ONE HUNDRED YEARS LATER: REVIEWING THE WORK OF THE MASSACHUSETTS STATE BOARD OF HEALTH ON THE INTERMITTENT SAND FILTRATION OF WASTEWATER FROM SMALL COMMUNITIES

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Communities in Massachusetts effectively utilized sand filter systems for wastewater treatment beginning in the late 1800's. The community of Lenox was the first to construct a system in 1876 (State Board of Health, Massachusetts, 1893). By 1893, six more communities were using sand filters for wastewater treatment. Between 1891 and 1937, the Massachusetts State Board of Health monitored the performance of over 25 community sand filter systems.

The detailed reports of the operation of community sand filters in Massachusetts are contained in 21 volumes of the Annual Reports of the State Board of Health, (1892 - 1913) and in 9 volumes of the Annual Reports of the Department of Public Health (1928 - 1937). This paper will summarize the characteristics of 26 sand filters reported by the Massachusetts State Board of Health. The performance of 7 of the community sand filter systems will also be presented and discussed. Information on 26 community sand filters is presented in Table 1. These filters started receiving wastewater between 1891 and 1928. Data was reported on 25 of the filters until 1937.

The population in the area was growing. In 1903, 12 of the filters served communities of less than 10,000 people. The 1935 census reported that the community populations served by sand filters increased from 0.24 to over 6 times. The average community size served by sand filters in 1935 was over 23,000 people.

Obviously the sand filters had to vary in size to serve the population of the communities as shown in Table 1. In 1903 the filter areas were as small as 0.15 hectares (0.36 acres) to as large as 10 hectares (24.8 acres). The filters also had to grow along with the communities. In 1937, the smallest community filter system was 0.6 hectares (1.53 acres) and the largest was 16.65 hectares (41.15 acres). The relationship of filter size to people served averaged 0.76 hectares/1000 people (1.89 acres/1000 people) in 1903. The relationship dropped to an average of 0.41 hectares/1000 people (1.01 acres/1000 people) served in 1937. As much as 1.82 hectares/1000 people (4.5 acres/1000 people) to as little as 0.08 hectares/1000 people (0.21 acres/1000 people) was used to treat wastewater.

The level of pretreatment of the wastewater varied among communities (Table 1). Seven sand filter systems treated raw wastewater. Eleven systems used either settling tanks or septic tanks to pretreat the wastewater. Three of the systems separated the solids from the wastewater in a settling tank and applied the settled solids to separate sand filters. Imhoff tanks, coke strainers and chemical precipitation were also used to pretreat wastewater.

SAND CHARACTERISTICS

The characteristics of the community sand filters are listed in Table 2. It is interesting to compare this historic experience to the modern design recommendations (Table 3) presented by US EPA in the Design Manual: Onsite Wastewater Treatment and Disposal Systems (1980). The community sand filters ranged in depth from 0.9 to 2.4 meters (3 to 8 feet) with an average depth of 1.45 meters (4.75 feet). The US EPA recommendation for "modern" sand filters is 0.6 to 0.9 meters (2 to 3 feet). The US EPA recommendation for effective size is 0.35 to 1.0 mm. All but one

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Table 1. Community Sand Filter Systems In Massachusetts

City	Year started	Year last reported	Popul. served in 1903	Popul. served in 1935	Pretreatment	Filter size in 1903 (Hectares) c	Filter size in 1937 (Hectares)
Andover	1902	1937	3,600	- a	Septic Tank	1.54	-
Attleboro	1912	1937	-	21,835	None	-	6.27
Brockton	1893	1937	25,000	62,407	Solids Separation	8.70	14.97
Clinton	1898	1937	10,000	12,373	Solids Separation	9.51	10.62
Concord	1899	1937	1,200	7,723	None	1.34	3.00
Easthampton	1908	1937	-	10,486	Settling Tank	-	0.89
Farmington	1890	1937	7,500	22,651	None	8.05	11.56
Franklin	1915	1937	-	7,494	Settling Tank	-	1.31
Gardner b	1891	1937	3,500	20,397	Settling Tank	1.08	6.68
Gardner(West)	1901	1937	4,500	b	Coke Strainer	0.91	-
Hopedale	1900	1937	2,000	3,068	Septic Tank	-	1.53
Leicester	1894	1937	500	-	Septic Tank	0.15	-
Marion	1906	1937	-	1,867	Settling Tank	-	0.62
Marlborough	1891	1937	10,000	15,781	Settling Tank	4.82	8.17
Milford	1907	1937	-	15,008	Imhoff Tank	-	3.76
Nantucket	1930	1937	-	3,495	-	-	3.24
Natick	1896	1937	4,000	14,394	None	4.49	-
North Attleborough	1909	1937	-	10,202	Settling Tank	-	3.54
Northbridge	1906	1937	-	10,577	Settling Tank	-	4.86
Pittsfield	1901	1937	15,000	47,516	Solids Separation	10.04	16.65
Southbridge	1908	1937	2,200	15,786	None	2.93	4.43
Spencer	1897	1937	3,000	6,487	None	3.76	4.98
Stockbridge	1899	1937	800	-	None	1.46	-
Westborough	1892	1937	3,000	6,773	-	-	2.68
Winchendon	1928	1937	-	6,603	Settling Tank	-	1.62
Worchester	1898	1925	122,000	190,471	Chem. Precip.	9.39	-

