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SLOW SAND FILTER MAINTENANCE COSTS AND EFFECTS ON WATER QUALITY

by

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Slow sand filters have provided quality water for many years. Recently interest in this technology has been revived especially as a technique which is appropriate for small supplies. This study was conducted to determine how slow sand filter efficiency is affected by maintenance operations and to quantify the labor required to operate and maintain a slow sand filter.

Francis T. Mayo, Director
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ABSTRACT

A study was conducted to determine how slow sand filter efficiency is affected by scraping 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-size 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, and in four of these operations there was 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. The length of the ripening periods ranged from 6 hr to 2 weeks. The data also suggests 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. The 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.

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 per 1000 ft^2 of filter plan area. The resanding operation in which 6 to 12 in. of sand is applied to a bed that has been depleted of sand by repeated scraping operations, requires approximately 50 manhours per 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.

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SECTION 1

INTRODUCTION

STATEMENT OF PROBLEM

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 limit (MCL) in the U.S. Environmental Protection Agency 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.

Slow sand filters have been shown to be very effective for removing a variety of microorganisms (1,2,3 and 4). For certain types of raw water, slow sand filters are also very effective for removing turbidity-causing particulates (5). Slow sand filters have been successfully used to remove various trace elements such as copper, lead, and zinc (6).

When slow sand filters are used by water utilities, the raw water typically is 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 head loss increases. When 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 filter cleaning operation tends to be labor intensive. For small installations, manual cleaning procedures are generally used. Use of shovels and wheelbarrows to remove the sand layer and haul away the dirty sand would be typical practice at smaller slow sand filter plants. Sand filter cleaning and maintenance work would generally be the most time-consuming aspect of slow sand filter operation, and it would be expected to have a strong influence on the labor costs associated with slow sand filter operation.

When the slow sand filter is scraped and the dirty sand is removed from the filter bed, some disturbance of the filter bed is inevitable. Huisman and Wood (7) state that disturbing the upper layers of the sand bed can be detrimental to the bacterial population in the filter. They also indicate that when a slow sand filter is placed into operation after scraping, filter effluent is run to waste until the normal filtered water quality standards are met, as shown by analysis of water samples.

Though the literature (8,9 and 10) contains evidence that scraping may affect effluent quality in full scale filters, the results of recent slow sand filter research have not shown this. Research at Iowa State (11) and Colorado State Universities (12) has confirmed that pilot slow sand filters do not show quality deterioration after scraping.

A reason for this difference in results may be related to the size of the facilities and the extent to which the filter is disturbed during the scraping operation. The older evidence in the literature was obtained with full scale filters, whereas the recent data have been obtained using pilot units that are generally only a few square feet in area.

Additional information needs to be developed on the extent to which filter cleaning can influence the effluent quality as well as the cost of the slow sand filter operation. Evidence (13) exists that resanding of a filter bed has a more detrimental effect on effluent quality than scraping. This research focused on these aspects of slow sand filtration by studying municipal slow sand filters before, during, and after the filter scraping and resanding operations.

BACKGROUND

Slow sand filters have been used to treat drinking water since 1829, when James Simpson constructed a plant to treat water for the Chelsea Water Company in London. Information is available on slow sand filters, but much of the work published on slow sand filtration in this country was done in the late 1800's or early 1900's, before rapid sand filtration became almost universally popular in the United States. Recent research on slow sand filtration has used analytical techniques that were not available in 1900 or that have been modified since then.

Treated Water Quality as Influenced by Filter Scraping

Slow sand filter scraping is generally thought to result in deterioration of filter effluent quality immediately upon resumption of operation. The duration of the water quality improvement or filter ripening period is variable, but it could last as long as several days. Higher plate count bacteria concentrations were observed in a slow sand filter pilot plant study conducted at Pittsburgh in 1898 (14). For 1 to 2 days after scraping, plate count bacteria concentrations were 2 to 6 times the monthly average plate count data from which the 48 post-scraping data were excluded. This sort of result is suggested by Huisman and Wood (7), although they did not present data to show the extent of quality deterioration that might occur.

