr. 10	3.02	0.57	30	15	0	750	5,000	29	0
Apr. 11	3.04	0.61	66	16	0	4,000	550	25	1.11
Apr. 12	3.09	0.72	72	13	0	14,000	2,200	17	1.15
Apr. 13	3.07	0.88	80	19	0	13,000	3,900	25	1.14
Apr. 14	2.98	1.04	77	18	1		Sunday.		1.17
Apr. 15	2.97	1.20	62	18	1	7,060	2,200	19	1.09
Apr. 16	3.01	1.32	47	17	1	3,600	900	22	1.08
Apr. 17	3.05	1.44	39	19	0	1,600	1,100	12	0
Apr. 18	3.04	1.41	30	20	1	1,810	1,870	14	0
Apr. 19	3.04	1.35	25	18	1	790	910	14	0
Apr. 20	3.07	1.30	20	15	1	540	480	15	0
Apr. 21	3.07	1.26	20	15	1		Sunday.		...
Apr. 22	3.04	1.21	18	12	0	235	420	21	0
Apr. 23	3.06	1.22	15	10	0	170	420	8	0
Apr. 24	2.99	1.26	19	10	0	150	250	17	0
Apr. 25	3.04	1.27	34	12	0	700	260	19	0
Apr. 26	3.07	1.28	46	12	0	1,200	320	80	0
Apr. 27	2.94	1.49	52	...	0	1,700	1,500	70	0
Apr. 28	2.96	1.88	45	...	1		Sunday.		0
Apr. 29	2.99	2.40	44	33	1	600	1,400	19	0
Apr. 30	3.00	2.83	39	29	1	550	1,200	14	0
May 1	3.01	2.71	31	21	1	500	1,300	20	0
May 2	3.01	2.51	24	15	1	500	850	16	0
May 3	3.00	2.36	19	12	1	280	650	34	0
May 4	3.01	2.29	16	10	0	400	550	24	0
May 5	3.01	2.25	15	9	0		Sunday.		0
May 6	3.06	2.32	13	8	0	390	460	80	0
May 7	2.96	2.46	12	7	0	190	...	18	0
May 8	3.00	2.51	10	5	0	...	...	...	0
May 9	3.00	2.77	10	5	0	390	1,100	14	0
May 10	3.01	2.87	10	5	0	300	500	21	0
May 11	2.99	3.16	12	6	0	390	650	16	0
May 12	3.00	3.34	17	7	0		Sunday.		0
May 13	3.00	3.44	35	9	0	600	470	27	0
May 14	3.01	3.46	39	12	0	500	550	25	0
May 15	3.01	3.56	17	...	0	500	900	23	0
May 16	2.93	4.07	24	...	0	290	2,500	25	0
May 17	3.01	4.34	18	...	0	260	2,000	16	0
May 18	2.93	4.25	15	8	0	190	600	19	0
May 19	2.97	4.36	12	8	0		Sunday.		0

May 20	3.01	4.64	12	8	0	260	450	15	0
May 21	2.99	4.55	16	8	0	260	330	14	0
May 22	3.01	4.57	20	8	0	280	390	22	0
May 23	3.00	4.51	15	8	0	130	240	19	0
May 24	2.98	4.44	15	8	0	170	240	30	0
May 25	3.00	4.38	15	8	0	340	400	41	0
May 26	3.00	4.38	18	8	0		Sunday.		0
May 27	Shut down to scrape sand filter; 1.09 in. of sand removed.								
May 28	Cleaning coagulant basin and treating coagulant basin with 1:2,000,000 solution of copper sulphate.								
May 29			16	...	...	solution of copper sulphate.			
May 30	3.00	0.11	14	8	1		Holiday.		0
May 31	3.01	0.10	17	8	1	380	18,000	150	0
June 1	3.01	0.09	15	8	1	900	7,000	150	0
June 2	3.01	0.10	17	8	1		Sunday.		0
June 3	3.01	0.10	24	10	1	550	8,000	130	0
June 4	3.04	0.11	37	13	1	6,500	7,500	140	0
June 5	3.00	0.11	65	29	1	3,200	3,600	110	0
June 6	3.00	0.11	77	46	1	1,500	800	60	1.17
June 7	2.99	0.12	64	21	1	2,100	1,500	90	1.18
June 8	2.98	0.17	46	22	1	660	1,000	60	0
June 9	3.00	0.18	44	30	1		Sunday.		0
June 10	3.01	0.18	36	26	1	240	400	32	0
June 11	3.00	0.17	30	20	1	280	300	31	0
June 12	3.00	0.17	34	22	1	330	...	28	0
June 13	2.99	0.17	35	25	1	480	480	39	0
June 14	2.98	0.17	31	22	1	440	550	32	0
June 15	2.99	0.19	32	22	1	420	450	27	0
June 16	3.02	0.21	26	18	1		Sunday.		0
June 17	2.99	0.23	26	16	1	340	750	14	0
June 18	3.02	0.25	31	20	1	440	750	21	0
June 19	3.02	0.29	37	27	1	500	460	35	0
June 20	3.00	0.32	30	21	1	330	440	88	0
June 21	3.01	0.36	25	16	1	170	370	23	0
June 22	3.00	0.40	20	12	1	100	300	17	0
June 23	2.97	0.43	26	11	1		Sunday.		0
June 24	2.97	0.44	140	36	1	1,700	350	22	1.59
June 25	3.02	0.45	130	27	1	400	250	16	1.55
June 26	Interrupted, defective meter.					750	330	...	0
June 27	3.00	0.43	65	15	0	...	1,400	...	0
June 28	3.00	0.44	47	19	0	...	1,400	120	0
June 29	2.99	0.44	37	20	0	220	300	...	0
June 30	2.97	0.42	30	19	0		Sunday.		0
July 1	2.99	0.37	30	18	0	400	600	85	0
July 2	3.01	0.33	32	19	0	180	1,000	50	0
July 3	3.00	0.31	36	21	0	350	310	21	0
July 4	3.00	0.30	44	30	0		Holiday.		
July 5	3.00	0.29	44	35	0	550	400	41	0
July 6	3.00	0.28	39	30	0	250	280	22	0
July 7	3.00	0.28	34	24	0		Sunday.		0
July 8	3.00	0.28	25	16	0	220	260	27	0
July 9	3.00	0.27	22	13	0	50	40	19	0
July 10	2.98	0.27	47	27	1	Lost.	Lost.	Lost.	0
July 11	3.00	0.27	90	41	1	150	50	8	1.27
July 12	3.00	0.29	97	21	1	300	200	13	1.27
July 13	3.00	0.34	90	20	0	220	160	17	1.27
July 14	3.00	0.40	90	19	0		Sunday.		1.27
July 15	3.00	0.54	95	18	0	375	150		1.27
July 16	3.00	0.59	120	20	0	Lost.	50	Lost.	1.36
July 17	3.00	0.58	85	16	0	270	60	3	1.26
July 18	2.99	0.61	56	13	0	1,675	70		1.17
July 19	3.01	0.61	41	18	0	450	700	11	0
July 20	2.99	0.51	62	27	0	300	720	8	0
July 21	3.00	0.47	62	32	0		Sunday.		0

July 22	3.00	0.47	80	34	0	1,400	560	14	1.17
July 23	3.01	0.49	105	21	0	3,700	490	40	1.25
July 24	3.01	0.60	95	19	0	770	110	80	1.27
July 25	3.00	0.68	77	16	0	250	80	5	1.22
July 26	2.99	0.68	67	17	0	140	40	4	0
July 27	3.00	0.69	54	20	0	300	130	21	0
July 28	3.00	0.72	46	27	0		Sunday.		0
July 29	3.00	0.74	36	26	0	470	290	100	0
July 30	2.99	0.76	29	19	0	Lost.	Lost.	Lost.	0
July 31	2.99	0.77	21	12	0	Lost.	Lost.	Lost.	0
Aug. 1	3.00	0.75	16	9	0	Lost.	Lost.	Lost.	0
Aug. 2	3.00	0.74	15	8	0	130	140	4	0
Aug. 3	3.00	0.74	16	7	0	120	180	6	0
Aug. 4	3.00	0.75	21	6	0		Sunday.		
Aug. 5	3.00	0.76	29	8	0	230	100	44	0
Aug. 6	3.00	0.79	34	12	0	85	470	...	0
Aug. 7	2.99	1.01	21	12	0	200	450	...	0
Aug. 8	3.00	1.31	19	11	0	100	180	45	0
Aug. 9	2.98	1.44	16	9	0	75	80	16	0
Aug. 10	3.00	1.44	24	9	0	60	90	11	0
Aug. 11	3.00	1.49	62	22	0		Sunday.		
Aug. 12	3.00	1.62	120	39	0	620	260	16	1.45
Aug. 13	2.97	2.06	107	22	0	820	520	10	1.38
Aug. 14	2.97	3.06	82	19	0	850	120	26	1.22
Aug. 15	2.81	3.91	65	15	0	150	260	6	1.17
Aug. 16	3.00	4.29	45	18	0	270	340	17	0
Aug. 17	3.00	3.86	35	22	0	340	200	13	0
Aug. 18	3.00	3.47	21	13	0		Sunday.		
Aug. 19	3.00	3.49	18	10	0	180	220	17	0
Aug. 20	3.00	3.56	20	8	0	210	180	16	0
Aug. 21	3.00	3.58	20	10	0	1,300	650	8	0
Aug. 22	2.99	3.73	27	13	0	3,800	360	6	0
Aug. 23	3.00	4.00	49	34	0	2,500	700	10	0
Aug. 24	3.00	4.05	36	26	0	3,900	630	12	0
Aug. 25	2.98	4.06	34	24	0		Sunday.		
Aug. 26	3.00	4.20	21	13	0	700	310	16	0
Aug. 27	3.00	4.31	19	11	0	470	250	12	0
Aug. 28	2.99	4.40	18	10	0	500	160	18	0
Aug. 29	3.01	4.41	17	9	0	360	110	9	0
Aug. 30	2.98	4.46	15	8	0	320	310	14	0
Aug. 31	Scraped. 1.88 in. of sand removed.		13	...	...	200	100	...	0
Sept. 5	3.00	0.10	34	4	0	360	950	...	1.04
Sept. 6	3.00	0.10	160	3	0	15,000	1,500	190	1.35
Sept. 7	3.00	0.09	64	3	0	2,000	260	100	1.20
Sept. 8	3.00	0.08	56	4	0		Sunday.	...	1.04
Sept. 9	3.00	0.08	59	3	0	220	180	38	1.04
Sept. 10	2.97	0.07	57	3	0	18,000	150	29	1.06
Sept. 11	2.98	0.07	65	2	0	2,700	200	37	1.04
Sept. 12	2.98	0.08	72	2	0	1,000	125	19	1.04
Sept. 13	3.00	0.08	87	3	0	2,300	200	72	1.20
Sept. 14	3.00	0.08	72	3	0	2,400	360	36	1.12
Sept. 15	3.00	0.08	65	3	0		Sunday.		1.04
Sept. 16	3.00	0.08	65	2	0	Lost.	Lost.	38	1.04
Sept. 17	3.00	0.08	52	2	0	420	200	38	1.07
Sept. 18	3.00	0.08	60	2	0	900	200	17	1.07
Sept. 19	2.98	0.08	85	2	0	2,000	220	25	1.12
Sept. 20	2.98	0.09	100	2	0	4,200	320	31	1.24
Sept. 21	2.99	0.09	120	3	0	1,100	160	19	1.33
Sept. 22	3.00	0.09	137	3	0		Sunday.		1.45
Sept. 23	3.02	0.09	112	4	0	2,100	190	15	1.41
Sept. 24	3.00	0.10	100	4	0	4,000	620	13	1.33
Sept. 25	3.00	0.11	432	3	0	56,000	290	7	1.83
Sept. 26	2.99	0.11	385	2	0	1,300	950	19	2.34

Sept. 27	3.00	0.12	245	4	0	4,000	Lost.	20	1.91
Sept. 28	2.98	0.13	127	4	0	15,000	1,000	8	1.54
Sept. 29	2.98	0.14	105	4	0		Sunday.		1.34
Sept. 30	2.99	0.15	115	3	0	Lost.	Lost.	46	1.35
Oct. 1	3.00	0.15	82	3	0	600	1,700	22	1.24
Oct. 2	2.98	0.16	65	3	0	4,400	550	8	1.09
Oct. 3	3.00	0.17	59	2	0	900	330	15	1.04
Oct. 4	2.99	0.17	55	2	0	850	250	11	1.03
Oct. 5	2.99	0.19	59	2	0	2,000	450	25	1.04
Oct. 6	2.98	0.20	59	2	0		Sunday.		1.04
Oct. 7	2.98	0.21	52	2	0	1,250	2,300	42	1.04
Oct. 8	2.97	0.21	54	2	0	11,000	100	15	1.04
Oct. 9	2.98	0.22	51	2	0	2,000	1,600	7	1.04
Oct. 10	2.98	0.24	50	2	0	800	Lost.	24	1.04
Oct. 11	2.98	0.25	47	2	0	2,000	1,200	21	0
Oct. 12	2.97	0.26	36	3	0	1,200	1,200	19	0
Oct. 13	2.98	0.27	40	4	0		Sunday.		0
Oct. 14	2.98	0.29	47	5	0	1,200	830	25	0
Oct. 15	2.99	0.31	41	5	0	900	Lost.	105	0
Oct. 16	2.99	0.32	35	4	0	Lost.	550	19	0
Oct. 17	2.98	0.34	30	4	0	550	800	21	0
Oct. 18	3.00	0.35	25	4	0	260	350	9	0
Oct. 19	3.00	0.35	25	4	0	750	310	35	0
Oct. 20	3.00	0.35	20	3	0		Sunday.		0
Oct. 21	3.00	0.35	19	3	0	480	540	35	0
Oct. 22	2.99	0.36	18	3	0	230	440	17	0
Oct. 23	2.99	0.37	15	3	0	250	440	39	0
Oct. 24	2.98	0.38	15	3	0	300	500	60	0
Oct. 25	2.99	0.39	15	3	0	450	410	65	0
Oct. 26	2.99	0.40	15	3	0	450	500	44	0
Oct. 27	2.99	0.41	13	2	0		Sunday.		0
Oct. 28	2.99	0.43	13	2	0	190	500	50	0
Oct. 29	2.98	0.44	25	2	0	380	60	75	0
Oct. 30	2.99	0.46	21	2	0	450	180	3	0
Oct. 31	2.96	0.48	25	3	0	2,300	390	75	0
Nov. 4	3.00	0.51	125	2	0	...	...	...	0
Nov. 5	3.00	0.53	185	2	0	6,000	1,600	90	1.70
Nov. 6	2.99	0.56	170	2	0	5,000	3,900	6	1.70
Nov. 7	2.99	0.60	100	3	0	14,000	300	9	1.48
Nov. 8	2.99	0.64	95	3	0	1,900	230	2	1.27
Nov. 9	2.99	0.70	80	4	0	4,000	2,700	200	0
Nov. 10	2.99	0.79	67	4	0		Sunday.		0
Nov. 11	2.99	1.00	52	6	0	1,900	2,000	200	0
Nov. 12	2.99	1.46	40	9	0	7,500	2,300	160	0
Nov. 13	2.98	2.09	36	10	0	1,600	1,100	170	0
Nov. 14	2.99	2.74	42	9	0	2,700	950	130	0
Nov. 15	2.99	2.98	35	8	0	1,800	800	11	0
Nov. 16	2.99	3.03	26	8	0	1,100	800	90	0
Nov. 17	3.00	3.07	20	6	0		Sunday.		0
Nov. 18	3.00	3.09	17	5	0	1,600	700	100	0
Nov. 20	2.99	3.17	45	3	0	6,500	120	120	0
Nov. 21	2.99	3.22	52	3	0	9,900	1,000	80	0
Nov. 22	2.99	3.27	65	5	0	10,000	3,200	90	0
Nov. 23	2.99	3.33	49	8	0	18,000	2,400	100	0
Nov. 24	2.99	3.41	134	11	0		Sunday.		0
Nov. 25	2.98	3.54	225	12	1	50,000	2,100	65	1.68
Nov. 26	2.98	3.68	237	13	1	40,000	2,400	95	1.76
Nov. 27	2.99	3.96	185	16	1	16,000	2,600	60	1.74
Nov. 28	2.98	4.29	130	18	1		Holiday.		1.57
Nov. 29	2.97	4.48	80	19	1	10,000	2,500	65	1.50
Nov. 30	2.97	4.54	54	15	1	3,800	1,900	85	0
Dec. 6	Scraped, 1.62 in. of sand removed.								

