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Project Summary

Slow Sand Filter Maintenance: Costs and Effects on Water Quality

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A study was conducted to determine the effects of scraping on slow sand filter efficiency and to quantify the labor required to operate and maintain a slow sand filter. The data were obtained by monitoring scraping and other maintenance operations at a number of full-sized slow sand filtration plants in Central New York.

Ripening periods (the time required for filtrate quality to improve after filter scraping) were evident in the slow sand filtration plants visited. Ten maintenance operations were monitored in six filtration plants. In four of the ten operations, there was some evidence of a ripening period. This evidence included filtrate turbidity and/or HIAC particle counts that were greater for a recently scraped filter than for an on-line control filter. The length of the ripening period ranged from 6 hr to 2 wk. The data also suggest that a recently scraped filter is less efficient than a control filter in attenuating a spike input of lower-quality raw water. Factors such as the use of prechlorination, water temperature, scraping methodology, and frequency of filter maintenance did not seem to be related to the presence or absence of a ripening period. However, the nature of the particulate matter in the raw water apparently has an important effect on filtrate quality, and a pilot plant study should always be conducted before a slow sand filtration plant is constructed. Continuous monitoring of the turbidity of each filter effluent may be required to ensure that slow sand filter maintenance operations do not have a detrimental effect on treated water quality; the capability to waste individual filter effluent for a period of time may be necessary in some cases to prevent quality deterioration.

Typical labor requirements for filter scraping are approximately 5 man-hours/1000 ft^2 of filter surface. The resanding operation requires approximately 50 man-hours/1000 ft^2. No clear relationship was observed between the frequency of scraping and the raw water quality or maintenance procedures. Operational convenience appears to be a controlling factor in the plants visited.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A large proportion of the public surface water supplies in the United States are small and unfiltered. Many of these systems have experienced difficulty in meeting the 1 nephelometric turbidity unit (NTU) maximum contaminant level (MCL) in the U.S. Environmental Protection Agency (EPA) Drinking Water Regulations. Some of these communities have failed to meet the MCL for coliform group bacteria. The slow sand filtration process may be an appropriate treatment alternative for many of these small systems.

When slow sand filters are used by water utilities, the raw water is typically given no pretreatment. Uncoagulated water is applied and slowly passed through the sand filter. As the run progresses, a layer of soil particles and biological matter (the schmutzdecke) accumulates on the top of the sand bed and the head loss increases. When the terminal head loss is reached, the water level is drawn down to 10 cm or more below the surface of the sand, and the schmutzdecke and a thin layer of sand are removed.

The primary goal of this research was to determine the effects of slow sand filter scraping on water quality and operation and maintenance costs. The major objectives were as follows:

1. To evaluate filter water quality before and after slow sand filters are scraped and to compare it with the quality of raw water and control filter effluent to determine how filter efficiency is affected by scraping.
2. To quantify the labor required to operate slow sand filter plants and to compare the labor needed for routine operation and monitoring with that needed for scraping filters.
3. To determine the frequency of filter scraping (length of run or volume of water filtered per run) and relate this information to raw water quality, water treatment before filtration (if any), filtration rate, sand size, and other relevant design factors. A related objective was to determine whether and to what extent the frequency of filter scraping varies with the depth of sand removed during the scraping operation.

Seven treatment plants were studied in New York State: Auburn, Geneva, Hamilton, Ilion, Newark, Ogdensburg, and Waverly. The typical study visit involved traveling to the plant site 1 or 2 days before a filter was to be scraped. The plant was toured, and the plant records were examined to determine filter run lengths and historical water quality. The effluent from the filter to be scraped was sampled, along with the raw water.

The manpower, techniques, and equipment used in scraping (or resanding) the filters were determined by observation and interview and recorded.

Approximately 50 samples were taken during each plant visit. When water flow through the filter was started after scraping, grab samples were collected for a period of at least 24 to 48 hr. Samples were withdrawn from the scraped filter effluent, a control filter effluent, and the raw water. The control was a filter that had been on-line for at least 1 month.

The water temperature and turbidity were measured immediately after the sample was drawn. Standard plate count and total coliform bacteria analyses were started within 0 to 4 hr after sampling.

The samples were transported to Syracuse University for particle count and size analysis on an HIAC particle size analyzer.

Samples of the filter sand were sieved to determine the size distribution, and a sand dissolution test was conducted using the procedure given in AWWA Standard B100-80.

Results

The average operating flow rate for the sites visited ranged from approximately 0.3 MGD at Hamilton to 6.0 MGD at Auburn (Table 1). The average raw water turbidity was less than 3.0 NTU for every site except Waverly, where the average was approximately 8 NTU. Filters are covered at all of the sites but Hamilton, and two filters at Ilion are uncovered.