In the book, The Filtration of Public Water Supplies (9), Hazen stated that Piefke in Germany had suggested wasting filtered water for one day after scraping and for a full week after filter sand was replaced (p. 74). Hazen reported that the Imperial Board of Health rules required that German filters should be constructed so that filtered water could be wasted. Hazen also reported (pp. 75,76) that experiments in Germany and at the Lawrence Experiment Station in the United States had shown higher bacterial counts in filtered water for one or more days after scrapings. The increase in the bacterial count was greater when the sand filter depth was reduced and when the rate of filtration was higher.

Results of recent slow sand filter research have not shown the detrimental effects of scraping on effluent quality. Results of EPA research presented by Logsdon and Lippy (15) indicate no deterioration of water quality during two different runs when a filter was restarted after scraping (Figure 6 in Logsdon and Lippy). This is in contrast to the 6 week interval of poor effluent quality observed when the filter operation first started and water was passing through new, clean sand. Information available from EPA's Drinking Water Research Division also indicates that other pilot slow sand filters operated at Iowa State University and Colorado State University did not show quality deterioration after scraping (11,12).

One possible reason for the differences in results could be the size of the facilities and the extent to which filters have been disturbed during scraping and cleaning. The municipal filters observed decades ago were large, and the sand could not be removed without walking on the filter. Even the pilot filters at Pittsburgh studied by Hazen were large enough (11 ft. x 23 ft.) that sand would have been disturbed during cleaning. In contrast to the large sizes of the filters on which the deteriorated water quality observations are based, the pilot scale slow sand filters currently under study are generally very small. The DWRD filter (2) is 1.5 x 1.5 feet and other filters being used are from 1 to 2.5 feet in diameter. The absence of the walking action and the resulting disturbances to the sand bed may be a factor in the high quality of water observed within the first day of renewed operation of the slow sand pilot filters.

Influence of Scraping on Operation and Maintenance Costs

During routine operation, slow sand filters do not require much labor on a daily basis. In less than an hour, a plant operator should be able to monitor filter flow rate versus water consumption and adjust the rate if needed, obtain a filtered water turbidity sample and analyze it, check chlorine residual and adjust if necessary, monitor head loss, and record the appropriate operating data.

When a slow sand filter is removed from service for cleaning, the labor needs rise dramatically. One or more persons may have to work for a portion of a day or longer to clean the filter. The extent of labor required is related to working conditions, filter access (closed versus open filters), extent to which sand removal is mechanized, size of the filter, depth of sand removed in the scraping process, and extent of cleaning performed on filter walls. Resanding (adding more sand to the bed when the depth of the sand has reached the minimum desired amount) would be expected to take considerably longer than simply removing 2 to 4 cm. of dirty sand from the top of the filter bed. Sand washing may also involve extra labor if the water utility reuses sand previously removed from the filter during cleaning.

Data that can be used to relate slow sand filter costs to filter size are very limited, even though cleaning costs could exceed filter monitoring costs if the area of the filters were sufficiently large. Up-to-date information needs to be developed so that costs of operation and maintenance of slow sand filters of various sizes can be estimated by engineers when conceptual designs are prepared and process options are considered.

RESEARCH OBJECTIVES

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

(1) To evaluate filtered water quality before and after slow sand filters are scraped and compare it with the quality of raw water and control filter effluent to determine how filter efficiency is affected by scraping. A determination can then be made of the volume of water per unit plan area of filter bed which must be wasted before the filtrate meets the MCL's for turbidity and coliform group bacteria.

(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. Labor requirements can then be related to the area of filter cleaned, volume of sand removed, extent of mechanization, and working conditions.

(3) To attempt to ascertain the frequency of filter scraping (length of run or volume of water filtered per run) and relate this information to raw water quality, pretreatment 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.