Dec. 8	2.97	0.16	12	3	0		Sunday.		1.17
Dec. 9	2.98	0.16	11	3	0	1,200	410	10	1.17
Dec. 10	2.98	0.15	12	3	0	800	550	150	1.17
Dec. 11	2.99	0.15	255	3	0	6,500	600	130	1.52
Dec. 12	3.00	0.13	212	2	0	48,000	500	130	1.99
Dec. 13	2.98	0.13	495	4	0	42,000	500	120	2.06
Dec. 14	2.99	0.14	357	5	0	49,000	750	150	2.12
Dec. 15	2.99	0.15	157	6	0		Sunday.		1.69
Dec. 16	2.98	0.16	90	9	0	19,000	900	20	1.28
Dec. 17	2.98	0.20	70	12	0	21,000	400	170	1.17
Dec. 18	2.98	0.24	49	12	1	6,500	7,000	350	1.17
Dec. 19	2.98	0.29	39	9	1	Lost.	Lost.	Lost.	1.17
Dec. 20	2.98	0.36	42	7	1	Lost.	Lost.	Lost.	1.17
Dec. 21	2.97	0.45	26	5	0	Lost.	Lost.	Lost.	1.17
Dec. 22	2.98	0.57	20	4	0		Sunday.		1.17
Dec. 23	2.98	0.71	34	3	0	1,400	1,300	220	1.17
Dec. 24	2.98	0.83	195	2	0	9,000	1,000	140	1.49
Dec. 25	2.98	0.97	445	2	0		Holiday.		2.43
Dec. 26	2.98	1.11	370	2	0	51,000	1,000	39	2.15
Dec. 27	2.98	1.27	245	3	0	55,000	1,600	70	1.91
Dec. 28	2.98	1.40	102	4	0	10,000	1,000	80	1.50
Dec. 29	2.98	1.60	75	3	0		Sunday.		1.21
Dec. 30	2.97	1.85	56	3	0	4,400	700	80	1.17
Dec. 31	2.98	2.07	39	2	0	14,000	1,200	65	1.17
1908.									
Jan. 1	2.99	2.11	31	2	0		Holiday.		1.17
Jan. 2	2.98	2.17	39	2	0	4,400	700	19	1.17
Jan. 3	2.98	2.26	36	2	0	3,100	1,000	13	1.17
Jan. 4	2.98	2.34	32	2	0	2,400	550	19	1.17
Jan. 5	2.98	2.41	26	2	0		Sunday.		1.17
Jan. 6	2.98	2.49	20	2	0	600	230	18	1.17
Jan. 7	2.98	2.58	20	2	0	1,100	370	12	1.17
Jan. 8	2.99	2.61	22	2	0	1,900	1,100	20	1.17
Jan. 9	2.99	2.63	45	2	0	13,000	1,200	22	1.21
Jan. 10	2.98	2.67	70	2	0	10,000	700	16	1.17
Jan. 11	2.98	2.72	56	2	0	16,000	1,200	11	1.17
Jan. 12	2.98	2.78	40	2	0		Sunday.		1.17
Jan. 13	2.98	2.84	110	2	0	8,500	90	6	1.27
Jan. 14	2.98	2.95	210	2	0	16,000	150	23	1.56
Jan. 15	2.98	3.07	325	3	0	24,000	1,100	19	1.92
Jan. 16	2.98	3.23	360	5	6	28,000	1,000	14	2.10
Jan. 17	2.97	3.73	242	6	0	65,000	490	23	1.91
Jan. 18	2.98	4.42	137	6	0	7,000	1,600	14	1.66
Jan. 19	2.99	4.75	117	5	0		Sunday.		1.50
Jan. 21	Scrape, 1.45 in. of sand removed.								
Jan. 23	3.00	0.14	40	3	0	...	...	...	1.17
Jan. 24	3.00	0.14	40	3	0	2,300	550	55	1.17
Jan. 25	3.00	0.13	39	3	0	1,100	850	95	0
Jan. 26	3.00	0.13	32	3	0		Sunday.		0
Jan. 27	3.00	0.13	32	2	0	300	280	60	0
Jan. 28	2.99	0.15	45	3	0	1,200	700	70	0
Jan. 29	2.99	0.20	69	6	1	1,000	900	75	0
Jan. 30	2.99	0.24	57	8	1	1,400	650	50	0
Jan. 31	2.99	0.30	42	6	1	1,100	600	36	0
Feb. 1	2.99	0.34	39	5	1	750	50	25	0
Feb. 2	2.99	0.41	27	4	1		Sunday.		0
Feb. 3	2.99	0.51	29	3	0	1,300	220	16	0
Feb. 4	2.99	0.56	25	3	0	600	370	10	0
Feb. 5	2.99	0.58	24	4	0	750	700	21	0
Feb. 6	2.99	0.61	20	6	0	2,000	650	4	0
Feb. 7	3.00	0.64	17	8	1	...	410	26	0
Feb. 8	2.99	0.66	15	8	1	900	160	42	0
Feb. 9	3.00	0.67	14	8	1		Sunday.		0
Feb. 10	2.99	0.67	11	8	1	850	450	18	0

Feb. 11	3.00	0.66	10	7	1	1,000	600	26	0
Feb. 12	3.01	0.64	8	6	1	750	350	16	0
Feb. 13	3.00	0.62	9	5	1	700	120	10	0
Feb. 14	3.00	0.61	9	5	1	1,200	950	43	0
Feb. 15	3.00	0.60	61	5	1	5,500	1,000	23	0
Feb. 16	3.00	0.60	80	6	1		Sunday.		0
Feb. 17	3.00	0.62	80	14	1	33,000	6,100	36	0
Feb. 18	2.99	0.67	130	20	1	...	2,000	11	0
Feb. 19	2.99	0.76	320	18	2	28,000	9,000	120	0
Feb. 20	2.99	0.83	177	15	2	22,000	8,500	190	0
Feb. 29	3.00	0.85	123	8	1	...	...	...	0
Mar. 1	3.00	0.87	97	9	1		Sunday.		0
Mar. 2	2.99	0.92	82	13	1	8,000	4,400	50	0
Mar. 3	2.98	0.96	87	19	1	11,000	2,100	26	0
Mar. 4	2.99	1.02	67	21	1	6,000	4,700	7	0
Mar. 5	2.99	1.08	59	25	1	4,400	10,000	36	0
Mar. 6	2.99	1.15	72	25	2	7,000	7,400	50	0
Mar. 7	2.98	1.21	82	25	2	9,500	6,500	28	0
Mar. 8	2.99	1.25	92	29	2		Sunday.		0
Mar. 9	2.99	1.30	125	34	2	11,000	4,800	25	0
Mar. 10	2.99	1.35	142	39	2	8,500	1,200	23	0
Mar. 11	2.99	1.39	155	35	2	6,500	2,400	20	0
Mar. 12	2.99	1.42	135	29	2	5,900	1,500	11	0
Mar. 13	2.99	1.46	122	19	2	1,900	1,100	12	0
Mar. 14	2.99	1.47	97	12	1	1,800	700	6	0
Mar. 15	2.99	1.48	77	8	1		Sunday.		0
Mar. 16	3.00	1.52	65	9	0	1,400	700	8	0
Mar. 17	2.99	1.66	59	7	0	900	800	11	0
Mar. 18	2.99	1.72	67	11	1	1,000	650	8	0
Mar. 19	2.99	1.75	60	24	1	...	600	18	0
Mar. 20	2.99	1.81	57	25	1	1,300	750	20	0
Mar. 21	2.99	1.89	67	22	1	800	480	18	0
Mar. 22	2.99	1.95	80	21	1		Sunday.		0
Mar. 23	3.00	2.00	90	26	1	4,600	440	19	0
Mar. 24	2.98	2.06	82	32	1	2,500	1,200	10	0
Mar. 25	2.99	2.17	67	39	1	1,600	650	20	0
Mar. 26	2.99	2.24	60	36	1	550	410	7	0
Mar. 27	2.99	2.29	59	30	1	900	900	29	0
Mar. 28	3.00	2.32	51	21	1	650	250	42	0
Mar. 29	2.99	2.35	31	18	1		Sunday.		0
Mar. 30	3.00	2.38	30	14	1	500	650	28	0
Mar. 31	2.99	2.43	39	9	1	750	290	30	0
Apr. 1	2.99	2.50	44	7	1	750	390	32	0
Apr. 2	2.99	2.58	42	8	1	1,100	280	47	0
Apr. 3	2.99	2.65	41	11	1	1,500	550	70	0
Apr. 4	2.99	2.74	54	12	1	700	380	4	0
Apr. 5	3.00	2.82	50	12	1		Sunday.		0
Apr. 6	2.99	2.88	41	14	1	440	150	4	0
Apr. 7	2.99	2.98	35	13	1	650	270	42	0
Apr. 8	2.98	3.15	39	11	1	550	210	65	0
Apr. 9	2.99	3.35	40	8	1	390	160	95	0
Apr. 10	2.98	3.50	40	8	1	500	130	130	0
Apr. 11	2.99	3.65	45	7	0	430	145	100	0
Apr. 12	2.99	3.79	52	5	0		Sunday.		0
Apr. 13	2.99	3.92	50	4	0	490	160	80	0
Apr. 14	2.99	4.05	45	4	0	550	170	90	0
Apr. 15	2.99	4.16	45	3	0	420	160	12	0
Apr. 16	...	4.24	45	3	0	360	130	90	0
Apr. 21	Scraped, 0.12 in. of sand removed.								
Apr. 23	...	0.13	25	2	0	140	140	...	0
Apr. 24	3.00	0.12	21	2	0	200	Lost.	150	0
Apr. 25	3.00	0.10	20	2	0	85	550	45	0
Apr. 26	3.00	0.10	21	3	0		Sunday.		0

Apr. 27	3.00	0.10	18	3	0	95	850	50	0
Apr. 28	3.00	0.10	20	3	0	70	220	48	0
Apr. 29	3.00	0.09	24	3	0	110	210	95	0
Apr. 30	3.00	0.09	21	3	0	70	140	29	0
May 1	3.00	0.09	32	3	0	130	210	65	0
May 2	3.00	0.09	26	3	0	140	140	55	0
May 3	3.00	0.11	22	5	0		Sunday.		0
May 4	3.00	0.11	19	4	0	85	210	75	0
May 5	3.00	0.11	18	4	0	130	150	48	0
May 6	2.99	0.12	18	3	0	230	430	50	0
May 7	3.00	0.13	19	3	0	160	90	40	0
May 8	3.00	0.14	19	3	0	375	425	7	0
May 9	2.99	0.14	18	3	0	1,209	180	6	0
May 10	3.00	0.14	30	3	0		Sunday.		0
May 11	3.00	0.13	60	3	0	2,800	150	12	0
May 12	3.00	0.13	70	3	0	2,900	225	26	0
May 13	3.00	0.13	66	7	0	1,800	450	53	0
May 14	3.00	0.14	45	9	0	2,700	550	10	0
May 15	2.99	0.14	39	7	0	950	300	65	0
May 16	2.99	0.22	49	6	0	800	250	49	0
May 17	2.99	0.33	46	4	0		Sunday.		0
May 18	2.99	0.44	31	3	0	700	1,700	80	0
May 19	2.98	0.62	36	3	0	375	950	53	0
May 20	2.99	0.75	41	3	0	425	700	46	0
May 21	2.99	0.89	31	4	0	300	600	6	0
May 22	2.99	1.01	50	5	0	950	230	17	0
May 23	2.99	1.12	127	5	0	2,400	32	28	0
May 24	2.99	1.20	110	6	0		Sunday.		0
May 25	2.99	1.24	90	9	0	1,100	850	9	0
May 26	2.98	1.31	135	11	0	3,200	150	17	0
May 27	2.97	1.54	110	12	0	1,450	175	8	0
May 28	2.97	1.81	90	10	0	1,000	132	7	0
May 29	2.97	2.08	70	7	0	1,100	230	8	0
May 30	2.97	2.36	50	5	0		Holiday.		0
May 31	2.98	2.63	34	4	0		Sunday.		0
June 1	2.98	2.77	35	2	0	...	...	...	0
June 2	2.98	2.84	39	2	0	...	...	...	0
June 3	2.98	3.02	35	3	0	...	...	...	0
June 4	3.00	3.01	30	4	0	...	...	...	0
June 5	3.00	2.97	30	5	0	...	...	...	0
June 6	3.01	2.81	27	5	0	...	...	...	0
June 7	3.01	2.62	22	5	0	...	...	...	0
June 8	3.01	2.38	20	4	0	...	...	...	0
June 9	3.00	2.19	20	3	0	...	...	...	0
June 10	3.01	2.02	17	3	0	...	...	...	0
June 11	2.99	1.89	12	3	0	...	...	...	0
June 12	2.98	1.92	11	2	0	...	...	...	0
June 13	2.98	1.99	36	2	0	...	...	...	0
June 14	2.98	2.08	39	2	0	...	...	...	0
June 15	2.98	2.25	25	4	0	...	...	...	0
June 16	2.98	2.54	34	5	0	...	...	...	0
June 17	2.97	2.85	64	5	0	...	...	...	0
June 18	2.97	3.20	57	5	0	...	...	...	0
June 19	2.98	3.47	46	7	0	...	...	...	0
June 20	2.99	3.73	37	8	0	...	...	...	0
June 21	2.99	4.10	29	8	0	...	...	...	0
June 22	2.99	4.44	25	6	0	...	...	...	0
June 23	2.99	4.61	25	5	0	...	...	...	0
June 26	3.01	0.09	15	2	0	...	...	...	0
June 27	3.00	0.09	12	2	0	...	...	...	0
June 28	3.00	0.09	9	2	0	...	...	...	0
June 29	3.00	0.08	8	2	0	...	...	...	0

June 30	3.00	0.07	10	2	0	...	...	...	0
July 1	3.00	0.07	6	2	0	80	75	3	0
July 2	3.00	0.07	8	2	0	290	20	3	0
July 3	3.00	0.07	8	2	0	350	140	4	0
July 4	3.00	0.07	9	2	0		Holiday.		0
July 5	3.00	0.07	10	2	0		Sunday.		0
July 6	3.00	0.07	9	2	0	300	52	4	0
July 7	3.00	0.07	8	2	0	110	35	2	0
July 8	3.00	0.07	9	2	0	85	105	2	0
July 9	3.00	0.07	8	2	0	85	80	3	0
July 10	...	...	...	...	...	300	65	1	0
July 11	3.00	0.08	12	2	0	145	95	11	0
July 12	3.00	0.08	11	2	0		Sunday.		0
July 13	3.00	0.08	10	2	0	115	105	7	0
July 14	3.00	0.09	16	2	0	800	34	1	0
July 15	3.00	0.09	17	2	0	180	165	3	0
July 16	3.00	0.10	14	2	6	100	95	2	0
July 17	3.00	0.10	10	2	0	65	65	1	0
July 18	3.00	0.11	11	2	0	38	200	24	0
July 19	3.00	0.11	12	2	0		Sunday.		0
July 20	3.00	0.12	10	2	0	95	31	1	0
July 21	3.00	0.12	10	2	0	70	100	2	0
July 22	3.00	0.13	13	2	0	450	13	4	0
July 23	2.99	0.13	54	2	0	650	325	4	0
July 24	2.99	0.14	305	2	0	1,650	325	...	0
July 25	3.00	0.15	330	4	0	2,600	55	2	0
July 26	3.00	0.15	290	9	0		Sunday.		0
July 27	3.00	0.16	335	11	0	35,000	1,200	6	0
July 28	2.99	0.17	170	10	0	1,200	675	6	0
July 29	3.00	0.17	180	8	0	2,000	270	11	0
July 30	2.99	0.18	237	7	0	800	190	2	0
July 31	3.00	0.19	250	6	0	1,000	310	6	0

Table 20—Summary of Results of Experimental Filters.