The average operating filtration rate is the average operating flow rate for the slow sand filters divided by the total filter plan area. Filtration rates ranged from 0.04 to 0.19 m/hr and had an average value of 0.15 m/hr.

Three of the plants visited (Ilion, Newark, and Waverly) practice prechlorination. At Newark, prechlorination is used to control biological growth in the transmission line between the lake and the treatment plant. Waverly uses prechlorination to oxidize iron and manganese and to decrease the filtrate turbidity. The purpose of prechlorination at Ilion was not stated by plant personnel.

Table 1. *Characteristics of the Slow Sand Filtration Plants Visited*

Location	*Average Operating Flow Rate for Slow Sand Filtration (MGD)*	*Raw Water Source*	*Average Raw Water Turbidity from Plant Records (NTU)*	*Total Slow Sand Filter Plant Area (ft^2)*	*Design Filtration Rate (m/hr)*	*Average Operating Filtration Rate (m/hr)*	*Prechlorination*	*Covered Filters*
Auburn	*6.0*	*Owasco Lake*	*1.5–2.0*	*74,100*	*0.11*	*0.14*	*NO*	*YES*
Geneva	*2.5*	*Seneca Lake*	*1.0*	*30,492*	*0.19*	*0.19*	*NO*	*YES*
Hamilton	*~0.3*	*Woodman's Pond*	*1.0–1.5*	*12,724*	*--*	*0.04*	*NO*	*NO*
Ilion	*1.5*	*Several small streams feeding reservoir*	*3.0*	*19,526*	*--*	*0.16–0.18*	*YES*	*2 uncovered, 3 covered, and 1 not used*
Newark	*2.0*	*Canadaigua Lake*	*3.0 (summer) 1.0 (winter)*	*21,684*	*0.16*	*0.16*	*YES*	*YES*
Ogdensburg	*3.6*	*St. Lawrence River*	*1.0–1.4*	*33,600*	*0.20*	*0.18*	*NO*	*YES*
Waverly	*1.2*	*Surface runoff to reservoirs*	*7.0–9.0 (may be as high as 20–40 during high runoff periods)*	*12,000*	*0.16*	*0.16*	*YES*	*YES*

The efficiency of filtration in a slow sand filter is at least partly determined by the presence of viable microorganisms within the filter bed; thus the use of prechlorination in these systems would be detrimental to filter performance. The effluent average turbidity (for the control filter) was compared with the influent average turbidity at each site and for each monitoring period in which a control filter was sampled. The values were averaged for the entire length of each sampling period (using weighted averages based on flow volume) and used to calculate the percent turbidity remaining in the effluent. For the three cases in which prechlorination was used (4 sets of data), the average and the standard deviation of the percent turbidity remaining were 17% and 7.9%, respectively. For the three cases in which there was no prechlorination (6 sets of data), the average and standard deviation of the percent turbidity remaining were 21% and 7.6%, respectively. Though other factors may have obscured the true significance of adding chlorine before slow sand filtration, these results do not clearly indicate that prechlorination is detrimental to performance. In fact, it may have had a slightly positive effect on turbidity removal in the plants sampled.

The effective size of the filter sand ranged from 0.15 mm at Waverly to 0.45 mm at Auburn. The average effective size for all sites was 0.33 mm. The uniformity coefficient averaged 2.1 and ranged from 1.7 at Newark and Ogdensburg to 2.4 at Auburn, Hamilton, and Waverly.

Standard B100-80 of the American Water Works Association states that a high-quality filter sand should not lose more than 5% of its weight when it is treated in a prescribed way with 1:1 HCl solution. At two of the seven sites, the sand meets this requirement. When the sand dissolution tests were conducted, significant effervescence was noted in most of the treated samples, suggesting that these sands contain significant amounts of $CaCO_3$. The significance of this in terms of filter performance and operation is not known.

Table 2 summarizes the results that pertain to the filter scraping operation. The water production per filter run ranged from approximately 3000 gal/ft^2 at Ogdensburg to 16,000 gal/ft^2 at Geneva and Ilion. The average frequency of filter scraping ranged from approximately twice a year at Geneva, Hamilton, and Ilion to 12 times a year at Ogdensburg. Twice a year at Auburn (usually during the colder months), the filters are raked and no sand is removed. According to Auburn personnel, raking effectively reduces the headloss across the bed without having an adverse effect on filtrate quality. The frequency of 4.3 times per year listed in Table 2 for Auburn includes scraping (i.e., sand removal) and raking.

The water production (3200 gal/ft^2) and scraping frequency (9.7 times/year) listed for Waverly in Table 2 are based on an estimated future filter run length of 900 hr. This estimate is based on data obtained in a 9-mo study in which Waverly personnel developed an operational strategy for effectively dealing with the high raw-water turbidity and the high iron and manganese concentrations that frequently occur in their reservior supply. In the past, Waverly operators experienced filter run lengths as short as 2 days. If in the future the raw water is high in turbidity (>12.5 NTU) and/or high in total iron (>3.0 mg Fe/L) and manganese (>1.0 mg Mn/L), the New York State Department of Health will require Waverly to take the slow sand filtration plant off-line and to use their well water supply exclusively.