SECTION 2

CONCLUSIONS

1. In four of the ten scraping and resanding maintenance operations monitored during the study, there was 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 hours to 2 weeks. 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 the use of a prechlorination step, water temperature, scraping methodology or frequency of filter maintenance.

3. The results suggest that a recently scraped filter is less efficient than a "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 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. There is limited evidence 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 per 1000 ft^2 of filter plan area. The resanding operation in which 6 to 12 in. of clean sand is applied to the depleted bed, requires approximately 50 man-hours per 1000 ft. The average operation and maintenance cost for the plants visited was 2.4¢/1000 gal.

SECTION 3

RECOMMENDATIONS

1. The continuous monitoring of each filter's effluent turbidity in a slow sand filtration plant will be necessary in many cases to ensure that maintenance operations such as scraping and resanding do not have a detrimental effect on treated water quality.

2. The capability to waste individual filter effluent for a period of time is recommended to prevent water quality deterioration. The length of time that filter effluent wasting is required can be determined with turbidity or particle count measurements.

3. Pilot plant studies should be used to determine whether slow sand filtration is a feasible treatment alternative.

SECTION 4

SAMPLING AND ANALYTICAL METHODS

INTRODUCTION

Seven treatment plants were chosen for study because of their proximity to Syracuse University: Auburn, Geneva, Hamilton, Ilion, Newark, Ogdensburg, and Waverly, New York (See Figure 1). The typical study visit involved traveling to the plant site one or two 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. Each plant provided space to set up laboratory equipment.

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

SAMPLING

When water flow through the filter was started after scraping, grab samples were collected for a period of 24-48 hours. Initially, the grab samples were collected every hour and gradually the interval was increased to every two hours. Finally, the samples were collected over four and eight hour intervals. Samples were withdrawn from the scraped filter effluent, a control filter effluent and the raw water. The control was a filter which had been on-line at least one month. All of the samples were taken before post-chlorination; three of the plants visited practiced pre-chlorination (Ilion, Newark and Waverly). At two of the three plants with pre-chlorination (Ilion and Waverly), raw water samples were obtained both before and after the point of chlorine addition. The samples were not dechlorinated.

Between 25 and 66 samples were taken during each plant visit. Samples were obtained by dipping a polystyrene bottle into the water or drawing water directly from taps. The details concerning sampling at each site are discussed in the Results and Discussion sections. Every sample bottle and cap was rinsed with the water three times before the sample was collected.

The water temperature and turbidity were measured immediately after the sample was drawn. Standard plate count and total coliform bacteria analyses were almost always started within 0-4 hours after sampling. The longest time

Figure 1. Locations of Slow Sand Filtration Plants Visited During the Study.

period between sampling and beginning the microbiological tests was 12 hours. If the analysis was not carried out immediately, the samples were kept refrigerated at 42-45°F.

The samples were finally transported to Syracuse University for particle count/size analysis on the HIAC Particle Size Analyzer. These counts were obtained 6 - 48 hours after sampling. The samples were kept refrigerated or iced at all times.

ANALYTICAL METHODS

Turbidity

A Turner Designs Model 40-100 Digital Nephelometer was used for all turbidity measurements. The instrument was calibrated twice daily with AMCO AEPA-1 standards of 0.5 and 5.0 NTU. (AMCO Polymerics, Inc., Mountain View, CA)

Particle Count

The HIAC Model PC-320 Particle Size Analyzer was calibrated using PVC microspheres from Particle Data Labs, Inc. Four, ten mL replicates were counted for each sample and the results were averaged. The samples were brought to room temperature before the measurements were made. Dilution of the samples was not required; all samples were below the recommended particle concentration limit of the 1 - 60 µm HIAC detector. The particle counts recorded are the particles in the 2 µm to 60 µm effective diameter size range.