Filter number Number of runs	1 3	2 6	3 11	4 12	5 25	6 28
Rate, million gallons per acre per day:						
Maximum..............	1.35	3.95	7.96	12.60	37.5	118.9
Minimum...............	0.62	2.30	3.73	5.77	6.68	7.1
Average................	1.06	3.26	6.69	10.17	26.1	38.54
Length of run, in days:						
Maximum..............	233.5	150.5	75.2	90.9	48.71	39.83
Minimum...............	181.7	42.0	14.5	10.1	0.67	0.62
Average................	206.4	109.6	48.89	40.5	14.41	12.61
Million gallons filtered per acre per run:						
Maximum..............	242.61	484.46	534.67	960.72	1,463.35	1,022.27
Minimum...............	202.60	135.66	93.79	92.57	19.53	53.32
Average................	218.58	302.82	326.76	417.23	374.14	361.92
Cubic yards of sand removed per acre at end of each run:						
Maximum..............	269	269	672	1,612	2,420	3,360
Minimum...............	269	134	101	134	134	101
Average................	269	213	272	392	583	635
Cubic yards of sand removed per acre per million gallons filtered..........	1.23	0.70	0.83	0.94	1.55	1.72
Average initial loss of head.........	0.07	0.19	0.51	0.78	3.88	5.38
Turbidity, influent:						
Maximum..............	120	120	120	120	90	100
Minimum...............	2	2	2	2	2	2
Average................	20	20	21	22	18	19
Turbidity, effluent:						
Maximum..............	11	13	17	18	30	30
Minimum...............	0	0	0	0	0	0
Average................	1	1	2	2	4	3
Percentage reduction.........	95.0	95.0	90.5	90.9	77.8	84.3

Bacteria, influent:						
Maximum..............	180,000	180,000	180,000	110,000	180,000	37,500
Minimum...............	22	20	22	20	25	24
Average................	4,800	5,100	4,500	4,200	6,900	5,900
Bacteria, effluent:						
Maximum..............	4,000	1,300	3,200	5,400	12,800	2,400
Minimum...............	2	3	1	1	2	2
Average................	160	85	110	120	190	180
Percentage,Reduction.........	96.7	98.3	97.6	97.3	97.3	97.0
Number of samples examined for *bacillus coli* in influent:						
10 c.c.	549	478	476	436	325	336
1 c.c.	560	492	486	445	335	342
0.1 c.c.	525	459	452	413	318	317
0.01 c.c.	511	443	439	405	308	304
0.001 c.c.	500	434	429	394	299	294
Number of samples examined for *bacillus coli* in effluent:						
10 c.c.	512	452	454	404	296	309
1 c.c.	513	454	457	406	299	311
0.1 c.c.	480	419	426	383	271	286
0.01 c.c.	478	406	410	367	261	276
0.001 c.c.	478	406	410	367	261	276
Number samples positive, influent:						
10 c.c.	226	211	201	258	136	152
1 c.c.	127	123	116	108	81	93
0.1 c.c.	55	59	54	51	43	42
0.01 c.c.	26	34	33	33	27	25
0.001 c.c.	6	6	5	6	3	3
Number samples positive, effluent:						
10 c.c.	100	109	134	98	94	106
1 c.c.	51	61	55	56	46	50
0.1 c.c.	9	13	16	16	4	13
0.01 c.c.	0	0	0	0	0	0
0.001 c.c.	0	0	0	0	0	0
Percentage of samples showing *bacillus coli* in influent:						
10 c.c.	41.2	44.2	42.2	59.2	41.9	45.2
1 c.c.	22.7	25.0	23.9	24.3	24.2	27.2
0.1 c.c.	10.5	12.8	11.9	12.3	13.5	13.2
0.01 c.c.	5.1	7.7	7.5	8.2	8.8	8.2
0.001 c.c.	1.2	1.4	1.2	1.5	1.0	1.0
Percentage of samples showing *bacillus coli* in effluent:						
10 c.c.	19.5	24.1	29.5	24.2	31.7	34.3
1 c.c.	10.0	13.4	12.0	13.8	15.4	16.1
0.1 c.c.	1.9	3.1	3.8	4.2	1.5	4.5
0.01 c.c.	0	0	0	0	0	0
0.001 c.c.	0	0	0	0	0	0
Cost per million gallons for sand handling.........	$0.43	$0.25	$0.29	$0.33	$0.54	$0.60
Interest charges at 3%.........	6.85	2.25	1.12	0.73	0.32	0.22
Total.........	7.28	2.50	1.41	1.06	0.86	.82

Coli tests presumptive.

DISCUSSION

Allen Hazen, M. Am. Soc. C. E. (by letter).—This paper contains a most interesting and instructive record of the actual operation of a large filter plant, and also a record of a number of experiments. The author has described some useful arrangements for improving the efficiency or reducing the cost.

The utility of raking, as an intermediate treatment between scrapings, seems to have been clearly demonstrated. Its practical effect is to allow a greater quantity of water to be passed between scrapings, thereby saturating—if the term may be used—the surface layer with clay and other fine matter before removing it, instead of taking it off when only a thin surface layer of it has been thus saturated.

The large proportion of the total purification that takes place in passing through three reservoirs successively, holding in the aggregate a quantity of water equal to about 7 days' use, is very striking. Taking all the records, the percentage remaining after passing through these reservoirs, is as follows:

Sediment for the year, 1909-1910, Table 2	17%
Turbidities, 5-year average, Table 3	25%
Bacteria, 5-year average, Table 4	24%
Bacteria, selected winter months with high numbers in the raw water	20%
Bacteria, selected summer months with high numbers in the raw water	2.5%

There is considerable seasonal fluctuation in the results of settling and filtering, as is shown in Table 21.

Table 21—Average Removal of Turbidity and Bacteria by Washington Filters for Whole Period, Arranged by Seasons.

		Winter.	Spring.	Summer.	Fall.	Year.
Turbidity, in parts per million:	raw	135	96	144	42	105
	settled	33	28	27	15	26
	filtered	4	3	1	0.5	2
Percentage left from:	settling	24	29	19	36	25
	filtering	12	10	4	3	8
	both	3	1	0.3	1	2
Bacteria per cubic centimeter:	raw	16,600	4,150	4,100	1,960	6,700
	settled	6,300	980	160	270	1,940
	filtered	149	29	18	22	54
Percentage left from:	settling	38	24	4	14	29
	filtering	2.4	3.0	11.2	8.2	2.8
	both	0.90	0.79	0.44	1.12	0.81

The fluctuation in the efficiency of the plant as a whole by seasons is greater with the turbidity than with the bacteria. During the winter the effluent contains 3% of the turbidity of the raw water, and in summer only 0.3 per cent. Most of this difference is represented by the increased efficiency of the filters in summer, and only a little of it by the increased efficiency of settling. With bacteria, on the other hand, the seasonal fluctuation of the plant as a whole is comparatively small, but the settling and storage processes are much more efficient in summer than in winter, the filters being apparently less efficient. The writer believes that they are only apparently less efficient, and not really so, the explanation being that some bacteria always grow in the under-drains and lower parts of the filter, and are washed away by the effluent. The average number of bacteria in summer in the settled water is 160 per cu. cm. and in the filtered water 18. These are very low numbers. It is the writer's view that nearly all of these 18 represent under-drain bacteria, and practically bear no relation to those in the applied water, and, if this view is correct, the number of bacteria actually passing through the various processes is at all times less than the figures indicate. In the warmer part of the year the difference is a wide one, and the hygienic efficiency of the process is much greater than is indicated by the gross numbers of bacteria.

The reduction of the typhoid death rate has not been as great with the change in water supply as was the case at Lawrence, Albany, and other cities, apparently because the Potomac water before it was filtered was not the cause of a large part of the typhoid fever.

The sewage pollution of the Potomac is much less than that of the Merrimac and the Hudson, and it is perhaps not surprising that this relatively small amount of pollution was less potent in causing typhoid fever than the greater pollution of rivers draining more densely populated areas.

The method of replacing the washed sand hydraulically seems to have worked better than could have been reasonably anticipated, and the writer believes that this was due, in part, to the excellent method of manipulation described in the paper. It is his feeling, however, that part of the success is attributable to the very low uniformity coefficient of the sand. In other words, the sand grains are nearly all of the same size, due to the character of the stock from which the filter sand was prepared; and, therefore, there is much less opportunity for separation of the sand according to grain sizes than there would be with the filter sand which has been available in most other cases. Filter sand with a uniformity coefficient as low as that obtained at Washington has been rarely available for the construction of sand filters, and while the method of hydraulic return should certainly be considered, it will not be safe to assume that equally favorable results may be obtained with it with sands of high uniformity coefficients until actual favorable experience is obtained.

The writer believes that in calculating the cost of the water used in the plant itself the price chosen by the author, covering only the actual operating expenses of pumping and filtering, is too low. The capacity of the whole Washington Aqueduct system is reduced by whatever quantity is used in this way, and, in calculating the cost of sand handling, the value of the water used should be calculated on a basis which will cover the whole cost of the water, including all capital charges, depreciation, operating expenses, and all costs of every description. On this basis the water used in the sand-handling operations would probably be worth five or more times the sum mentioned by the author.

The cost of operation of the plant has come within the estimates made in advance, and has certainly been most reasonable. The cost of filter operations has averaged only about 50 cents per million gallons, and is so low that it is obvious that the savings which may be made by introducing further labor-saving appliances would be relatively small. It will be remembered that ten or fifteen years ago the cost of operating such filters under American conditions was commonly from $2 to $5 per million gallons.

The experiments represented by Tables 17 to 19, inclusive, serve to show that preliminary filtration, or multiple filtration, or any system of mechanical separation is incapable of entirely removing the finer clay particles which cause the residual turbidity in the effluent. They also show that this turbidity may be easily and certainly removed by the application of coagulant to the raw water during the occasional periods when its character is such as to require it.

These general propositions were understood by those responsible for the original design of the plant, as is shown by the author's quotations. These experiments, however, were necessary in order to demonstrate and bring home the conditions to those who thought differently, and who believed that full purification could be obtained by filtration alone, or by double filtration, without recourse to the occasional use of coagulant.

The experiments briefly summarized in Table 20 are of the greatest interest and importance. Six small filters, otherwise alike and like the large filters, all received the same raw water and were operated at different rates to determine the effect of rate on efficiency.

That the experimental results from the filter operating at the same rate as the large filters were on the whole somewhat inferior to those from the large filters for approximately the same period, may be attributed to the fact that the experimental filter was new while the large filters had been in service for some time and had thereby gained in efficiency. The greatest difference was in the *coli* results in Table 20, where it is shown that 24% of the 10-cu. cm. effluent samples from the experimental filter contained *coli*, in comparison with only from 1 to 3% of such samples from the main filters.

The results from the experimental filter operating at a rate of 1,000,000 gal. per acre daily may fairly be excluded, as the effluent probably contained more under-drain bacteria in proportion than filters operated at higher rates. The number of bacteria in the filter operating at a 3,000,000-gal. rate were 1.7% of those in the applied water; for the filter operating twice as fast, the percentage was 2.4; and, for the one operating more than ten times as fast, was only 3.0; thus indicating a surprisingly small increase in the number of bacteria with increase in rate.

Further and more detailed study by the writer of the unpublished individual results, briefly summarized in Table 20, confirms the substantial accuracy of the comparison based on the average figures as stated in that table.

It must be kept in mind, in considering these results, that the number of bacteria in each case is made up of two parts, namely, those coming through the filter—which number is presumably greater as the rate is greater—and, second, those coming from harmless growths in the under-drains and lower parts of the filter—the numbers of which per cubic centimeter are presumably less as the rate is greater—and these two parts, varying in opposite directions, may balance each other, as they seem to do in this case, through a considerable range. It may thus be that the number of bacteria really passing the filter varies much more with the rate than is indicated by the gross results.

It is also of interest to note that the sand filter (called a preliminary filter) in Table 18, filled with the same kind of sand, when operated at an average rate of 50,000,000 gal. per acre daily for a year, allowed 18% of the applied bacteria to pass, in comparison with 3% found in Filter No. 6 of Table 20, operated at an average rate of 38,000,000 gal. per acre daily.

There was one point of difference in the manipulation: the preliminary filter was washed by a reversed current of water, as mechanical filters are washed, while Filter No. 6 was cleaned by scraping off the surface layer, as is usual with sand filters. Whether the great difference in bacterial results with a relatively small difference in rate is to be attributed to this difference in manipulation the writer will not undertake to state.

If the experimental results of Table 20 indicate correctly the conditions which obtain in filtering Potomac water, then increasing the rate of filtration so as to double it, or more than double it, would make but little difference in the quality of the effluent as measured by the usual bacterial methods. If the increase in rate were accompanied by the preliminary filtration of the water, then, presumably, there would be little change in the quality of the effluent, and the maintenance of excellent results might be incorrectly attributed to the influence of the preliminary filter.

It would also seem that the apparatus which is sometimes used for determining and controlling the rate with more than the ordinary degree of precision is hardly justified by such experimental results as those presented by the author.

In contrast to these results may be mentioned those obtained by Mr. H. W. Clark,[1] for experimental filters operated with Merrimac River water, at rates ranging from 3,000,000 to 16,000,000 gal. per acre daily. The results are the average of nearly two years of experimental work, the period having been nearly coincident with that covered by the author's experiments, and of many hundreds of bacterial analyses of each effluent, and form, with the author's experiments, the most thorough-going studies of the effect of rate on efficiency that have come to the writer's attention.

Mr. Clark's results are given in Table 22.

[1] *Journal*, New England Water-Works Association, Vol. 24, p. 589.

Table 22.