a [-] indicates no data reported
b Gardner and Gardner (West) were combined
c conversion factor: hectare = 0.4047 acres

Table 2. Community Sand Filter Characteristics

City	Filter depth	Effective size	Uniformity coefficient	Loading rate
	(meters)a	(mm)		(l/m2/day)c
Andover	1.2 to 1.5	.15 to .20	7.7 to 8.3	31.75
Attleboro	1.2 to 2.1	- b	-	60.34
Brockton	1.7	.04 to .75	-	37.97
Clinton	2.4	-	-	44.28
Concord	-	.10 to .24	2.8 to 3.2	78.22
Easthampton	1.1	-	-	-
Farmington	1.8	.06 to .12	8.0 to 13.9	52.73
Franklin	1.4	-	-	77.06
Gardner	1.5	.12 to .18	4.2 to 8.0	112.15
Gardner(West)	0.9 to 1.2	-	-	103.14
Hopedale	0.9	-	-	56.72
Leicester	1.2	-	-	77.33
Marion	1.5	-	-	105.83
Marlborough	1.4 to 1.8	.14 to .15	2.5 to 3.1	66.94
Milford	1.5	-	-	-
Nantucket	-	-	-	65.91
Natick	1.8	.13 to .18	3.3 to 7.0	47.35
North Attleborough	1.5 to 2	-	-	88.20
Northbridge	1.2	-	-	64.06
Pittsfield	1.2	.15 to .18	2.9 to 3.7	92.93
Southbridge	1.2	-	-	65.13
Spencer	1.2	.18 to .34	4.2 to 10.6	54.91
Stockbridge	0.9 to 1.4	.17 to .27	11.7 to 14.6	19.31
Westborough	1.5	-	-	65.45
Winchendon	-	-	-	50.13
Worchester	-	-	-	-

a conversion factor: meters = 3.28 feet
b [-] indicates no data reported
c conversion factor: l/m2/day = 0.025 gal/ft2/day

Table 3. Design Criteria for Intermittent Sand Filters (US EPA, 1980)

Item	Design Criteria
Sand Depth	0.6 to 0.9 meters
Effective Size	0.35 to 1.00 mm
Uniformity Coeff.	Less than 4.0
Loading Rate	81.5 to 203.7 l/m2/day

of the community sand filters used sand with smaller effective sizes ranging from 0.06 to 0.34. The sand filter system for Brockton used sand with an effective size ranging from 0.04 to .75 mm. The uniformity coefficients of the sand used for the community sand filters were quite large with a range of 2.9 to 14.6. Only three of the community sand filters used sand with uniformity coefficients of less than 4.0, which is the range recommended by US EPA. All of the community filters were loaded at moderate to low rates. Loading rates ranged from 19.59 l/m^2/day to 113.06 l/m^2/day (0.48 gal/ft^2/day to 2.77 gal/ft^2/day). These loading rates were generally lower than the recommended loading rate for modern filters of 81.63 l/m^2/day to 204.08 l/m^2 /day (2 to 5 gal/ft^2/day).

MANAGEMENT

Sand filters, like all wastewater treatment systems, require management. The distribution system for the wastewater must be maintained so that it continues to provide uniform coverage. The sand filter media requires management to eliminate clogging. Winter operation sometimes requires special management.