Standard Plate Count

Portions (1 mL and 0.1 mL)of undiluted sample were plated in triplicate by pouring 10 mL of medium tempered to 45°C into the plate and gently mixing. The culture medium was autoclaved plate count agar prepared according to the manufacturer's (BBL Microbiology Systems, Becton, Dickinson and Co., Cockeysville, Maryland) specifications. The agar was allowed to harden for 10-15 minutes after which the plates were incubated at 35°C for 48 ± 2 hours. All plates containing 30-300 colonies were counted with the aid of a Quebec colony counter (counts from 1.0 mL portions having less than 30 colonies were also recorded).

Total Coliform Group Bacteria Concentration

Portions (100 mL) of each sample were tested in triplicate using a standard membrane filter apparatus. Each membrane filter was placed on M-endo agar and incubated for 24 ± 2 hours at 35° ± 0.5°C. The M-endo plates were placed in a separate covered container lined with a water soaked towel to maintain 100% humidity.

The BBL M-endo agar was prepared by mixing 2.4 g M-endo broth, 0.4 standard methods agar, 50 mL water, and 1 mL 95% ethanol. This mixture was heated to the boiling point and 2.2 mL portions were added to the coliform plates using a pipette and allowed to harden. The filters were placed on the surface of this agar.

Sand Analysis

All sand samples were washed in distilled water and dried for 1-2 hours at 110°C. The analyses were conducted in duplicate and the results were averaged.

Sieve Analysis--

A 100 to 110 g quantity of sample was weighed and placed in a sieve stack. The sieve stack was composed of the following sieve screen sizes from top to bottom:

lid

3.327 mm
2.000 mm
1.410 mm
0.850 mm
0.589 mm
0.295 mm
0.208 mm
0.104 mm

pan

The pre-weighed sieve stack was placed in a mechanical sieve shaker. The shaker was turned on for five minutes. Next the weight of the sand retained on each sieve was measured and the percent of sand retained was determined. Finally, the percent passing each sieve was calculated and plotted vs. the sieve size. The effective size (opening which 10% passes) and the uniformity coefficient (opening which 60% passes divided by the effective size) were determined using the graph.

Sand Dissolution Test--

Between 100 and 110 grams of the clean, dry sand was placed in a 1 liter beaker and 1:1 HCl (minimum volume of 320 mL) was added. The beaker was allowed to stand for 30 minutes after the effervescence (if any) had ceased.

The acid was then removed by pouring and the sample was washed several times with distilled water and dried for 1-2 hours at 110°C. The sample was cooled and weighed and the weight loss reported as:

$$\frac{\text{weight lost}}{\text{original weight}} \times 100 = \%\ \text{weight lost}$$

SECTION 5

RESULTS AND DISCUSSION

SITE 1 - AUBURN

The city of Auburn, New York is located in Cayuga County on the Owasco River, thirty miles west of Syracuse. With a population of 35,000, it is the industrial center of an agricultural area.

Water Source

The city of Auburn receives its water from Owasco Lake, the second of the long, narrow Finger Lakes located two miles south of the city.

Owasco Lake is 11 miles long and 1.5 miles wide and 177 feet deep at its deepest point. The summertime turbidity of the raw water being pumped from the lake is usually in the range 1 - 2 NTU. In the winter the turbidity may decrease to a value as low as 0.8 NTU if the lake freezes over. Coliforms are rarely detected by Auburn water plant personnel in Owasco Lake water. The water chemistry results of a United States Geological Survey analysis (16) of Owasco Lake are listed in Table 1.

Water Treatment

Slow Sand Plant--

A slow sand filter plant designed by Allen and Hazen Consulting Engineers was put into service in Auburn in 1919. As shown in Figure 2, there are four identical covered filters, each 195' x 95', giving a total filtration area of 74,100 feet^2 (1.7 acre). The slow sand plant was built to treat 5 MGD, however, it normally operates at approximately 6 MGD. The design filtration rate is, therefore, 0.11 cubic meters per square meter per hour (m/hr). The plant normally operates at 0.14 m/hr. The water flowing through the slow sand plant receives no pretreatment.