The last three columns in Table 2 summarize the methods used and manpower required for filter scraping at the sites visited. Most of the sites remove approximately 1 in. of sand from the filter surface with broad shovels.

The man-hours required for scraping depend on the depth of sand scraped. In the cases where 0.5 to 1.0 in. was removed, the labor requirement ranged from 2 to 9 man-hours/1000 ft^2. At Ilion, where 3 to 4 in. were removed, the labor requirement was significantly greater (23 to 42 man-hours/1000 ft^2).

The method used to convey the dirty sand from the filter area also affects the labor requirement. For example, the lowest labor requirement was at Newark (2 man-hours/1000 ft^2), where

Table 2. *Summary of Filter Scraping Data*

Location	Average Filter Run Water Production (gal/ft^2)	Average Frequency of Filter Scraping Operations (Number per year)	Amount of Sand Removed in Scraping Operation (in.)	Method(s) Used in Removing Sand from Filter Surface	Time Required to Scrape Filters (man-hours/1000 ft^2)
Auburn	6,844	4.3*	0.5	Shovels, hydraulic	4
Geneva	15,718	2.0	1.0	Shovels, motorized buggy	4–5
Hamilton	4,302	2.0	1.0	Shovels, 50 gal drums, backhoe	8–9
Ilion	15,487	1.8	3–4	Shovels, hydraulic	23–42
Newark	10,122	3.3	1.0	Shovels, motorized buggy	2
Ogdensburg	2,978	12.0	1.0	Shovels, hydraulics	4–5
Waverly	3,200†	9.7†	1.0	Shovels, wheelbarrows	5

At Auburn, two scraping operations per year are actually occasions when the filters are raked and no sand is removed.

†Water production and scraping frequency estimated by the Waverly personnel for the future using data from a 9-month operations study. Waverly has had runs as short as 2 days.

Table 3. *Estimated Operation and Maintenance Costs for Slow Sand Filters**

Location	Average Operational Flow (MGD)	Labor for Scraping (man-hours/year)	Labor for Resanding (man-hours/year)	Labor for Day-to-Day Activities (man-hours/year)	Total Labor Costs ($/year)	Total Operation and Maintenance Unit Cost (¢/1000 gal)
Auburn	6.0	1007	618	365	10,597	0.5
Geneva	2.5	374	218	365	7,390	1.1
Hamilton	0.3	224	NA	365	5,890	5.3
Ilion	1.5	905	563	365	18,331	3.3
Newark	2.0	143	226	365	7,640	1.1
Ogdensburg	3.6	8736	†	365	23,811	2.0
Waverly	1.2	582	420	365	13,670	3.7

**All cost figures are based on a $10/hr wage rate except at Auburn, where $3/hr was used because the workers are usually summer students.*

†Ogdensburg scrapes and resands simultaneously.

an efficient, motorized buggy was used to haul the dirty sand from the filter. The greatest labor requirement for the plants that scrape 0.5 to 1 in. of sand was at Hamilton (8 to 9 hr/1000 ft^2), where the dirty sand removal process involved filling 55-gal drums and hauling them away with a tractor.

Under typical conditions (i.e., removal of about 1 in. of dirty sand with shovels and conveyance of this sand from the filter hydraulically), the labor requirement was approximately 5 man-hours/1000 ft^2 of filter surface.

Table 3 compares the estimated operating costs for slow sand filters the treatment plants visited. Day-to-day activities devoted exclusively to the filters (collecting samples, checking the filters, etc.) were assumed to require 1 man-hour/day. The labor requirement for scraping is based on the scraping frequency listed in Table 2. Resanding was assumed to require 50 man-hours/1000 ft^2, based on data from Auburn.

The estimated operational unit costs ranged from 0.5¢/1000 gal at Auburn to 5.3¢/1000 gal at Hamilton. The mean value for all plants was 2.4¢/1000 gal. The exceptionally low value at Auburn was partly because of their using low wage summer help ($3/hr) for most scraping and resanding operations.

Table 4 summarizes the results for filters that exhibit a ripening period. The ripening period is the interval immediately following filter scraping and/or resanding during which the turbidity or particle count is significantly greater than that for a control filter.

Ripening periods were observed at Auburn, Ilion, Newark, and Waverly. At Auburn, one out of the three scraping operations monitored exhibited a short ripening period. For a period of about 6 hr, the filtrate turbidity and particle count data for the scraped filter exceeded the corresponding values for the control filter by a factor of about 2. However, the turbidity values were always below the MCL of 1 NTU.