Effective size of sand.	Filter No.	Rate in gallons acre daily.	Bacteria per cubic centimeter in	Bacteria efficiency.	*B. Coli* in 1 cu. cm. (percentage of positive tests).
0.28	A	3,000,000	48	99.1	5.0
0.25	B	5,000,000	85	98.4	24.0
0.22	C	7,500,000	105	98.1	25.0
0.22	D	10,000,000	110	98.0	25.0
0.22	E	16,000,000	280	95.0	38.0

It will be seen that the number of bacteria passing increases rapidly with the rate, and whether the total number of bacteria is considered or the *B. coli* results, the number passing is approximately in proportion to the rate. In other words, doubling the rate substantially doubles the number of bacteria in the effluent.

This is entirely in harmony with all the Lawrence experimental results extending over a period of 20 years. There have been occasional apparent exceptions, but, on the whole, experience with Merrimac River water has uniformly been that more bacteria pass as the rates are higher.

The theory sometimes advanced, that the efficiency of filtration is controlled to a certain extent by gelatinous films, and that, as far as thus controlled, is less dependent on rate, would not seem to be borne out by these results. The Merrimac River water, carrying large amounts of organic matter, would certainly seem better adapted to the formation of such films than the clay-bearing Potomac water, comparatively free from organic matter; but it is the Potomac water which seems to show the least influence of rate on efficiency.

The experiments show that turbidity passes more freely at the higher rates with the Potomac water, as has also been found to be the case with other clay-bearing waters.

In the last lines of Table 20 are given cost per million gallons for filtering at various rates. There is no discussion of these figures, and as they differ considerably from those which the writer has been accustomed to use, the calculation in Table 23, made three years ago for a particular case, may be of interest.

Table 23—Relative Cost of Filtering at Different Rates.

	Nominal rate, in millions of gallons per acre daily:			
	3	5	10	20
Percentage which average yield is of nominal rate	85	80	75	65
Average output per acre, in millions of gallons per day	2.55	4.00	7.5	13.0
Cost of that part of filters per acre dependent on rate	$12,000	$20,000	$40,000	$80,000

Cost of that part of filters per acre not dependent on rate	50,000	50,000	50,000	50,000
Total cost of filters per acre	60,000	70,000	90,000	130,000
Cost per million gallons of capacity	20,600	14,000	9,000	6,500
Cost per million gallons of average daily output	24,400	17,500	12,000	10,000
Capital charges and depreciation at 6% on cost per million gallons	4.00	2.87	1.97	1.64
Operating expenses, the same at all rates	1.00	1.00	1.00	1.00
Total cost of filtering, excluding pumping, storage, and all auxiliaries	5.00	3.87	2.97	2.64
Relative cost	1.29	1.00	0.77	0.68

When the costs of pumping, pure-water reservoirs usually necessary, etc., are taken into account (which add equally to the cost at all rates), the cost of filtering will vary less with the rate than is indicated.

The effect of rate on cost, as calculated in Table 23, and also the percentages of the bacteria of the raw water found in the effluents by the author and by Mr. Clark, are shown on Figure 10.

Considering all these results together, and also all the other evidence known to the writer bearing on this point, it seems clear that filters are not as sensitive to changes in rate, within reasonable limits, as has been frequently assumed; but, on the other hand, there is usually a substantial increase in the percentage of bacteria passing through a filter with increased rate.

Filters furnish relative, not absolute, protection against infectious matter in the raw water. The higher the bacterial efficiency, the more complete is this relative protection.

The cost of filtering does not decrease in inverse ratio to the rate, but at a much slower rate. This is especially true with rates of more than 5,000,000 or 6,000,000 gal. per acre daily.

In general, a rate of filtration may rationally be selected at which the value of the possible danger resulting from an increase in rate is equal to the saving that may be made in cost by its use. This point must be a matter of individual judgment. The tendency of the last few years has been to use higher rates, or, in other words, to cheapen the process and to tolerate a larger proportion of bacteria in the effluent. The use of auxiliary processes has been favorable to this, especially the use of chloride of lime, in connection with either the raw water or the effluent.

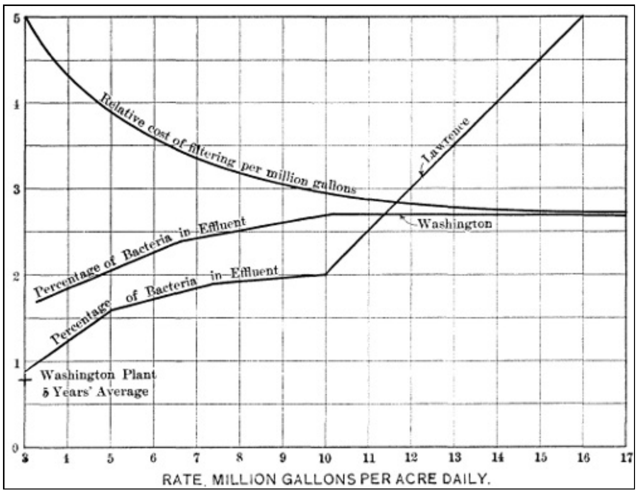

Figure 10—Rate Million Gallons Per Acre Daily.

By the judicious use of this substance, efficiency may be maintained while using higher rates than would otherwise have been desirable.

The writer believes that there will be many cases where the added risk of using too high a rate is not worth the relatively small saving in cost that accompanies it.

George A. Johnson, Assoc. M. Am. Soc. C. E.—This paper contains information of an exceedingly interesting nature. There is comparatively little difficulty in obtaining accurate figures on the cost of construction of water purification works, but, with costs of operation of such works, it is different. The data available in published reports and papers are usually more or less fragmentary, and unexplained local conditions with reference to the character of the raw water, the cost of labor and supplies, and methods of apportioning these costs, introduce variables so wide as frequently to render the published figures almost useless for purposes of comparison.

Mr. Hardy's paper is noteworthy in that it presents certain relatively new features of slow sand filter operation which have been only lightly touched on in water purification literature up to the present time. These refer particularly to means whereby a filter may be continued in service without removing a portion of the surface layer of the filter surface itself when the available head has become exhausted, and to methods whereby washed sand may be expeditiously and more economically restored to the filter than has been the case hitherto.

Sand handling is the most important item of expense in the operation of a slow sand filter. Quite recently a charge of $1.50 per cu. yd. for sand scraping, transportation to sand washers, washing, and restoring to the filter, was not considered exorbitant, but the improved methods developed during recent years at Washington, Philadelphia, Albany, and more recently at Pittsburg (at all of which places hydraulic ejection plays an important part), have shown the feasibility of reducing this figure by nearly, if not quite, two-thirds.

The practice observed at Washington of raking over the surface of the sand layer when the available head becomes exhausted, in order to avoid the cost and loss of time necessitated by shutting down the filter and scraping off the surface layer, is unquestionably one of the most striking advances in slow sand filter operation in recent years. In rapid sand filter operation, to prolong the period of service between washings, agitation of the filter surface has been used to advantage for many years. The full value of surface raking may not be generally appreciated, but the results which have followed a trial of this procedure at Washington, Philadelphia, and Pittsburg have shown that the output of filtered water between scrapings may be doubled or trebled thereby, with no injury to the filter itself or to the quality of the filtered water. The cost of raking over the surface of a 1-acre slow sand filter unit is less than $10 at all the above-mentioned places, which fact in itself shows the great saving in money and time effected by periodically substituting surface raking for scraping. Under ordinary conditions it has been found that a filter can be raked to advantage at least twice between scrapings.

In the case of filters thus raked, a deeper penetration of suspended matter into the sand layer is inevitable, but at Pittsburg, as at Washington, such penetration does not extend more than about 2 in. below the filter surface. When the filter is finally scraped, a deeper layer is removed, of course, but it is clearly more economical to remove a deep layer at one operation than to remove separately several thinner layers of an equal total thickness.

The lost-time element is an important one, and at Washington this was the main reason for trying surface raking. It became necessary to increase the output of the filters, and the ordinary scraping consumed so much time that the sand-handling force was increased, working day and night. The raking expedient introduced at this time overcame this, and Mr. Hardy states that it is still followed when the work is at all pressing. The speaker has found at Pittsburg, as Mr. Hardy has found at Washington, that raking is nearly if not quite as effective as scraping in restoring the filter capacity.

Eleven years ago the speaker was connected with the preliminary investigations into the best methods of purifying the Potomac River water for Washington. It then appeared that while for the greater part of the time during an average year the Potomac River could be classed among the clear waters of the East, there were periods when excessive turbidity made it necessary to consider carefully methods of preparatory treatment before this water could be filtered effectively and economically. As Mr. Hardy has said, considerable prejudice existed against the use of a coagulating chemical, and the expedient was therefore adopted of giving the water a long period of sedimentation in order to remove enough of the suspended matter to allow the clarified water to be treated on slow sand filters. The expert commission, consisting of Messrs. Hering, Fuller, and Hazen, recommended the occasional use of a coagulating chemical, but this recommendation was not carried out.

The Potomac River is somewhat peculiar, in that the turbidity of its waters, as shown by the results presented in Mr. Hardy's paper, ranges from 3,000 to practically nothing. The bacterial content also varies widely, and Mr. Hardy's tables show this variation to be from 76,000 to 325 per cu. cm. Such a water as this requires particularly careful preparatory treatment. The Dalecarlia Reservoir has a capacity of something like 2 days' storage, the Georgetown Reservoir the same, and the McMillan Park Reservoir nearly 3 days, making a total sedimentation of more than 7 days. Without the use of a coagulant, it is significant that during a period of five years, even with 7 days' sedimentation, the average maximum turbidity of the water delivered to the filters was 106 parts per million, and the maximum average turbidity in one month was 250 parts per million. The water filtration engineer can readily understand that waters as turbid as this cannot be treated economically and efficiently in slow sand filters. It would appear that coagulating works might advantageously have been installed at the entrance to the Dalecarlia Reservoir. If this had been done, and coagulant had been added to the water at times when it was excessively turbid, a considerably shorter period of subsequent sedimentation than now exists would in all probability have rendered the water at all times amenable to efficient and economical slow sand filter treatment.

The prejudice in Washington against the use of coagulants has also manifested itself in other localities, but the results which have been obtained during the past twenty years from rapid sand filters and from slow sand filters, treating waters previously coagulated with salts of iron or alumina, have shown how thoroughly unreasonable were these objections. In this connection it is interesting to note that there are in the United States more than 350 rapid sand filter plants, and that nearly 12% of the urban population of Continental United States is being supplied with water filtered through rapid sand filters, in connection with all of which a coagulating chemical is used in the preparatory treatment.

Table 24—Typhoid Fever Death Rates in Cities of the United States With Populations in 1910 of 100,000, or More.

Statistics gathered by correspondence and from Reports of the Bureau of the Census, Department of Commerce and Labor, Mortality Statistics.

Note.—Statistics from Birmingham, Ala., Dayton, Ohio, Fall River, Mass., Louisville, Ky., Memphis, Tenn., Oakland, Cal., and Providence, R. I., are not included, as they are incomplete.

City.	Typhoid Fever Death Rate per 100,000 Population.							
	1906	1907	1908	1909	1910	Average for six years, 1900-05, inclusive.	Average for five years, 1906-10, inclusive.	Average for 11 years, 1900-11, inclusive.
Albany, N. Y.	20	20	11	19	15	25	17	21
Atlanta, Ga.	50	64	47	44	43	65	50	58
Baltimore, Md.	34	41	31	23	41	36	34	35
Boston, Mass.	22	10	26	14	11	23	16	20
Bridgeport, Conn.	10	13	13	13	9	15	12	14
Buffalo, N. Y.	24	29	21	23	20	29	23	26
Cambridge, Mass.	18	10	10	9	12	18	12	15
Chicago, Ill.	18	18	15	12	14	27	16	22
Cincinnati, Ohio	71	46	19	13	6	54	31	44
Cleveland, Ohio	20	19	13	12	19	51	17	36
Columbus, Ohio	45	38	110	17	13	61	45	54
Denver, Colo.	68	67	58	24	30	37	49	42
Detroit, Mich.	22	28	22	19	16	17	22	19
Grand Rapids, Mich.	39	30	30	17	27	34	28	31
Indianapolis, Ind.	39	29	26	22	31	76	30	55
Jersey City, N. J.	20	14	10	8	10	19	12	16
Kansas City, Mo.	38	40	35	23	38	48	35	42

Los Angeles, Cal.	18	23	19	18	12	35	18	27
Lowell, Mass.	7	9	24	11	21	19	14	17
Milwaukee, Wis.	31	26	17	21	45	19	28	23
Minneapolis, Minn.	33	26	18	20	58	38	29	34
Nashville, Tenn.	66	85	62	53	48	54	58	56
Newark, N. J.	18	24	12	11	13	17	16	17
New Haven, Conn.	54	30	34	20	17	44	31	38
New York, N. Y.	15	17	12	12	12	19	14	17
New Orleans, La.	30	56	31	25	28	40	34	37
Omaha, Nebr.	28	24	22	31	75	20	36	27
Paterson, N. J.	4	11	10	5	7	25	7	17
Philadelphia, Pa.	74	60	36	22	17	47	42	45
Pittsburg, Pa.	141	135	53[1]	13[1]	12[1]	132	71	104
Richmond, Va.	44	41	50	24	22	66	36	53
Rochester, N. Y.	17	16	12	9	13	15	13	14
St Louis, Mo.	18	16	15	15	14	33	16	25
St Paul, Minn.	21	17	12	20	20	14	18	16
San Francisco, Cal.	...	57	27	17	15	20	29	24
Scranton, Pa.	11	76	11	11	14	18	35	26
Syracuse, N. Y.	10	16	15	12	30	14	17	15
Toledo, Ohio	45	36	40	31	32	36	37	36
Worcester, Mass.	12	14	10	8	16	17	12	15
Washington, D. C.	52	36	39	33	23	59	37	49

[1] Filtered water section. Allegheny District not included.

Attention has repeatedly been called to the fact that the relatively high typhoid death rate in Washington, since the filter plant was installed, was a possible indication that the filters were inefficient. It is true that there has not been the marked reduction in the typhoid death rate in Washington, following the installation of the water filtration works, that has been observed in other cities in America. For the six years prior to the date on which filtered water was supplied to the citizens of Washington, the average typhoid fever death rate was 59 per 100,000 population, as against 37 per 100,000 for the five years following, a reduction of 37 per cent. At Albany, N. Y., where the first modern slow sand filter was built in 1899, the typhoid death rate has been reduced by 75 per cent. At Cincinnati, Ohio, the average death rate from typhoid ranged around 50 per 100,000 for years, but since the installation of the filtration plant it has been reduced to a point which places that city, with respect to freedom from typhoid fever, at the head of all the large cities in America; in 1910 the death rate from typhoid in Cincinnati was 6 per 100,000. Similarly, at Columbus, Ohio, where the typhoid death rate before the installation of the filtration plant in 1906 was even higher than at Cincinnati, it was reduced to less than 13 per 100,000 in 1910, whereas, for the previous five years, it was 61 per 100,000. Philadelphia, before the installation of the filtration works, had a typhoid death rate of 60 or more per 100,000, and in 1910 the death rate from this disease was 17. Pittsburg, at least that part of it now supplied with filtered water, for years had a typhoid death rate of more than 130 per 100,000, but the present rate is about 12 per 100,000.

Table 25—Average Monthly Results for the Period, 1905-1910.