The US EPA (1980) design manual lists raking, weed removal, surface layer sand removal or replacement, hydrogen peroxide treatment, and resting as possible management techniques. In the winter, modified application systems, such as ridge and furrow application or continuous flooding are suggested. The manual also points out the importance of maintaining the pretreatment units. Grease traps, septic tanks, or other devices must be maintained to protect the filter from scum, grease, or solid material which could prematurely clog the filter.

Seventeen of the community sand filter systems had at least one full-time person hired for maintenance. Fourteen of these systems also hired additional part-time help when necessary. Two of the large filters had additional full-time help; Clinton with 2 and Brockton with 3 full-time employees. Only 6 of the systems relied exclusively on part-time labor to manage the sand filter system.

Preparation for winter operation of the community filters was important in Massachusetts. The State Board of Health Reports listed nine sand filters that were ridged before winter with the wastewater applied to furrows. The ridge-furrow system allowed ice to form across the ridges and still provide a space down the furrows for wastewater application. Five of the filter systems were used for corn production. The sale of the corn helped to support the management of these systems.

SYSTEM PERFORMANCE

Tremendous quantities of performance data are included in the volumes of the Massachusetts State Board of Health and the Department of Public Health. Results were reported at least annually, and sometimes as frequently as every 2 weeks. Tests for oxygen consumed, total residue, loss on ignition, albuminoid ammonia, ammonia, nitrate, iron, and chlorides were conducted at the same laboratory during the monitoring period. After 1930, tests were also conducted for BOD_5 and Kjeldahl nitrogen.

In order to compare the community system results to "modern" filters, conversion were made from oxygen consumed to BOD_5 and from albuminoid ammonia to Kjeldahl nitrogen. Figure 1 illustrates the relationship of oxygen consumed to BOD_5. Conversions from oxygen consumed from raw sewage to BOD_5 were made using equation (1).

$$\text{mg/l } BOD_5 = 27.204 + 2.2359 * \text{mg/l of oxygen consumed from raw sewage} \quad (1)$$

Conversions from oxygen consumed from sand filter effluent to BOD_5 were made using equation(2).

$$\text{mg/l } BOD_5 = -4.2964 + 1.0972 * \text{mg/l of oxygen consumed from sand filter effluent} \quad (2)$$

Figure 2 illustrates the relationship of albuminoid ammonia to Kjeldahl nitrogen. Conversions from albuminoid ammonia in raw sewage to Kjeldahl nitrogen were made using equation (3).

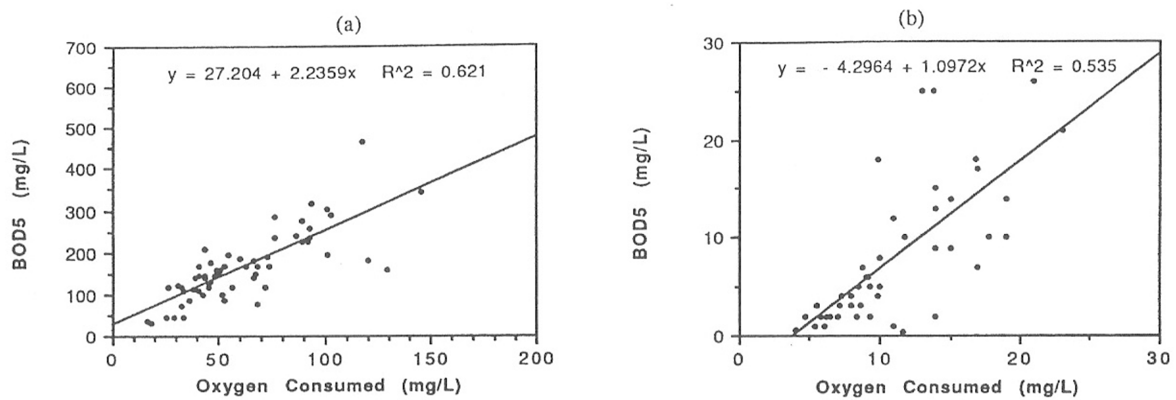

Fig. 1 Oxygen Consumed versus BOD_5 for Raw Sewage (a) and Sand Filter Effluent (b)