Auburn's sand has the largest effective size (0.45 mm) and with Hamilton and Waverly the largest uniformity coefficient (2.4) of any of the sites visited. The weight loss after dissolution in 1:1 HCl was 35% suggesting that the sand is not of high quality. The sand does not meet the AWWA Standard B100-80 requirement (17) that less than 5% dissolve in 1:1 HCl.

Table 1. Owasco Lake Water Chemistry From U.S. Geological Survey (16)

	mg/L		ug/L
silica	1.5 - 2.7	aluminum	93 - 230
calcium	4. - 45	barium	24 - 31
magnesium	7.5 - 8.3	beryllium	<0.8 - 2.0
sodium	3.7 - 4.1	bismuth	<4.0
potassium	1.1 - 1.2	boron	8.0 - 14.0
bicarconate	131 - 141	chromium	<4.0
sulfate	19 - 21	cobalt	<2.0 - 4.0
chloride	6.5 - 7.6	copper	4.0 - 28
fluoride	0 - 0.10	gallium	<2.0 - 4.0
total kjeldahl nitrogen as nitrogen	0.19 - 0.39	germanium	<4.0 - 8.0
nitrate as N	0.80 - 0.90	iron	74 - 140
phosphorous as PO_4	0.02 - 0.04	lead	<2.0 - 4.0
sum dissolved solids	152 - 161	lithium	<10
total hardness	133 - 145	manganese	5.0 - 10
non-carbonate hardness as $CaCO_3$	25 - 30	molybdenum	<0.7 - 2.0
total organic carbon	100	nickel	<2.0 - 4.0
		silver	<0.40 - 0.70
specific conductance	272-287 $\frac{\text{micromhos}}{\text{cm}}$	strontium	55 - 72
pH	8.0 - 8.3	tin	<4.0 - 8.0
coliforms	none found	titanium	4.0
		vanadium	<2.0 - 4.0
		zinc	<230 340
		zirconium	<6.0 - 8.0