Reservoirs.	Period of sedimentation in days.	Turbidity in parts per million.	Bacteria per cubic centimeter.	Percentage Removed	
				Turbidy	Bacteria
River	...	106	6,400	...	...
Dalecarlia	2.2	50	5,000	53	22
Georgetown	2.2	38	3,400	24	32
McMillan	2.8	26	2,000	31	41
Totals and averages	7.2	...	...	75	69

While it may perhaps seem unreasonable to single out Washington as a particular sufferer in this respect, it is highly probable that a large share of the typhoid is still caused by secondary infection, flies, impure milk, and private and public wells. The speaker remembers distinctly that ten years ago, when he made an investigation into the purity of the water of about 100 public wells in that city, a large number of them showed unmistakable evidence of being polluted with sewagic matter. Conclusive evidence would be secured to dispel any doubt as to the sanitary quality of the filtered product if hypochlorite of lime were added to the filtered water throughout one year or throughout the typhoid months. It seems strange to the speaker, that for this, if for no other reason, this safe and non-injurious germicide has not as yet been used at Washington, in view of the fact that at the present time it is being used continuously or intermittently in the treatment of the water supplies of scores of the most important cities of this country, among which may be mentioned New York, Philadelphia, Cincinnati, Pittsburg, St. Louis, and Minneapolis.

Morris Knowles, M. Am. Soc. C. E. (by letter).—This description of the operation of the Washington Filtration Works is timely and of great interest. It is ten years since the writer, in collaboration with Charles Gilman Hyde, M. Am. Soc. C. E., presented a similar record for the Lawrence, Mass., filter. That paper was the first complete, detailed, and continuous history of the actions and results obtained for a long period of time with such a purification works. [1] Since then, the art of filtration has advanced in many ways, particularly in regard to the methods of cleaning slow sand filters and in the accompanying processes. It is well, therefore, again to take account of stock and see really what progress has been made. Therefore, Mr. Hardy's paper, giving a description of the operations of a system thoughtfully designed, after long consideration of the problem, and of operations carried on under efficient and economical administration, with thorough record of all details, should furnish a groundwork for the careful consideration of the question stated above.

The writer, using as a text some of the ideas given in the paper, but more particularly some of those becoming prevalent elsewhere, desires to discuss methods and costs of operation, especially in relation to sand handling; and to offer suggestions looking toward greater efficiency, as well as economy, in carrying out the standard and well-tried methods.

Theory of Slow Sand Filtration.—First, what is the process of slow sand filtration? The answer to this question involves many factors, some of which are even yet but imperfectly understood. In the early history of filtration, at the time of the construction of the London filters, only the straining capacity of the sand bed, to remove gross particles, was known. Later, when the organic contents of water had become better understood, the chemical or oxidizing powers of the process were recognized as performing an important part. Finally, co-existent with the discovery of the so-called "germ theory of disease," a study of the bacterial action of filters resulted in the recognition of its importance. It is now universally thought that each of these factors performs its useful function; that the size of the sand, the amount of organic matter remaining on the surface of the bed, the turbidity of the applied water, and the bacterial content of the influent, are some of the things on which depends the determination of the relative importance of each.

[1] *Transactions*, Am. Soc. C. E., Vol. XLVI, p. 258.

Engineers have been taught to believe, by the German school of thought, that the film of organic matter on the surface of the sand plays a very important role in filtration. This *Schmutzdecke*, as it is called, has been considered so precious that stress has been placed on treating it with great care. It was not to be wholly removed at the time of cleaning, and it was not to be walked on, or indented, or in any other way consolidated or destroyed. In fact, in some cases, the wasting of the first water after cleaning has been advocated, for the reason that not a sufficient amount of this organic film would be left on top of the sand to begin the filtration process properly immediately after the cleaning.

In late years, however, there has been a tendency to depart from this fundamental doctrine of slow sand filtration. Various new processes for cleaning the sand surface have been advocated; some of these partly destroy and others completely exterminate any semblance of a bacterial film on the sand bed. These ideas, advanced without any real and serious discussion of their intrinsic merits, or their effects on the public health, are not founded on long continuous records of such results as are necessary to establish confidence in the final value of any of these methods.

Rapid advances along this line have been made more recently, notwithstanding the occurrence of notable instances of trouble and the resultant need of complete repair of filtration beds. Because of the rough treatment of the sand surface, a penetration of organic matter and filth into the bed had taken place. This caused deep clogging, prevented the usual yield of water, and brought about a lessened bacterial efficiency, due to the attempt to force water through the filters, and because some organic matter and growths in the lower part of the bed had furnished a breeding place for more bacteria.

All these endeavors to reduce the work of cleaning have been commendable, because scraping and sand handling are the items of greatest expense in slow sand filter maintenance. Every one has been desirous of minimizing this cost. However, as the writer will endeavor to show, it seems that attempts along this line should be with the idea of doing more economically, as well as efficiently, the things which one knows will accomplish the proper results, rather than unwisely to adopt new methods which have not been tried for a long enough period to determine their effect on the public health.

Pittsburg Methods.—When first taking up the problem of design in Pittsburg, in 1902, the writer had presented to him for consideration and adoption, a suggestion that a certain method of cleaning sand filters, which would involve the washing of the sand in place (similar to that recently tried at the Jerome Park Experiment Station, New York City), would be advisable and economical. The decision then made has never been regretted. As this plan involved such a complete departure from those principles which had been well tried and had proven successful, it was believed that it was not safe to adopt such a method on the municipal filtration works, from which the people were to derive their drinking water. There is more to be considered in such a problem than mere economy of operation; the economy of human life, the effect on which requires far longer than a few months of trial to determine, is a much more important factor. Believing that no one should depart, until after a long period of conclusive experimentation, from that principle which is known to be safe (viz., to take off a small portion of the clogging surface), the writer studied to determine more efficient and economical methods of accomplishing this end.

A device for scraping the material, in just the same way as with shovels, but more efficiently and more exactly, was developed by George P. Baldwin, M. Am. Soc. C. E., under the general supervision of the Bureau of Filtration, of which the writer was in charge. However, on account of the unfortunate and earlier arrangement of other constructive matters, which the City's Legal Department advised could not be changed without upsetting the contract, the entrance doors to the original forty-six filters were not built large enough to permit the rapid and economical transfer of these machines, and, as this act takes so large a proportion of the total time of operation, it has not been found economical to use them. The additional ten filters, recently constructed, with doors especially designed and large enough to pass the machines, have not yet been placed in operation. This is said to be on account of lack of funds and of employees. Therefore, there has been no opportunity to demonstrate what the scraping machines can do, under the conditions for which they were designed to operate. The restoring machine, a complementary device in mechanical operation, which simply replaces the sand in the same condition that it would be if wheeled back, but, with a small percentage of moisture, has accomplished its purpose well and economically. The sand is placed in the filters so that there is no further settling; with a smooth surface, needing no additional adjustment; with absolutely no possibility of sub-surface clogging; and with the filters starting off exceedingly well in operative results.

Washington Methods.—In Washington, it is stated that the filters are still cleaned by the old-fashioned method of scraping with shovels, throwing the sand into piles, and afterward removing it with a movable ejector. Between scrapings there is also an occasional mid-period action of raking the unwatered sand surface, for the purpose of stirring up the dirty film. This process does not remove any of the clogging material from the bed, but it is said that no injurious effects are produced, and that it is economical. It is stated that the so-called "Brooklyn method," of stirring the surface of the sand while the water is on the bed, has been tried at Washington, but with unsatisfactory results. It seems to have been advocated with greater fervor in some other places.

The method of dry raking does not remove the dirty material, but loosens up the pores of the surface, and through this porosity permits clogging to penetrate deeper into the filter. The method of raking with water on the bed, although it removes some of the organic dirt, also permits deeper penetration of the remainder. The latest devised system of washing the sand in place, by upward spraying with water, called the "Blaisdell method," thoroughly destroys the *Schmutzdecke* above, and, at the same time, must permit the formation of a subsidiary one below. In the Nichols method, the material removed by shovel scraping is conveyed by an ejector to a portable separator, where it receives a single washing; the dirty water overflows to the sewer, while the washed sand is discharged through a hose and deposited on the recently scraped surface. As the latter is partly impregnated with impurities, there is, by this process, a tendency toward sub-surface clogging.

All these processes are marked and serious departures from the well-tried method of cleaning slow sand filters, which, it is well known, will operate successfully to purify polluted river waters and make them safe to drink. In all there is the danger that they have not been sufficiently and carefully tried, under scientific observation, as to results and possible effects on the public health, to be sure that the bacterial efficiency can long continue to be satisfactory, with the application of specifically infected waters. It is dangerous, and may even jeopardize the safety of human lives, to experiment on water which is furnished for drinking purposes. There is also the added danger, well known from past experience, that in a few years (it may be more or less, depending on the extent and intensity of the new workings) the filters will need renovation, partly, if not wholly, throughout the entire bed. Thus, considering the total cost during a long term of years, the apparently cheaper method may become the most expensive.

There is also an interesting query in regard to the Washington method of replacing sand in the filters, and it is worthy of most careful thought and attention. If the process described can be carried on with success and safety, it will prove to be a long and progressive step in the methods of operation. The difficulty, however, is in determining from any short-term runs whether such a process can be continued permanently without impairing the efficiency of the sand bed. Apparently good conditions may change, after a few years' trial, and be followed by unsafe results and predicaments. This replacing of sand with whatever dirt and detritus may travel with it in the carrying water is certainly not equivalent to the care with which it has been understood that sand should be deposited in filters. It is not comparable with the care with which it is placed, when wheeled from a washer, where dirty water overflows the lip, or where it is placed by a machine restorer in the filter, where the transporting water also overflows the weir and is carried to the sewer.

These cheap and rapid methods of doing the work, advanced in the interests of economy, and the idea that sand filters, receiving polluting waters, can operate at higher rates than those which we have demonstrated, and, therefore, have been led to believe are safe, is a speeding up of the whole organization and of operating conditions. It is like speeding up a machine for the purpose of getting a greater output, with the usual result that fast running means quicker wearing out of both man and machine. Quicker operations generally mean carelessness in doing the work, especially in municipal service. Carelessness is engendered by the thought that such work can be handled in a rough and rapid way, and, further, by the ridicule of all these things, which we have learned to be careful about, as old-fogyish, out-of-fashion, and archaic. Carelessness in operation breeds contempt for the art. Some of the less efficient filter plants, from the standpoint of effect on the public health, may reflect such ill-considered methods.

Economy with Efficiency in Operation.—It is particularly important to find out whether one can secure the desired economy, and, at the same time, the required efficiency. The development of efficiency in every line of human endeavor is receiving much attention at present, and not the least cause for this is the growing recognition of the demand for a high standard of service for the expense caused. One of the first requirements is to have well-defined ideals and standards. When one knows how to secure a good and safe result, it is unwise to depart therefrom for a mere whim, or to secure a supposedly lessened expense, unless other facts be also determined favorably. The desire for economy must be tempered by good sense, which means that one should be willing to change a method only when the wisdom of such has been clearly demonstrated. Efficient service can only be secured by strict discipline, accompanied by fair dealing. This means employing no more men than are actually necessary, paying them on the basis of the standard of service and output produced, taking an interest in the working conditions, and providing for their health and welfare.

About twelve years ago, the writer made some investigations of the efficiency of laboring gangs in scraping and handling sand at filter beds, [1] and found that ten men was the most economical number to use in scraping the surface of the Lawrence filter, as then built and operated. This result was determined by numerous studies of the output per man per minute, with different numbers of men working under different conditions. This same sort of study has been carried further by adepts in the art, in reference to shop and similar management, but one fails to find corresponding development along this line in municipal organization except by a few of the scattered Bureaus of Municipal Research. These results, also, have related to a few of the more common and general factors, such as determining the cost per mile, or per square yard, of street cleaned, or per million gallons of water pumped.

[1] *Transactions,* Am. Soc. C. E., Vol. XLVI, p. 291.

The cost of the management of water-works, one of the largest factors of public enterprise, has never been investigated extensively and thoroughly. There is much possibility in planning for greater efficiency and in determining what can be accomplished under economical administration. Every one is aware of the multiplicity of men in municipal service. Some of these are entirely incompetent, others partly so; the recent appointees may be more efficient, but the majority of them gradually deteriorate under the subtle influence of the prevailing atmosphere, and each new incoming administration places more and more men on the work, without reason or necessity. All these tendencies have made the cost and maintenance of public work greater and greater, and, at the same time, have resulted in frequently and steadily decreasing the output and efficiency per employee.

The Washington situation, however, presents an admirable contrast to this, because of the methods of administration of the public works of the District of Columbia and their freedom from petty political influence. The limited number of employees has tended toward economy, and rendered this plant the envy of all who have desired to obtain good management. Its cost items have been looked on as a result long hoped for, but seldom obtained. It is to be regretted, therefore, that such an abrupt change in methods of removing clogging material and replacing sand has taken place without years of experimental trial on filters not furnishing drinking water to the public, and without an attempt, under such excellent conditions, to maintain the efficiency by a better labor output and by improved working and machine methods in the performance of the older and established order of doing things.

In preparing water for the use of the people, the realms of the unknown are so much larger than those which have been investigated and developed that there may be many undiscovered factors affecting the public health, and many ways in which it is dangerous to depart from well-known and surely safe methods. Who can say that in some subtle and, at present, unknown manner, the failure in some places, where filtration is practiced, to reduce the death rate from typhoid fever may not be due to the introduction of radical departures from the older, slower, safer, and more efficient methods which have produced such excellent results, both in America and in Europe? Further, in cases where there has been a falling off in the typhoid death rate, the failure to secure an accompanying improvement in general health conditions, which follows so closely in communities supplied by water filtered in accordance with the more conservative principles, may be due to the introduction of some of these not thoroughly tried processes. Some day full information may be available as to the influence of these methods of plant operation on the health of the community. Until that time, is it not a much better policy to follow the principles which have been proven by many years of experience to produce safe results, and to make the foremost object the improvement of the methods of operation in accordance with these established truths?

There is opportunity for the upbuilding of greater efficiency in the conduct of employees and in securing the maximum output, by establishing more comfortable and healthful conditions than usually exist. The elimination of political influence from municipal service is also a task which challenges the people of to-day, and the operating and managing engineer is in a position to perform an important part in accomplishing this end. The number of employees can be reduced to those actually needed, and the way opened for the employment of men who thoroughly understand the necessities of honesty and efficiency in the conduct of public affairs. It should be remembered that to design and construct well is only half the job; to operate economically and efficiently is even more of a problem than to build, and requires just as good talent, just as keen appreciation of the various problems, and is even more essential to public welfare. It seems to the writer that the logical development of the art of obtaining economy as well as efficiency should be along these lines, rather than to revolutionize methods, without having a long-period test of their value, and at the same time allow political influences to control, to a large extent, the labor item.

Preliminary Treatment.—The decision as to the preliminary treatment of the Potomac River water before filtration is of interest, particularly because various other conclusions have been reached in different sections of the country. However, in the main, these decisions have been due to differences in the character of the waters, but it must be evident that they have sometimes been the result of ill-considered action, or the desire to promote some special interest. The use of preliminary filters, which involves a large investment, is not always to be commended, particularly because at times of reasonably good water the removal of some of the organic matter is really injurious and lessens the effect of the final filters.

For a long time, the writer has believed that, where other things are equal, and where there is no important reason for double or preliminary filtration, long periods of storage, accompanied by the use of coagulant at times of severe and extreme muddiness, as planned at Washington, solves the problem in the most practical and economical way. It is true that the investment for a large storage basin may equal, or even exceed, that required for preliminary filters; but the influence of storage on the quality of raw water is never injurious, and, by ripening the condition of the water, may be greatly beneficial in the process of filtration.