The measurements made at Ilion are difficult to interpret with respect to a ripening period. The scraped and control filters yielded very similar turbidities after scraping, but approximately 6 hr after the scraped filter was brought back on line, the particle counts for the scraped filter began to exceed the values of the control filter by a factor of about 2. The time required for this disparity to disappear was about 12 hr.

Two operations were monitored at Newark. One was a typical scraping operation and the other involved resanding the bed. No ripening period was observed when the scraping operation was monitored, but a ripening period was clearly evident in the resanding case. During the ripening period, the filtrate turbidity of the scraped filter exceeded that of the control by a factor of about 3. The effluent turbidity of the control and scraped filters never exceeded 0.5 NTU; however, the particle count values were always less than 1000/mL for both filters.

Ripening periods are a routine occurrence at Waverly. Operating personnel are not surprised if 2 weeks elapse before the scraped filter turbidity decreases to values approaching those of the control filter. During this study, ripening was most apparent in the turbidity results: particle counts for the scraped and control filters appeared to coincide after about 30 hr, whereas the turbidity values converged after about 10 days.

The reason for the Waverly's problems is not clear. The raw water appears to contain submicron-sized particles that scatter light and increase the turbidity but are not efficiently removed by slow sand filtration. According to the particle count data, Waverly removes particles larger than 2 μm as efficiently as the other plants visited.

Conclusions

1. Four of the ten scraping and resanding maintenance operations monitored produced some evidence of a ripening period. This evidence included filtrate turbidity and/or HIAC particle count values that were greater for a filter that was maintained than for a control filter that had been on line for a significant period of time.
2. The length of the ripening periods observed ranged from 6 hr to 2 wk. The factor that seemed to have the most significant effect on filtrate quality was the nature of the particulate matter in the raw water. The presence or absence of a ripening period does not seem to be related to prechlorination, water temperature, scraping method, or frequency of filter maintenance.
3. The results suggest that a recently scraped filter is less efficient than a

Table 4. *Summary of Filter Ripening Data*

Location	Type of Operation During Visit*	Date of Site Visit	Raw Water Turbidity During Site Visit (NTU)	Water Temperature During Site Visit (°C)	Filtrate Turbidity Approximately 5 hrs after Filter Start-up (NTU)		Evidence of Ripening Period	Approximate Length of Ripening Period (days)
					Scraped/Resanded Filter	Control Filter†		
Auburn	(1)	July 83	1.2–2.0	~19	0.43	0.27	YES	0.25
Auburn	(1)	July 83	1.2–2.0	~19	0.28	0.27	NO	--
Auburn	(1)	July 84	2.0–2.8	~18	0.22	0.23	NO	--
Geneva	(1)	July 83	--	--	--	--	--	--
Hamilton	(1)	May 84	1.0–1.5	~12	0.28	NONE	NO	--
Ilion	(1)	July 83	2.0–4.0	~23	0.30	0.40	Minimal (particle count only)	0.5
Newark	(1)	Aug. 83	1.2–3.5	~13	0.35	0.35	NO	--
Newark	(2)	Jan. 84	0.6–2.7	~4	0.41	0.12	YES	2
Ogdensburg	(3)	Aug. 83	0.3–0.6	~15	0.12	0.10	NO	--
Ogdensburg	(3)	Feb. 84	1.0–1.2	~2	0.22	0.24	NO	--
Waverly	(1)	June 84	6.0–11.0	~15	2.3	1.6	YES	10

*(1) Scraping operation

(2) Resanding operation

(3) Scraping combined with resanding

†Control filter—filter on line at least 1 month, except at Ogdensburg where the filter was on line 1 week.

ripened control filter in attenuating a spike input of lower quality raw water. This behavior was observed at several sites and was apparent in both the turbidity and the HIAC particle count results.

4. The water production per filter run ranged from approximately 3000 gal/ft^2 at Ogdensburg to 16,000 gal/ft^2 at Geneva and Ilion. The average frequency of filter scraping ranged from twice per year at Geneva and Ilion to 12 times per year at Ogdensburg. No clear relationship exists between the frequency of scraping and raw water quality or maintenance procedures. Operational convenience and tradition seem to be the important factors. Limited evidence suggests that the filter run length is shorter during the summer.
5. Under typical conditions of filter scraping (i.e., removal of about 1 in. of dirty sand with shovels and conveyance of this sand from the filter with a motorized buggy or hydraulic transport), the labor requirement is approximately 5 man-hours/1000 ft^2 of filter plant area. A resanding operation that applies 6 to 12 in. of clean sand to the depleted bed requires approximately 50 man-hours/1000 ft.

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The complete report, entitled "Slow Sand Filter Maintenance: Costs and Effects on Water Quality," (Order No. PB 85-199 669/AS; Cost: $13.00, subject to change) will be available only from:
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