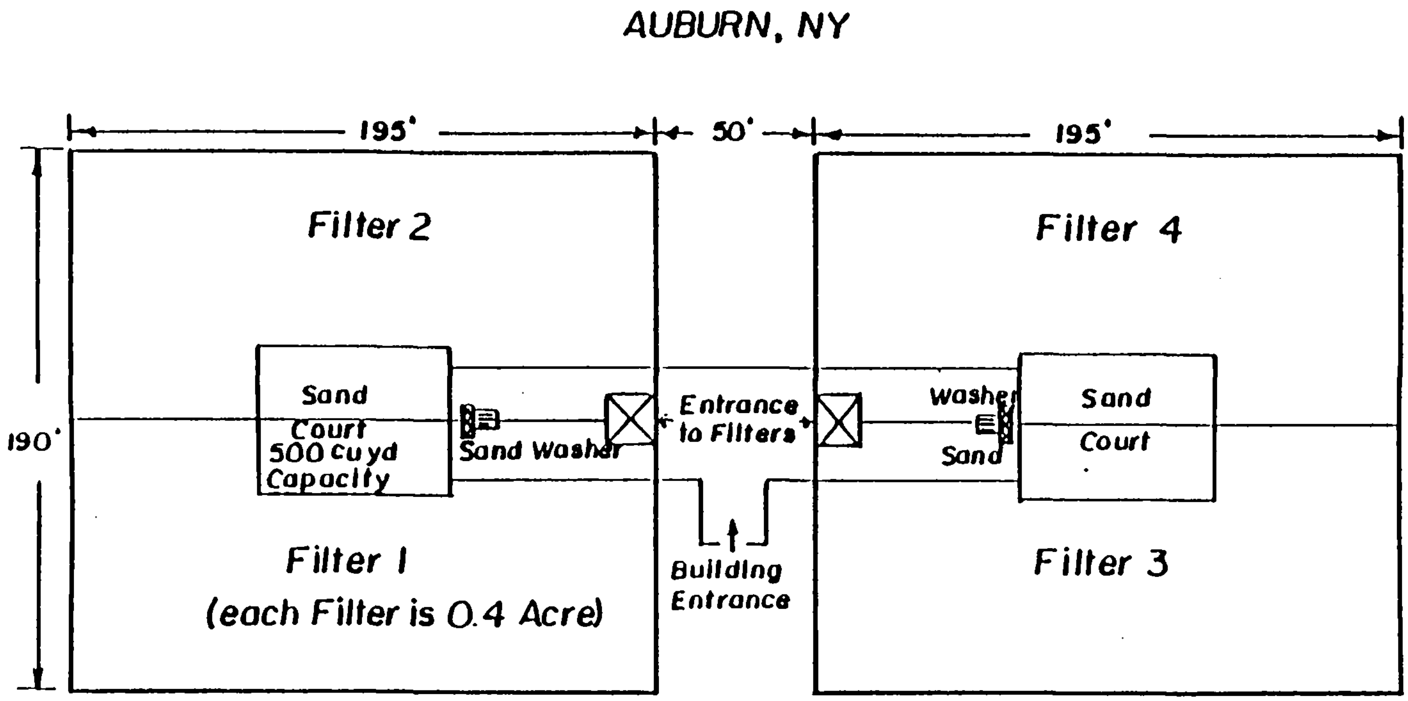

Figure 2. Plan Drawing of the Auburn Slow Sand Filtration Plant.

Rapid Sand Filtration Plant--

To meet an increasing water demand a rapid sand filtration plant was designed by Metcalf and Eddy and put into service in December of 1969. This plant was designed to treat 5 MGD (filtration rate of 7.25 m/hr); however it is normally operated at 4.5 MGD (filtration rate of 6.53 m/hr).

Each filter consists of a 16 inch graduated gravel layer covered by a 10 inch sand layer and a 10 inch anthracite layer.

The rapid sand filters receive water which has been pretreated with gaseous chlorine. The total chlorine usage rate at Auburn (a breakdown between pre and post chlorination and slow and rapid sand plants is not available) was 120 lb Cl_2/day. The free chlorine residual in the water leaving the combined plants was 0.8 mg Cl_2/L.

Normally the rapid sand filters are operated without the use of coagulants. However, when the raw water turbidity is high (4-5 NTU or greater), a dosage of 100 lbs per day of aluminum sulfate (2.7 mg/L)is added.

Operation

There is an operator on duty at Auburn twenty-four hours per day. Two operators are on duty during the eight-hour daytime shift. However, with the exception of scraping and resanding, very little of the operators' time is devoted to the slow sand plant. Most of the operators' time is consumed by the rapid sand plant or groundskeeping.

Scraping and Resanding--

Each filter is initially filled with a sand layer 36 inches thick. This allows seven to eight feet of space between the sand and the concrete and earth filter cover. When in operation there is six feet of water above the sand.

The decision to scrape a filter is made with the guidance of headloss gauges (although visually checking the water height in sampling wells may also be used). When the headloss reaches four feet (which represents a 50% decrease in flowrate through the filter), scraping is scheduled.

During the past ten years each filter was "cleaned" an average of 4.4 times per year. This corresponds to an average filter run length of 279 m^3/m^2 (6844 gal/ft^2). Scraping is usually scheduled for the summer months when Auburn can hire low wage workers (high school and college students). Scraping continues during the summer until approximately ten filters are finished (each filter is scraped at least twice). During non-summer months when help is not available the schmutzdecke is raked rather than scraped (this is usually done twice annually for each filter). Thus, the "cleaning" process at Auburn may consist of scraping or raking (to total an average of 4.4 operations per year). In addition, seven times during the past ten years a filter was resanded. Each of the operations will now be discussed.

Scraping Process--

During a normal scraping operation the filter is out of service for three days; one day to drain, one day to scrape, and one day to refill and put back in service. One day is considered to be the eight hour day shift when all the work is done. Therefore, this operation could be consolidated into 24 hours if the need arose. There is no effluent wasting period after cleaning.