The storage available in such a basin makes it possible to shut off the supply from the river during the worst conditions of the water. The duration of the most troublesome spells ordinarily does not exceed a few days, and it is usually possible to secure sufficient capacity in the basin to tide over these periods. Then again, long periods of storage, in addition to assisting in breaking up organic matter, permit the dying out of bacteria, particularly many of the pathogenic kind, and, therefore, the water is rendered much safer from this standpoint. In other words, there is additional insurance in long storage against the faulty and careless operation of incompetent filter employees. The addition of coagulant, especially the fact that only a very small investment of capital is required for the necessary apparatus for dosing the water, and that the cost of the coagulating materials has to be met only when used, seems to give the process, in a most satisfactory manner, the requirement for economical management and thoroughness in preparing the water for final filtration.

Parking Public Works.—It is disappointing that the author has not mentioned some of the steps contemplated in reference to the landscape treatment of the Washington filtration area. Probably every one has been impressed by the barren aspect of the works as they are approached, and as one looks over them. Recently, however, it is stated that some steps have been taken to lay out the grounds, treat the surface in an attractive manner, and make a park of the area. The writer has a firm opinion that when an investment is made for public works, it costs but little in addition to construct buildings along appropriate architectural lines, to treat the grounds in a pleasing manner, and to make the entire works a credit to the municipality from an artistic standpoint. When treated on broad lines, such areas become public parks, and afford open breathing places for the residents, and, if near centers of population, may well be equipped with playground facilities for the children. When thus developed they should have care, that the planting and equipment should not deteriorate and the last state become worse than the first.

The influence which these ever-present examples of attractiveness have on the community is becoming better recognized by students of social progress, and there seems to be no doubt that spending money on such features is not only desirable from the artistic standpoint, but is justified on practical grounds as well. It is cheaper than to create parks, when necessity and demand can no longer be resisted, by buying property and occasionally tearing down buildings and constructing *de novo.* That this work is now being done in Washington, even after construction, is certainly a recognition of the advisability of original efforts in this direction.

George C. Whipple, M. Am. Soc. C. E. (by letter).—Mr. Hardy's paper is an excellent presentation of the results of the operation of the Washington water filtration plant from the time of its construction in 1905 until June, 1910. Papers of this character are altogether too infrequent, and the actual results from the filters now in use are not readily accessible in detailed form. Yet it is only by studying the results obtained by filters in actual use that improvements can be made and the art advanced.

Among the many important facts brought out by Mr. Hardy, only a few can be selected for discussion. One of these is the operation of filters under winter conditions. It is well known that the efficiency of sedimentation basins and filters is lower during winter than at other times, yet it is just at this season of the year that there is the greatest danger of typhoid fever and similar water-borne diseases being transmitted by water. Most of the great typhoid epidemics have occurred during cold weather, and the very use of the term "winter cholera" is of significance. Apparently, typhoid bacilli and similar bacteria are capable of living and retaining their vitality longest during that season of the year. Just why this is so, bacteriologists have not satisfactorily explained. Doubtless many factors are involved. Because of the increased viscosity of the water, sedimentation takes place less readily at lower temperatures, and inasmuch as sand filtration is partly dependent on sedimentation, the efficiency tends to fall off in cold weather. During winter some of the external destroying agencies are less potent, such as the sterilizing effect of sunlight, and the presence and activity of some of the larger forms of microscopic organisms which prey on the bacteria. Another factor may be the greater amount of dissolved oxygen normally present in water during cold weather, as experiments have shown that dissolved oxygen favors longevity.

Still another reason for the larger numbers of bacteria that pass through a water filter during cold weather may be the effect that the low temperature has on the size of the bacteria themselves. A few experiments made recently by the writer appear to indicate that at low temperatures the gelatinous membrane which surrounds the bacterial cells tends to become somewhat contracted, thus decreasing the apparent size of the bacteria as seen under the microscope. Either this contraction occurs, or the cells themselves are smaller when they develop in the cold. It is possible also that low temperature affects the flagella of the organisms in the same way. It is not unreasonable to suppose that the effect of low temperature is to form what may be, in effect, a protective coating around the cells, which tends to make them smaller, less sticky, and less subject to outside influences. This would tend to make them pass through a filter more readily. In line with this idea also is the well-known fact that disinfection is less efficient in cold water than in warm water.

Another way of viewing the matter is that cold retards the growth of bacteria on the filter, thus reducing the effect of the *Schmutzdecke*. Still another view of the greater danger from bacterial contamination in winter is the theory that cold prolongs the life of the bacteria by merely preventing them from living through their life cycle and reaching natural old age and death as rapidly as in warm weather.

Another topic in Mr. Hardy's paper which has interested the writer is that of preliminary filters. The experiments described at length indicate clearly that such devices would prove of little or no benefit under the conditions existing in Washington, and that when the river contains considerable amounts of suspended clay nothing less than chemical coagulation will suffice to treat the water so that the effluent will be perfectly clear.

Preliminary filters have been used for a number of years at various places and with varying success. In few instances have they been operated for a sufficient length of time or been studied with sufficient care to determine fully their economy and efficiency as compared with other possible methods of preliminary treatment.

Among other experiments on this matter are those made at Albany, N. Y., and published by Wallace Greenalch, Assoc. M. Am. Soc. C. E., in the Fifty-ninth Annual Report of the Bureau of Water for the year ending September 30th, 1909. The Hudson River water used at Albany is quite different in character from the Potomac River water used at Washington, as it is less turbid and contains rather more organic matter. The results obtained in these experiments showed that during the summer the number of bacteria in the effluent from the experimental sand filter used in connection with a preliminary filter did not differ widely from the number found in the effluent of the city filter where there was no other preliminary treatment than sedimentation. In the winter, however, the numbers of bacteria did not increase in the effluent from the experimental filter as they did in the effluent from the city filter. This is shown by Table 26, taken from the report mentioned.

Apparently, therefore, at Albany the benefits of the preliminary filter, as far as bacterial efficiency is concerned, would be confined to a short period of three or four months in each year. Under such circumstances it may well be questioned whether the advantages of preliminary filtration justify its cost.

Table 26—Results of Experiments with Preliminary Filter at Albany, N. Y.

Month	Bacteria in raw water.	Bacteria in preliminary filter effluent.	Bacteria in effluent from experimental sand filter.	Bacteria in effluent from city filter.
1906.				
March	133,480	36,000	151	706
April	77,420	4,810	72	155
May	15,800	2,250	48	37
June	4,520	358	38	34
July	2,090	163	25	22
August	2,740	121	36	22
September	8,280	445	20	24
October	38,350	4,235	67	227
November	67,910	15,570	337	341
December	645,500	25,440	144	2,783
1907.				
January	127,560	4,660	48	443
February	28,000	1,800	13	116

On the diagram, Figure 11, will be found various data taken from the published records of the Albany filter, from 1899 to 1909. These data include: The numbers of bacteria before and after filtration; the percentage of bacteria remaining in the effluent; the average quantity of water filtered, in millions of gallons per day; the quantities of water filtered between scrapings; the turbidity of the raw water; the cost of filtration, including capital charges and cost of operation; and the typhoid death rates of the city per month. Several points are brought out conspicuously by this diagram. One is the uniformly low death rate from typhoid throughout the entire period. The filter was operated from 1899 until the fall of 1907 with raw water taken from what is known as the "Back Channel." Since then it has been taken from a new intake which extends into the Hudson River itself. Until the fall of 1908 the preliminary treatment consisted merely of sedimentation, but since then the water has received an additional preliminary treatment in mechanical filters operated without coagulant, along the lines of the experiments just mentioned. During this time the average rate of filtration of the sand filter has not changed materially, although it is said that the maximum rate has been increased since the preliminary filters were put in service. The study of the bacteriological analyses shows that the best results were obtained during 1902, 1903, and 1904. Since then the numbers of bacteria in both the raw and filtered water have increased. This was especially noticeable during the winters of 1907 and 1908 when the water was taken from the new intake. It will be interesting to compare the results after the preliminary filters have been operated for a long period to ascertain their normal effect on efficiency and on the increased yield.

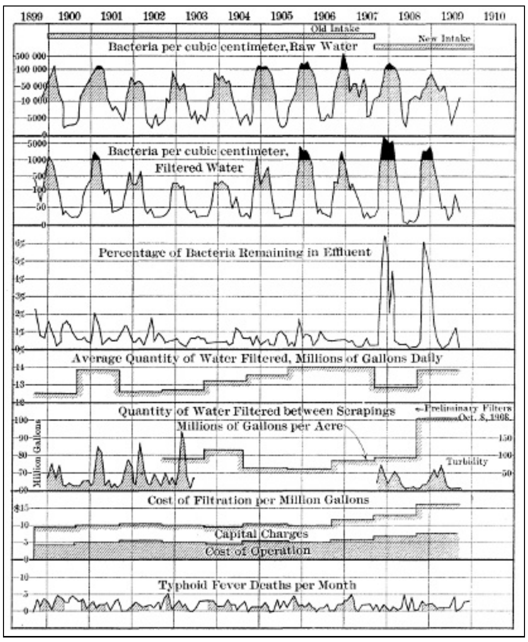

Figure 11—Filters at Albany, N. Y. Results of Operation. 1899-1909. Compiled from data in Annual Reports.

Another fact to be drawn from the plotted Albany data is the increase in the cost of filtration, both in capital charges and in operation. From 1899 until 1906 the cost of operation, including the cost of low-lift pumping, was approximately $5 per million gallons of water filtered; and the total cost of filtration, including capital charges, was about $10 per million gallons. During the year ending September 30th, 1909, the cost of operation had increased to $7.63 per million gallons, and the total cost of filtration to $15.92 per million gallons, or approximately 50% in three years.

Table 27—Results of Bacteriological Analyses of Samples of Water at Peekskill, N. Y., Before and After Filtration.

Bacteria per cubic centimeter.

Date.	Raw water.	Clear reservoir.	Effluent No. 1.	Effluent No. 2.	Effluent No. 3.	Effluent No. 4.	Tap in city.
1909.							
December 29th	190	100	...	...	...	...	...
1910.							
February 15th	135	10	10	30	20	...	265
March 31st	225	50	25	45	60	...	35
May 18th	300	29	22	26	35	43	36
July 6th	300	44	9	3	41	10	31
August 16th	60	5	0	4	1	13	15
October 3d	550	14	12	14	38	...	...
November 21st	315	22	26	17	6	...	...
1911.							
January 25th	415	7	8	4	6	...	7
Average	277	30	14	16	26	22	65

Table 27—(*Continued.*)
Filter Sand Tests for *B. Coli.*

Quantity of water tested.	Percentage of Samples Containing *B. Coli.*	
	Raw.	Filtered.
0.1 cu. cm.	0	0
1.0 cu. cm.	20	0
10.0 cu. cm.	40	0

As a matter of record, the results of a series of analyses made at Peekskill, N. Y., during 1910 are presented in Table 27. A sand filter was constructed for the water supply of this city in 1909, and put in operation in December. The filter has a capacity of 4,000,000 gal. per day. The supply is taken from Peekskill Creek, and the water receives about one week's nominal storage before flowing to the filters. An aerator is used before filtration during the summer, when algae are likely to develop in the reservoir. The filter was installed after an epidemic of typhoid which was apparently caused by an infection of the water supply. Normally, the water has been little contaminated, but the supply is subject to accidental contamination at any time, among other possible sources of infection being the camps of workmen now engaged in constructing the Catskill Aqueduct for New York City.

Table 28—Average Results of Chemical Analysis at Peekskill, N. Y., Made at Intervals of Six Weeks During 1910.

	Parts per Million.			Parts per Million.	
	Raw water.	Filtered water.		Raw water.	Filtered water.
Turbidity	2	0	Total residue	70	76.00
Color	25	20	Loss on ignition	19.00	17.00
Nitrogen as albuminoid amonia	0.112	0.076	Fixed residue	50.00	59.00
Nitrogen as free ammonia	0.024	0.006	Iron	0.17	0.13
Nitrogen as nitrites	0.001	0.001	Total hardness	38.70	45.10
Nitrogen as nitrates	0.06	0.06	Alkalinity	33.90	42.60
Incrustants	4.60	4.50	Chlorine	2.60	2.70

F. F. Longley, Assoc. M. Am. Soc. C. E. (by letter).—In this paper the author has presented a mass of data which will be welcomed by engineers engaged in water purification work, because complete operating records form a substantial basis for improvement in the art, and are often the inspiration for interesting discussions and the exchange of experiences of different observers whose views are mutually appreciated.

Recent tendencies in filtration engineering have been largely in the direction of reducing the cost of operation. A comparison of the operating costs of the earlier American plants of about a decade ago, with those here presented of the Washington plant, is very gratifying to those who have been intimately connected with the latter work. Through perfection in design and reasonable care in operation, the cost of filter cleaning, which is a very considerable part of the total cost, has been reduced to an unusually low figure, without any sacrifice in efficiency, and in the interests of the public health.

Table 14 shows that, from the first year, there has been a progressive increase in the total cost of operation per million gallons filtered, but this has not meant an increase in the annual total expenditure. The largest percentage of increase in any item has been in "Care of Grounds and Parking," and covers much-desired landscape improvements. Aside from this, the principal factor affecting the table of costs has been the reduction in water consumption in the District of Columbia. Nothing pertaining to this reduction has produced any corresponding reduction in the force required for the maintenance and operation of the filtration plant, office and laboratory, and pumping station, though probably there has been some reduction in filter cleaning. Obviously, then, the total cost per million gallons would increase.

This decrease in consumption has been brought about by the elimination of waste in the distribution system, which is not in the same department as the filtration plant, but with regard to which a word may not be amiss in connection with this discussion.

The Washington Aqueduct was built half a century ago on lines which at that time were considered extraordinarily generous. Until recently, therefore, there has been no occasion for concern over the high rate of consumption. During recent years, however, the use and waste of water have increased, reaching a climax under unusual conditions in the winter of 1904-05. The maximum capacity of the aqueduct system is about 90,000,000 gal. The maximum daily consumption at the time mentioned arose almost to 100,000,000 gal., with the result that, before normal conditions were restored, the reservoirs of the system were almost depleted.

This had a beneficial effect, as provision was made for an active campaign for reducing the waste of water, which was known to be very large. These investigations, using the pitometer, were begun in July, 1906, and have been pursued continuously since that time, with most excellent results. Up to January, 1909, leaks aggregating about 12,000,000 gal. per day were detected and eliminated, and about half the house services had still to be covered by the pitometer bureau.

Although this reduction in waste has brought about an apparent increase in the cost of filtration, its economical results have been far-reaching. The causes which brought about this investigation also resulted in securing an appropriation for the study of the question of increased supply. The writer was in charge of these studies, and the most significant conclusion was that, owing to the excellent results of the efforts for waste restriction, the total consumption and waste of water in the district during the next few years would be far enough below the safe working capacity of the existing aqueduct system to make it entirely safe to postpone the construction of new works, involving the expenditure of several million dollars, in spite of the threatening conditions of a few years ago.

There has been so much controversy over typhoid fever in the District of Columbia that the writer hesitates to discuss this subject. Viewing the situation through the perspective of several years, however, it does not seem to be as hopeless as the criticisms of four or five years ago would lead one to believe.

In Table 9, showing the typhoid death rates, out of nine years given prior to 1905-06, when the filters were started in operation, only one shows an annual death rate as low as the highest one since that year. Further than this, the annual average typhoid death rate for the period since that year has been one-third lower than for a corresponding period before the filters were started.