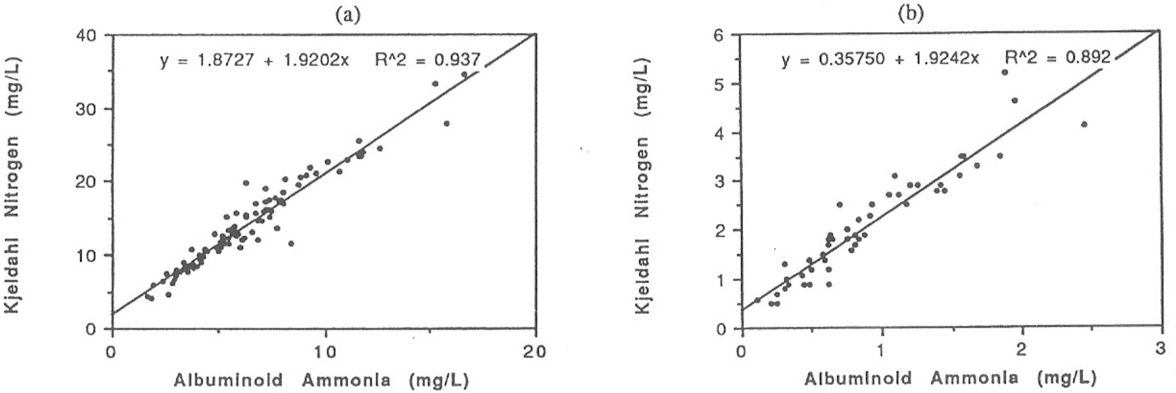

Fig. 2 Albuminoid Ammonia versus Kjeldahl Nitrogen for Raw Sewage (a) and Sand Filter Effluent (b)

mg/l Kjeldahl nitrogen = 1.8727 + 1.9202 * mg/l albuminoid ammonia fro [illegible] y sewage (3)

Conversions from albuminoid ammonia in sand filter effluent to Kjeldahl nitrogen were made using a slightly different equation (4).

mg/l Kjeldahl nitrogen = 0.3575 + 1.9242 *mg/l albuminoid ammonia from sand filter effl. (4)

Table 4 presents the converted BOD_5 values for 7 of the community sand filter systems. Annual averages are presented for a 6 to 10 year period beginning in the late 1800's. Annual averages are also listed for the last 2 years of record. The early performance of these 7 community filters is quite impressive. All but one produced average effluent BOD_5 levels of less than 20 mg/l. Four of the systems produced average effluent BOD_5 levels of less than 10 mg/l. One system, at Leicester, reported poor effluent quality for the first 3 years. In the next four years, the average dropped below 20 mg/l.

Results were published for at least 39 years of operation. For 4 of the systems, the effluent average BOD_5 levels were lower than in the early years of operation. The other 3 showed higher average BOD_5 levels after 39 years.

Table 5 presents the results of the nitrogen analysis for 7 of the community sand filter systems. Albuminoid ammonia has been converted to Kjeldahl nitrogen. All of the filter systems nitrified ammonia to nitrate. However, their performance did diminish with time. The average ammonia levels in the effluent for the first 6 to 10 years for each filter were less than 9 mg/l. After at least 39 years of service, the ammonia level were higher than the average of the first 10 years.

A total nitrogen balance for the 7 community sand filters revealed that from 39 to 87 percent of the nitrogen from the influent to the effluent was unaccounted for. The loss of nitrogen may have been due to dilution of the wastewater by surface or ground water and denitrification may have been occurring in these filters.

CONCLUSIONS

Intermittent sand filter systems have been effectively utilized to treat wastewater for communities ranging in size from 500 to 190,000 people. When these filters were initiated in the late 1800's an average of 0.76 hectares (1.89 acres) was used for every 1000 people. The average area decreased to 0.41 hectares (1.01 acres) for 1000 people by 1937.

The characteristics of the community filters differ from modern standards. The sand characteristics are the most striking difference. The sand used had a smaller effective size and higher uniformity coefficient than recommended for sand filters today. Sand depth was also greater than is recommended for "modern" filters.

Today's limited use of community sand filter systems can not be attributed to effluent quality or filter longevity. The results of the 7 filters presented in this paper illustrate the high level of treatment from intermittent sand filter systems. BOD_5 levels would easily meet many stream discharge requirements now in force across the country. The ability to nitrify ammonia and the potential for nitrogen removal must also be noted. These filters were able to sustain a high level of BOD_5 removal for up to 40 years without long term maintenance problems. Nitrification of ammonia did decrease with time.
Sand filter systems show a great deal of potential for renewed use in small communities. The vast quantity of information contained in the Annual Reports of the State Board of Health of Massachusetts form a foundation for modern design, operation, and management.