The scraping operation employs 12-14 people (summer help) directed by one operator. It takes 12 people approximatley six hours to scrape a filter which corresponds to 4 man hours per 1000 ft^2. Approximately 1/2 inch of sand is skimmed from the surface of the filter bed with broad shovels and placed in piles at strategic points on the filter. Each filter has three outlets from permanent piping to which a hopper may be connected. The sand is shoveled into the hopper and moved hydraulically to one of two sand washers (a sand agitator with a settling tank). After washing the sand is stored in an open sand court above the filters until needed (see Figure 2).

During the non-summer months (about 2 times per year) the schmutzkecke is raked rather than scraped. This operation still requires eight hours to drain the filter and eight hours to refill. However, raking only takes 5-6 men about 5-6 hours to complete or 1.4-2.0 man-hours/1000 $feet^2$. Auburn can reduce the headloss from four feet to one foot by raking the schmutzdecke. Therefore, raking is a good substitute for scraping when workers are not available.

Resanding Process--

Seven filter beds were resanded during the past ten summers. This corresponds, for each filter, to six years of operation between resandings. When the sand reaches a depth of approximatley thirty inches the bed is resanded to a depth of thirty-six inches. The resanding operation consists of placing previously washed and stored sand on top of the remaining sand in the filter bed. This sand is brought into the filter bed hydraulically.

Occasionally the workers will spade the sand in the bed before adding more sand to prevent subsurface hardening. This seems to break up any calcium carbonate or hardened mud deposits.

During a resanding operation a filter may be out of service for three weeks (up to 50 man-hours/1000 ft^2), however, no written records are available. Twice during the history of the plant (1957 and 1972-74) all of the sand in the filters was completely replaced. There is no record of the cost or duration of these operations.

Sampling

Each slow sand filter discharges into its own wet well. Samples were taken by climbing into the wells via an attached ladder and dipping the bottles into the water. Samples at the rapid sand filtration plant were taken from sampling taps built into the water lines. Raw water samples were taken by dipping bottles into the water which flowed onto the covered slow sand filter beds.

Results and Discussion - Auburn

Two filter cleaning operations were monitored in July 1983 (filter #1 and #3) and a third cleaning operation was monitored in July of 1984 (filter #1).

Turbidity--

According to plots of turbidity versus time (Figures 3, 4 and 5) two of the three filters tested (#3 and #1 in 1984) had no ripening period. The effluent was at control levels (0.2-0.3 NTU) as soon as the filters are put back in service.

Filter #1 (1983) (Figure 4) had a slightly higher turbidity (0.55 vs. 0.25 NTU for the control) for the first six hours off operation. After six hours it had decreased to control levels. Overall the water quality was satisfactory from a turbidity standpoint. It was always significantly less than the 1.0 NTU MCL.

Particle Count Data--

The water samples from two of the scraped filters (#1 in 1983 and 1984) were analyzed using the particle size analyzer. In general the trends were the same as the turbidity results (See Figures 6 and 7). The first filter (#1, 1983) (Figure 6) started high (600 particles/mL) and took four hours to reach control levels ($\sim$200 particles/mL). The other filter (1984) (Figure 7) started high (1142 particles/mL) at time-zero, but decreased to control levels ($\sim$400 particles/mL after just one hour.

Analysis of the change in particle size (in the range 2 to 60 µm) over a period of time (for July 1984) indicated that the count median particle size changed a small amount, from 3.2 µm (at 1 hr) to 3.5 µm (3 hr) and finally to 2.5 µm (29 hr).

The size of the particle which 90% of all particles counted are smaller than (d_{90}) and the size of the particle which 10% of all particles counted are smaller than (d_{10}) both decreased with time. This suggests that the particles that passed through the filter become slightly smaller with time. However, these are not statistically significant differences.