The exhaustive researches of the Public Health and Marine Hospital Service into this whole question, covering a period of about four years, have raised the present filtered water supply of the District of Columbia above any well-founded criticism. There has long been a strong and growing feeling that the water supply, before filtration was introduced, had been blamed for more than its share of the typhoid, and this is borne out by much evidence that has been presented from time to time.

It is not an unreasonable conjecture, therefore, that perhaps the reduction of one-third in the total typhoid death rate may represent a much larger reduction in that part of the total which was due to polluted water alone; and that, as the authorities in the District of Columbia and in certain other cities, particularly in the South, are now recognizing, the fight against much of the remaining typhoid must be in the direction of the improvement of milk supplies, precautions against secondary infection, and attention to a large number of details surrounding the individual, which may effectively protect him against the insidious attack of the disease favored by unknown agencies.

Experiments in Filter Cleaning.

The author refers to the difficulty encountered during the first two summers in keeping the filters cleaned fast enough to maintain the capacity of the plant. The real seriousness of this may be judged from the following facts. The average increase in loss of head on all the filters for the entire year, July 1st, 1906, to July 1st, 1907, was about 0.053 ft. per day. During the 1906 period of low capacity under discussion, the loss of head on twelve of the filters increased for a period of eight days at the average rate of 0.45 ft. per day, or about nine times the normal rate of increase. This difficulty was caused by the presence of large numbers of micro-organisms in the applied water. During the first summer (1906) this fact was not recognized, but the sudden decrease in capacity was supposed to have been caused by the unusually high and long-continued turbidity which prevailed during that summer in the Potomac River, and persisted in the water supplied to the filters even after about four days of sedimentation in the reservoirs. During the second summer (1907) the same phenomenon of suddenly and rapidly increasing losses of head appeared again, but without any unusual turbidity in the applied water. Investigation, however, showed the presence of large quantities of organisms, particularly *melosira* and *synedra*, in the applied water, and examinations in subsequent years have shown a periodic recurrence of these forms in quantities sufficient to cause the trouble mentioned. In June, 1907, examination showed repeatedly more than 1,000 and 1,500 standard units of *melosira* per cu. cm., and one count showed nearly 3,000 standard units.

Several expedients were tried in an effort to restore the rapidly decreasing capacity of the filters. One of the earlier conjectures as to the cause of the trouble was that it might be due to the accumulation of large quantities of air under the surface of the sand, as air had been observed bubbling up through the sand, especially in filters which had been in service for some time. The expedient was tried, therefore, of draining the water out of the sand and then re-filling the filter in the usual manner from below, in the hope of driving out the entrained air. Presumably this treatment got rid of the air, but it did not restore the capacity of the filter, as the point of maximum resistance was in the surface of the sand and not below it.

As the author states, raking the filters was tried and found to give results which were satisfactory enough to meet the emergencies already referred to. When the filters were first put in operation, in the fall of 1905, the method of bringing back the capacity of a filter after the end of a run was to remove all the dirty sand to a depth determined by the marked discoloration caused by the penetration of the clay turbidity. This sometimes necessitated the removal of large quantities of sand at a cleaning, as the turbidity was exceedingly fine, and penetrated at times to a depth of 3 or 4 in.

With the idea of effecting an economy in the cost of cleaning the filters, a schedule of experiments was arranged shortly before July 1st, 1907. The general object of the experiments was to determine, first, the relative costs of all different methods tried; second, whether the removal of only a thin layer of sand, or the mere breaking up of the surface of the sand by thorough raking, would give the filter its proper capacity for the succeeding run; third, whether the filters under these treatments would maintain a high standard of quality in the effluents; fourth, whether the continued application of any less thorough method than the one then in use might materially affect the future capacity of the filters.

To this end the filters were divided into four groups which, during a period of about six months, were subjected to treatments as follows:

Group *A*.— Filters scraped deep at the end of each run;
Group *B*.— Filters scraped light at the end of each run;
Group *C*.— Filters raked at the end of each run, until raking failed to bring back the proper capacity; then they were scraped light, and at the end of the next run the raking was resumed;
Group *D*.— Light scrapings and rakings alternate at ends of runs.

The term "deep scraping" means the removal of practically all the discolored sand, in accordance with the usual practice prior to the beginning of these experiments; "light scraping" means the removal of only a thin surface layer of sand. This depth has usually averaged about 3/8 in. "Raking" means the thorough breaking up of the clogged surface of the filter by iron-toothed rakes, to a depth of about 1 or 2 in.

Results.—A general summary of the results of these experiments is given in Table 29, which also shows the relative costs of the different methods per million gallons of water filtered. A normal period of 9 months just prior to the beginning of these experiments shows a labor cost (corresponding to that in Table 29) of $0.29-1/4 per million gallons filtered.

Table 29—Average Results.

	Per Run:					Per Million Gallons Filtered			
Group.	Number of filters.	Number of days of service.	Million gallons filtered.	Cost of labor per treatment.	Sand removed in cubic yards.	Sand removed in cubic yards.	Cost of labor.	Bacteria per cu. cm. in effluent.	Turbidity in effluent.
A	5	82	221.2	$68.44	215	1.11	$0.309	13	1
B	9	36	101.4	29.25	84	0.83	0.288	16	1
C	5	21	60.0	10.92	24	0.40	0.182	18	1
D	10	32	86.0	20.10	46	0.54	0.234	22	1

Capacity of Filters.—The capacity of the filters under the different methods of treatment are shown in a general way in Table 29 for days of service and millions of gallons filtered per run. This element by itself is decidedly in favor of the deep scrapings, and least in favor of the repeated rakings.

A clearer conception of the capacities of the filters under these different conditions may be obtained from the four diagrams, Figure 12, showing, for the four different groups, the average number of days of service of the successive runs. The diagram for Group *A* shows that the variations in the period of service of the filters scraped each time to clean sand follow a more or less definite curve from year to year. For the period covered by this curve, the tendency seems to be toward a slight decrease in capacity from year to year, as shown by the lower average maximum and minimum in the second year than in the first. Group *B* shows a sudden decrease in capacity following the first light scrapings and, since that time, a low but quite constant capacity. Group *C* shows a constantly decreasing capacity with successive rakings. The only significance attaching to the curve after the first raking is the prohibitively low capacity indicated, and the ineffectiveness of the measures taken to restore the capacity after the sixth raking. Group *D*, after the first raking, shows a prohibitively low and constantly decreasing capacity. The diagrams for *C* and *D* indicate a dangerous reduction in capacity if long persisted in. The method followed with Group *C* may be dismissed with the statement that it is entirely insufficient, and would be of use only in the rarest emergencies.

As far as the question of capacity is concerned, these diagrams indicate that a filter in normal condition may safely be raked once. It is believed that the constantly decreasing capacity shown in Group *D* is not due so much to the rakings as to the small quantities of sand removed at the alternate scrapings, and therefore it would not be proper to condemn this method of treatment without a further trial in which this defect was remedied. This view seems to be supported by the results of Group *B*. The low but approximately constant capacity there shown would undoubtedly have been higher if a greater depth of sand had been removed each time.

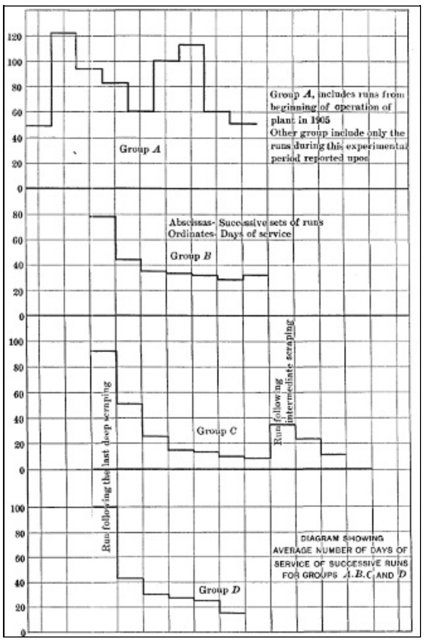

Figure 12—Average Number of Days of Service of Successive Runs for Groups *A*, *B*, *C*, and *D*.

Quality of the Effluent.—The averages given in Table 29 show but little difference in the bacterial contents of the effluents from the four groups of filters. All are entirely satisfactory, and the differences in favor of one method or another are small. In looking for possible differences in the quality of the effluents from the four groups, it was thought that such differences might be most apparent at a time when the entire plant was working under the most adverse conditions. The bacterial counts, therefore, were summarized for the period from December 23d, 1907, to January 6th, 1908, inclusive, following a period of high turbidity and high bacteria in the raw water, with results as follows:

Group...........	*A*	*B*	*C*	*D*
Maximum.......	204	178	189	206
Minimum........	61	45	62	57
Average.........	120	107	104	155

The following is a summary of the turbidity results for a similar period:

Group...........	*A*	*B*	*C*	*D*
Maximum.......	10.8	11.7	8.7	9.3
Minimum........	6.7	4.7	6.2	5.7
Average.........	8.7	8.3	7.2	7.9

These numbers, though high, do not show any significant differences. All the averages for each group are less than the lowest maximum, and all are greater than the highest minimum, and therefore vary less than do the individual filters, from other causes, within the different groups.

Future Capacity of the Filters.—An indication of the dangers which might affect the future capacity of the filters was shown in the above discussion of the present capacity. A more effective way of showing this was obtained by a study of the initial resistances or losses of head in the four groups. A filter kept in ideal condition would show no increase in this initial loss of head from one run to the next. If there is such an increase, it means that at some future time measures more heroic than ordinarily used would be necessary to restore the proper capacity.

The average initial losses of head for the different groups are plotted on the diagram, Figure 13. Group *A* shows an initial loss of head, increasing gradually but slightly during more than two years of service. In Group *B* the initial loss of head increased in a manner similar to that in Group *A,* up to the time of the beginning of these experiments; after which the increase becomes more rapid. Groups *C* and *D* show conditions generally similar to Group *B*, with some variations which are self-explanatory.

Conclusions.—The quality of the effluents from all four groups was satisfactory, and no consistent difference was apparent in favor of one or another method of treatment. The method pursued with Group *C* was entirely insufficient to maintain the capacity indefinitely. The methods pursued in Groups *B* and *D* were both insufficient, but would have been more effective if a greater depth of sand had been removed. The costs of treatment of Groups *B* and *D* were less than for Group *A*. It appears, then, that a treatment which would be more economical than the old method of Group *A*, and would still maintain the proper capacity, would be one similar to that of Groups *B* or *D*, with the removal of a quantity of sand greater than was done in the case of these two groups, but less than in the old method.

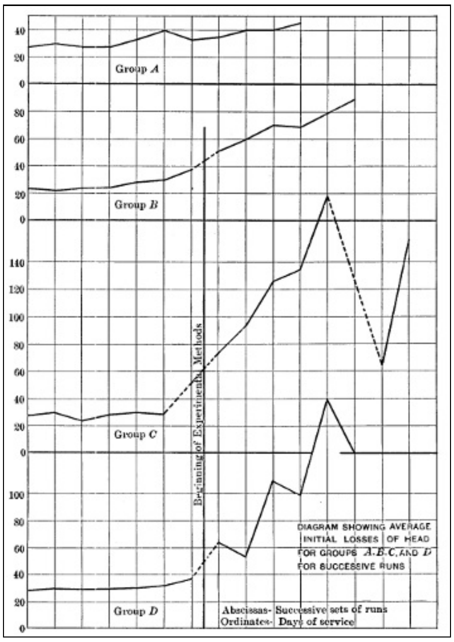

Figure 13—Average Initial Losses of Head for Groups *A*, *B*, *C*, and *D* for Successive Runs.

At the time the above results were summarized, it was proposed to proceed with the filter treatment along the lines just mentioned. The writer did not have an opportunity to study the subsequent results, as he was transferred to other work. A statement by the author of any new facts that may have come to light in this connection would be of interest.

Mention should be made, too, of another expedient that was used to hasten the restoration of the capacity of a filter, which proved to be a most useful one. The removal of the scraped sand from a filter was a matter of a good many hours' work, under the most favorable conditions. To get the filters quickly into service again, the dirty sand in a number of them was simply scraped from the surface, heaped into piles, and left there; then the water was turned in, and the filter was started again. This was done with some hesitation at first for fear the presence of the piles of dirty sand might cause high bacterial counts in the effluents of those filters. No such effect was observed, however, the counts being entirely normal throughout. The writer subsequently found the same treatment being applied as an emergency measure at the Torresdale plant, in Philadelphia, and, through the courtesy of the Chief Engineer of the Bureau of Filtration, was furnished with the bacterial counts through a number of runs made under these conditions, and there, too, the results were entirely normal.

There was practically no economy in this method, as the sand had ultimately to be ejected and washed. The piling up of the sand had the effect of reducing the effective filtering area by a small percentage, with a corresponding increase in the actual rate of filtration, but this was of trifling importance. The great benefit derived from the method was the saving of time in getting a filter back into service after scraping, and in this respect it was very valuable.

Physical Theory of Purification of Water by Slow Sand Filters.

The first and most natural conception of the action of a sand filter is that the removal of impurities is effected by a straining action. This, of course, is perfectly true as far as it relates to a large part of the visible impurities. Much of this is gross enough to be intercepted and held at the surface of the sand. This very straining action is an accumulative one. After a quantity of suspended matter thus strained out mats itself on the surface of the sand, it in turn becomes a strainer, even better adapted than the clean sand surface which supports it for the removal of suspended matter from the water.

This, however, cannot explain certain features of the purification of water by a layer of sand. The removal of color, the reduction of nitrates, and certain other changes in the organic content of the water have for a long time been recognized as due to a bio-chemical action carried on by certain bacteria in the sand. Both the straining action and this bio-chemical action are not all-sufficient for the explanation of certain phenomena, and it has been recognized, too, that sedimentation in the pores of the sand played a large part in the purification process in those cases in which it was apparent that the biological agencies were not the chief ones.

In the purification of water containing only insignificant quantities of suspended matter, but a relatively large amount of unstable organic matter, it will be conceded at once that the chief factor in the purification is the nitrification produced by the bacteria in the upper layers of the sand. On the other hand, the purification by sand filters of a hypothetical water containing no organic matter, but only finely-divided mineral matter in suspension, could take place only by the physical deposition of the particles upon the sand grains. Between these two extremes lie all classes of water. In all problems of water purification by filtration through sand, both these factors—biological action and sedimentation—play their parts, assisting and supplementing each other, the relative importance of one factor or the other depending on the place of the particular water in question on the scale between the two extreme conditions just mentioned.

In Mr. Hazen's paper on "Sedimentation"[1] there is an interesting development of the theory of the removal of suspended matter by sedimentation in the pores of a layer of sand. The factors influencing this removal are the rate of filtration, the effective size of the sand, and the temperature of the water. For the conditions at the Washington plant, it may be assumed that the first two of these factors are constant. The third factor, however, varies through wide limits, and the observations on the turbidity removal, and on the different phases of the filter operation of which the turbidity of the water is a factor under varying temperature conditions, together with the known relations between hydraulic values and temperatures of water, furnished good substantiative evidence that this highly-induced sedimentation may be a considerable factor in the purification of the water as effected at this plant. This temperature relation, briefly stated, is as follows: For particles of a size so small that the viscosity of the water is the controlling factor in determining the velocity of their subsidence in still water, that velocity will vary directly as $(T + 10) / 60$, in which T is the temperature, in degrees, Fahrenheit. That is, when the temperature of the water is between 70° and 80° Fahr., a particle will settle with twice the velocity it would have if the water were near the freezing point.