Table 5. Community Sand Filter Performance: Nitrogen

City	Date	NH3-N Influent (mg/l)	NH3-N Effluent (mg/l)	Kjeldahl Influent (mg/l)	Kjeldahl Effluent (mg/l)	NO3-N Effluent (mg/l)	% Nitrogen Unaccounted
Brockton	1897	23.60	0.91	12.8	0.56	12.25	62.3
	1898	30.10	1.77	28.0	0.59	17.29	66.1
	1899	36.60	1.32	21.5	0.56	16.37	68.5
	1900	39.90	1.58	23.4	0.61	21.23	62.8
	1901	51.40	0.82	30.3	0.53	22.02	71.3
	1902	50.10	1.63	31.1	0.67	31.67	58.1
	1903	53.20	2.25	32.0	0.68	30.75	60.4
	Ave.	40.70	1.47	25.6	0.60	12.90	77.0
	1936	51.20	11.90	15.90	1.80	21.65	47.2
	1937	50.80	13.90	16.20	2.70	12.37	56.4
Framingham	1893	20.30	1.79	9.6	0.54	12.20	51.1
	1894	24.40	0.48	11.7	0.53	10.75	67.3
	1895	27.20	2.56	15.3	0.52	12.24	63.8
	1896	28.60	2.07	54.3	0.57	7.68	87.5
	1897	31.40	1.43	57.2	0.60	9.86	86.5
	1898	31.00	6.39	62.2	0.70	10.53	81.1
	1899	26.40	3.11	21.5	0.69	14.01	62.7
	1900	27.90	3.40	41.4	0.86	13.50	74.2
	1901	28.40	2.94	24.9	0.80	7.78	78.3
	1902	27.70	3.00	10.9	0.76	17.73	44.0
	Ave.	27.33	2.72	30.88	0.66	11.63	74.1
	1936	46.30	19.70	13.70	3.10	5.49	52.5
	1937	40.70	19.20	11.70	2.70	3.10	52.0
Gardner	1893	18.80	4.63	11.1	1.17	7.78	53.7
	1894	15.70	4.17	9.0	1.13	9.37	39.5
	1895	16.50	5.03	12.6	1.42	7.55	51.5
	1896	26.20	7.44	13.8	1.83	4.53	65.0
	1897	16.90	5.60	15.5	1.33	4.59	64.1
	1898	23.70	6.61	15.1	1.60	6.13	62.7
	1899	29.80	8.08	20.7	1.94	8.19	63.2
	1900	24.30	11.64	18.4	2.23	2.86	60.3
	1901	19.10	11.41	12.0	1.91	1.83	50.2
	1902	21.00	10.07	13.0	2.04	1.70	58.8
	Ave.	21.20	7.47	14.12	1.66	5.45	58.1
	1936	61.50	24.20	28.00	4.10	27.78	36.9
	1937	36.00	11.40	18.70	5.20	14.32	43.1
Leicester	1897	26.30	15.08	17.6	4.43	0.49	54.0
	1898	35.60	11.45	18.8	1.98	11.78	53.3
	1899	35.40	8.81	17.8	2.17	8.38	62.8
	1900	35.20	5.70	14.7	1.56	12.28	59.9
	1901	31.20	5.70	9.6	1.56	15.15	44.5
	1902	32.50	10.46	8.8	2.20	5.85	53.9
	1903	26.70	7.07	11.5	1.92	9.12	51.6
	Ave.	31.84	9.18	14.11	2.26	9.01	54.8
	1936	44.20	13.60	16.30	3.90	1.00	69.1
	1937	23.70	9.70	10.90	1.70	3.30	56.5

Table 4. Community Sand Filter Performance: BOD5

City	Date	BOD5 Influent	BOD5 Effluent	City	Date	BOD5 Influent	BOD5 Effluent
		(mg/l)	(mg/l)			(mg/l)	(mg/l)
Brockton	1897	109	5.5	Leicester	1897	484	20.4
	1898	171	5.7		1898	571	24.3
	1899	282	6.1		1899	510	21.6
	1900	335	6.4		1900	317	13.0
	1901	358	5.7		1901	126	4.4
	1902	424	6.2		1902	99	3.2
	1903	516	7.9		1903	141	5.1
	Ave.	314	6.2		Ave.	321	33.9
	1936	129	9.0		1936	118	25.0
	1937	227	7.0		1937	112	6.0
Framingham	1893	27	4.3	Marlborough	1894	139	8.2
	1894	118	5.6		1895	133	8.0
	1895	159	6.1		1896	117	8.7
	1896	383	5.9		1897	132	8.8
	1897	547	5.9		1898	85	8.0
	1898	593	6.3		1899	159	9.9
	1899	246	6.8		1900	213	10.7
	1900	232	7.6		1901	131	10.4
	1901	174	7.5		1902	153	9.9
	1902	108	6.9		1903	126	12.3
	Ave.	259	6.3		Ave.	139	9.5
	1936	148	14.0		1936	142	7.0
	1937	167	14.0		1937	118	6.0
Gardner	1893	27	4.3	Natick	1897	54	7.4
	1894	100	9.0		1898	54	6.9
	1895	124	10.9		1899	93	7.7
	1896	115	10.2		1900	101	7.5
	1897	119	10.3		1901	74	7.4
	1898	128	10.1		1902	95	8.2
	1899	155	13.7		1903	100	9.1
	1900	157	15.6		Ave.	82	7.7
	1901	112	13.2		1936	121	22.0
	1902	186	16.5		1937	148	29.0
	Ave.	122	11.4				
	1936	343	26.0	Spencer	1898	91	9.2
	1937	238	14.0		1899	101	5.6
					1900	136	6.3
					1901	101	6.6
					1902	136	5.9
					1903	131	7.9
					Ave.	116	6.9
					1936	168	2.0
					1937	140	3.0

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Table 5. Community Sand Filter Performance: Nitrogen (Continued)

City	Date	NH3-N Influent	NH3-N Effluent	Kjeldahl Influent	Kjeldahl Effluent	NO3-N Effluent	% Nitrogen Unaccounted
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	
Marlborough	1894	32.50	4.98	16.5	1.08	11.28	64.3
	1895	19.40	6.43	9.6	0.93	9.06	42.9
	1896	21.10	6.24	10.1	1.16	6.89	54.0
	1897	23.90	7.61	14.7	1.21	5.24	63.2
	1898	19.90	6.20	10.7	0.99	5.44	58.2
	1899	40.10	8.50	17.4	1.28	9.01	66.9
	1900	44.20	8.00	24.3	1.37	11.93	68.5
	1901	37.30	9.00	16.3	1.48	7.87	65.4
	1902	39.00	10.04	15.7	1.30	11.20	58.4
	1903	31.50	12.37	12.2	1.55	3.52	59.5
	Ave.	30.89	7.94	14.76	1.24	8.14	61.6
	1936	48.00	10.20	14.60	1.60	15.73	55.6
	1937	42.30	10.80	13.00	1.80	13.28	52.4
Natick	1897	5.90	0.33	4.9	0.62	4.45	49.4
	1898	7.80	0.79	5.5	0.62	5.19	49.9
	1899	15.20	1.26	7.8	1.38	8.50	51.4
	1900	14.80	1.40	9.2	0.82	5.86	66.0
	1901	12.40	2.36	8.2	0.85	3.20	68.4
	1902	16.00	3.57	7.2	0.96	4.70	59.6
	1903	14.80	6.15	8.0	0.97	2.22	58.2
	Ave.	12.41	2.27	7.28	0.89	4.87	58.7
	1936	34.90	13.60	8.60	3.90		59.8
	1937	29.20	7.30	9.20	4.70		68.8
Spencer	1898	14.50	2.67	11.3	1.15	9.61	45.9
	1899	16.20	1.01	10.9	0.66	7.03	67.9
	1900	17.00	2.33	12.8	0.60	6.89	66.9
	1901	12.40	2.90	10.5	0.71	5.20	61.2
	1902	17.80	2.01	14.9	0.60	8.85	64.6
	1903	18.10	1.48	12.4	0.72	3.69	79.9
	Ave.	16.00	2.07	12.15	0.74	6.88	65.0
	1936	19.40	9.40	12.60	0.90	3.23	57.3
	1937	20.70	7.00	14.00	1.00	0.57	74.8

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