The layer of sand in a slow sand filter may be considered as a very great number of small sedimentation basins communicating one with another, not in the manner of basins connected in series, but rather, as Mr. Hazen has expressed it, as a long series of compartments connected at one side only with a passageway in which a current is maintained. In any section of the sand layer there are areas through which the water passes with a velocity much greater than its mean velocity through the total area of voids, while there are other areas in which the velocity is very much less, perhaps in an almost quiescent state from time to time, greatly favoring the deposition of particles, but with a gentle intermittent circulation, displacing the settled or partly-settled water and supplying from the main currents water containing more suspended matter particles to be removed. There is thus a considerable percentage of the total volume of voids in which the water is subjected to very favorable conditions for sedimentation, almost perfect stillness and an exceedingly small distance for a particle to settle before it strikes bottom on the surface of a grain of sand.

[1] *Transactions*, Am. Soc. C. E., Vol. LIII, p. 59.

If sedimentation were the predominating factor in the purification of the water, we would then expect to find the following phenomena in the operation of the filters: A more rapid deposition of a given amount of sediment under summer temperature conditions than under winter, as the water passes through the sand, and therefore, for the former condition of higher temperature:

(a) A greater concentration of this turbidity-producing material in the top layer of sand, or, in other words, a thinner sand layer to be removed in scraping if all the dirty sand is removed;

(b) Because of the greater concentration, a greater rate of Increase of the loss of head, and consequently shorter periods of service between scrapings;

(c) A higher limit for turbidity in the water applied to the filter to produce a given turbidity in the effluent.

The operation of this plant during the first year and a half offered an excellent opportunity for the study of sedimentation in the sand, and the data in Table 30 are presented to show that certain of the phenomena of filter operation observed during this period seem to be fairly explicable by the physical theory of purification. These data are given only for the period of operation before the summer of 1907. At that time the experiments in filter cleaning already described were begun. Before that time, whenever a filter had been cleaned, all the discolored sand had been removed, leaving for the following run a new sand surface substantially in the perfect condition of a newly-constructed filter. After that time the experimental methods of cleaning, and the new routine adopted as a result thereof, interfered with the tracing of the evidence as clearly as during the earlier periods.

Table 30—Service Periods and Scraping Depths for Runs Ending In Various Months; Covering Entire Period, October 1st, 1905, To March 1st, 1907.

Month.	Number of filters.	Average period of service in days.	Average depth of sand removed, in inches.	Mean temperature, in degrees, Fahrenheit.
January	13	75	2.09	39
February	6	98	2.46	37
March	5	130	2.66	41
April	8	149	2.96	53

May	7	130	2.80	67
June	11	124	2.35	77
July	17	70	2.12	81
August	2	49	1.98	80
September	5	73	2.48	76
October	37	70	1.56	64
November	20	42	0.81	49
December	14	57	0.94	40

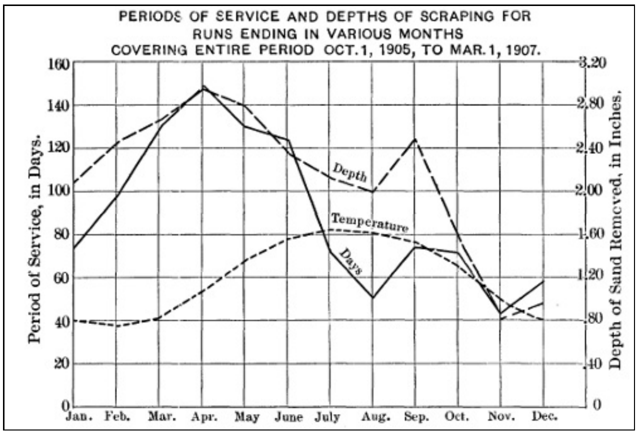

Figure 14—Periods of Service and Depths of Scraping for Runs Ending in Various Months Covering Entire Period Oct. 1, 1905, to Mar. 1, 1907.

Table 30 and the corresponding diagram, Figure 14, show the general variations in the length of runs and depth of penetration, with the seasonal temperature changes. The increase in length of runs and quantity of sand removed under low temperature conditions is very marked. There is, however, a secondary maximum which appears, as the diagram shows, where a minimum for the year would be expected. This may have been an irregularity occurring this one year, which will not appear in the average of several years, and caused by some factor which has escaped observation. A careful analysis of the data at hand fails to show any explanation for it. It may exist in some of the little-understood biological actions which have their maximum effect under warm-water conditions, or it may be due—in some obscure way—to the liberation of air under the surface of the sand, accumulating with pressure enough to break the surface at innumerable points, thereby reducing the loss of head and extending the period of service. Some evidence was observed pointing to this explanation, but it was never conclusively proven.

The general effect of temperature changes on the rapidity of removal of the sediment and its consequent concentration in the sand layer, however, seems plainly evident.

In corroboration of the third point mentioned in the theoretical consideration of turbidity removal in the filters, the daily turbidities of the filtered water have been classified and summarized for different turbidities in the applied water, and also for different temperatures. The average turbidities thus obtained are given in Table 31.

Table 31—Turbidity in Filtered Water at Different Temperatures Produced by Given Turbidity in Applied Water.

Turbidity of applied water.	Temperature, in Degrees, Fahrenheit.				
	40°	40°-50°	50°-60°	60°-70°	70°
20	1.8	1.3	1.2	1.5	1.7
20-40	4.8	5.0	3.5	3.0	2.6
40-60	7.9	6.9	5.4	...	3.7
60-80	10.7	7.7	...	...	5.4
80-100	11.3	...	...	...	...
100	...	...	...	...	12.0[1]

[1] For an average turbidity = 150. approximately.

The influence of the temperature of the water on the turbidity of the effluent is very pronounced. For a temperature of less than 40° Fahr. (actual average temperature about 35°), the turbidity of the filtered water for a given turbidity of the applied water is practically twice as great as for a temperature greater than 70° (actual average temperature about 75°). This fact fits in very nicely with the influence of temperature on sedimentation. Referring again to this temperature relation, as set forth on a previous page, the hydraulic subsiding value of a particle in water, of a size so small that viscosity is the controlling factor in its downward velocity, is approximately twice as great at 75° as at 35 degrees. We would then expect to find that, in order to obtain a given turbidity in the filtered water, a raw water may be applied at 75°, having twice the turbidity of the water applied at 35°, to produce the same turbidity; and further, as the turbidity of the filtered water, for a given temperature condition, varies quite directly in proportion to the turbidity in the applied water, it follows that an applied water of given turbidity will produce an effluent at 35° with a turbidity twice as great as at 75 degrees. This is quite in accordance with the facts obtained in actual operation, as indicated on the diagram, Figure 15.

Preliminary Treatment of the Water.—The most striking features of the bacterial results given in Table 4 are, first, the uniformly low numbers of bacteria in the filtered water during perhaps 8 or 9 months of the year, and the increase in numbers each winter. This is shown clearly in the analysis of bacterial counts in Table 32.

Table 32—Classification of Daily Bacterial Counts in the

Table 32—Classification of Daily Bacterial Counts in the Filtered-Water Reservoir During the Period, November 1st, 1905, to February 1st, 1908.

Bacterial count between:	No. of days.	Percentage of whole.	
0 and 20 per cu. cm.	291	41.0	
20 and 40 per cu. cm.	245	34.6	
40 and 60 per cu. cm.	63	8.9	
60 and 80 per cu. cm.	30	4.2	
80 and 100 per cu. cm.	28	4.0	92.7
100 and 200 per cu. cm.	29	4.1	
200 and 300 per cu. cm.	13	1.8	
300 and 500 per cu. cm.	5	0.7	
500 and 1000 per cu. cm.	5	0.7	7.3
Total			100.0

The tests for *Bacillus Coli* in Table 5 show results which correspond closely to these, with this organism detected only infrequently, except during the periods of high bacteria, and both of these are parallel to the turbidity variations in the filtered water. These variations follow closely the variations in the turbidity and in the bacterial content of the water applied to the filters.

By all standards of excellence, the sanitary quality of the water during the greater part of the time is beyond criticism. In view of the close parallelism of turbidity and bacterial results in the applied and in the filtered water, it is entirely logical to conclude that, if the quality of the applied water could be maintained continually through the winter as good as, or better than, it is during the summer, then the filtered water would be of the perfect sanitary quality desired throughout the entire year.

This was all foreseen ten years ago, when Messrs. Hering, Fuller, and Hazen recommended auxiliary works for preliminary treatment of the supply, although, as the author states, these works were not provided for in the original construction. As prejudice against the use of a coagulant seemed to be at the bottom of the opposition to the preliminary treatment, a campaign of education bearing on this point was instituted, in addition to the systematic studies of different preliminary methods to which the author refers. As a result of the combined efforts of all those interested in promoting this improvement, an appropriation was finally made for the work in 1910. The coagulating plant has since been built, and the writer is informed that coagulation was tried on a working scale a short time ago during a period of high turbidity. A statement of the results of this treatment on the purification of the water in the reservoir system and in the filter plant would be of great interest.

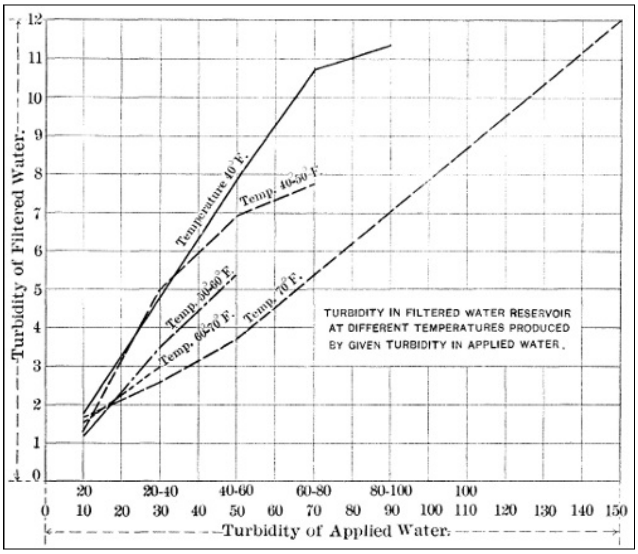

Figure 15—Turbidity in Applied Water.

Hydraulic Replacing of Filter Sand.—The author has adopted a method of replacing clean sand in the filters which will commend itself to engineers as containing possibilities of economy in operation. The first experiments in the development of this method at the Washington plant were carried out some three years ago, while the writer was still there. Substantially the same methods were used then as are described in this paper, but examination of the sand layer by cutting vertically downward through it after re-sanding in this manner showed such a persistent tendency toward the segregation of the coarse material as to hold out rather discouraging promises of success. The greatest degree of separation seemed to be caused by the wash of the stream discharging sand on the surface. It was observed that, near the point where the velocity of the stream was practically destroyed, there seemed to be a tendency to scour away the fine sand and leave the coarse material by itself, and pockets of this kind were found at many points throughout the sand layer. The author states that, in the recent treatment of the filters by this method, there has been no apparent tendency for the materials to separate into different sizes, and it is fortunate if this work can be done in such a manner as to avoid this separation entirely.

It may be questioned whether a certain amount of segregation of the materials will make any practical difference in the efficiency of a filter. In all probability this depends on the degree of the segregation, the quantity of pollution in the water to be filtered, the rate of filtration, and the uniformity of methods followed in the operation, etc. For an applied water as excellent in quality as that of the Washington City Reservoir during favorable summer conditions, a considerable degree of segregation might exist without producing any diminution in efficiency. For a badly polluted water, however, such as the applied water at this plant during certain winter periods, or the water of a great many other polluted supplies, it might be found that even a slight lack of homogeneity in the sand might make an appreciable difference in the results of filtration.

As a result of the experiments herein described, however, this method may be applied at other plants where conditions seem to warrant it, with a largely increased measure of confidence; although, as in the case of the adoption of any new or radical departure, that confidence must not be permitted to foster contempt of the old and tried methods, but its operation must be watched with the utmost caution, until long experience shall have demonstrated its perfect suitability and defined its limitations.

E. D. Hardy, M. Am. Soc. C. E. (by letter).—It was not the writer's original intention to enter into a discussion of either the theory of water purification or of the experimental work on sand handling, but simply to present the main results of operation largely in tabular form. He is gratified, however, to have these sides of the question so ably brought out in Mr. Longley's discussion.

Mr. Hazen referred to the inferior efficiencies of the experimental filters for rate studies (as shown in Table 20) in the removal of the *B. Coli* from the water tested. This inferiority is really less than the figures in the table would indicate, as the tests for the experimental filters were presumptive only (as shown by the note at the foot of Table 20), while those for the main filters were carried through all the confirmatory steps.

From experiments[1] made by Messrs. Longley and Baton in the writer's office, it would seem reasonable to assume that about one-half of the positive results, would have been eliminated had the confirmatory steps been taken. In other words, the figures showing the number of positive tests for *B. Coli* in Table 20 should be divided by two when comparing them with corresponding ones for the main filters.

Mr. Knowles seems somewhat apprehensive regarding the methods described in the paper of restoring the capacity of the filters by raking, and replacing sand by the hydraulic method, and yet, from Mr. Johnson's discussion, it would seem that the practice of raking filters between scrapings had recently been adopted at the Pittsburg plant.

[1] Published in the *Journal of Infectious Diseases*, Vol. 4, No. 3, June, 1907.

Before the practice of raking was finally adopted as a part of the routine filter operation, the subject was given a great deal of thought and study, as may be seen by referring to Mr. Longley's discussion.

The re-sanding has been done by the hydraulic method, for nearly two years, and, as far as the writer is able to judge, this method has been more economical and also more satisfactory in every way than the old one. As Mr. Hazen states, this does not prove that the hydraulic method would be as satisfactory for other filter plants and other grades of sand. The elevated sand bins at the Washington plant fit in well with this scheme, and save the expense of one shoveling of the sand; and the low uniformity coefficient of the sand is favorable in decreasing its tendency to separate into pockets or strata of coarse and fine sand. The method of washing is also well adapted to this method of re-sanding, as the sand is made very clean in its passage through the washers and storage bins. The hydraulic method of replacing sand tends to make it cleaner still, because any clay which may be left in the sand is constantly being carried away over the weir and out of the bed, to the sewer. Sand replaced by the hydraulic method is much more compact than when replaced by other methods, and consequently the depth of penetration of mud in a filter thus re-sanded is less. Careful tests of the effluents from filters which have been re-sanded by the two methods have invariably shown the superiority of the hydraulic method.

The experiment of replacing sand by water, referred to by Mr. Longley, was not considered a success at the time, and the method was abandoned for about a year. At that time an attempt was made to complete the re-sanding of a filter which had been nearly completed by the old method. The precaution of filling the filter with water was not taken, nor was any special device used for distributing the sand. When this method was again taken up, various experiments were tried before the present method was adopted.

Mr. Whipple's remarks on the results from the operation of filters under winter conditions are very interesting, and, considering his standing as an authority in such matters, they are worth careful consideration.

In the operation of the Washington plant, it has always been noticeable that the results were much poorer in winter than in summer. In fact, nearly all the unsatisfactory water which has been delivered to the city mains has been supplied during the winter months. On the other hand, the typhoid death rate has always been comparatively low in cold weather. These facts would seem to indicate that the water supply was not responsible for the typhoid conditions.