Standard Plate Count--

It is very difficult to detect any trends in the standard plate count results; the data exhibits significant scatter (See Figures 8, 9 and 10).

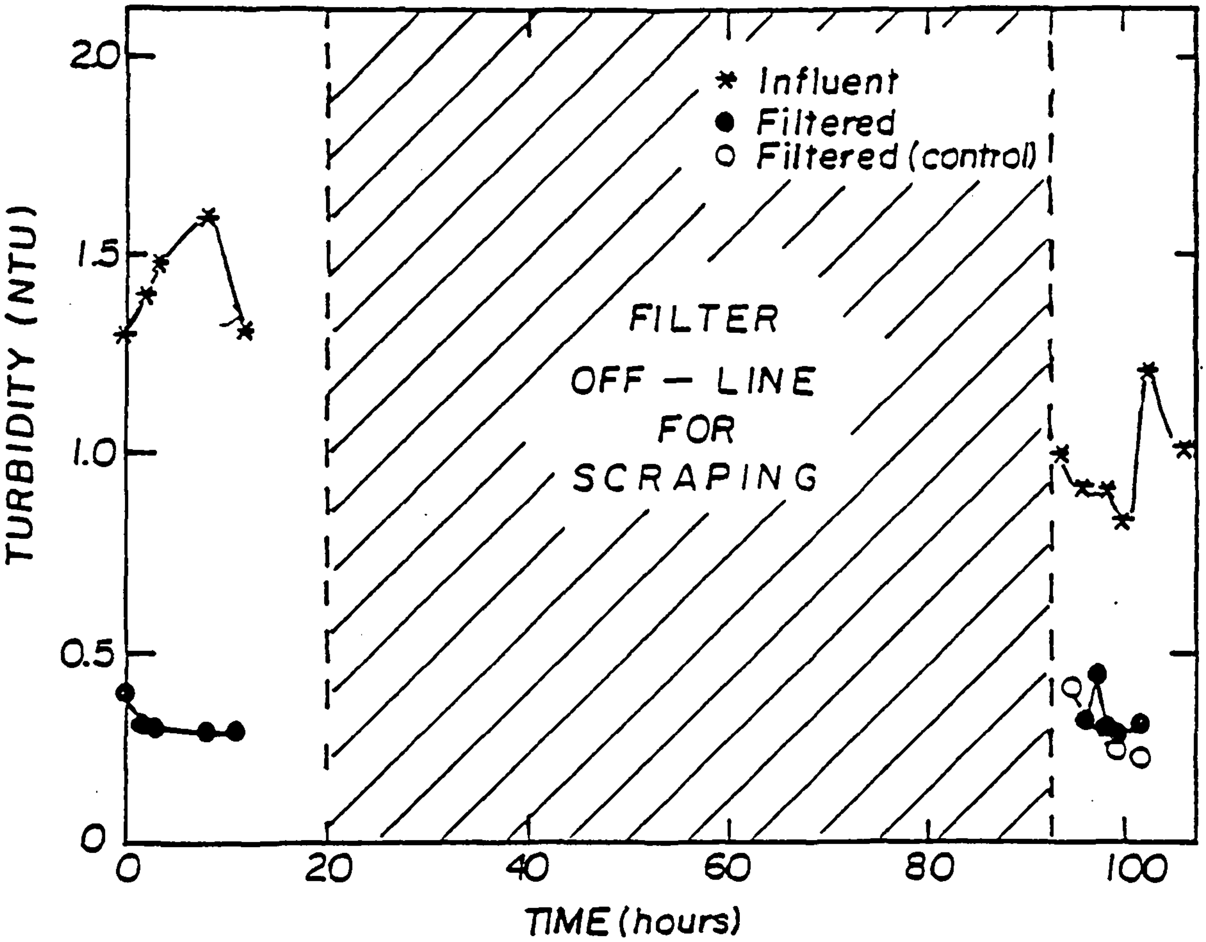

Figure 3. Turbidity versus Time at Auburn, July 1983, Filter #3

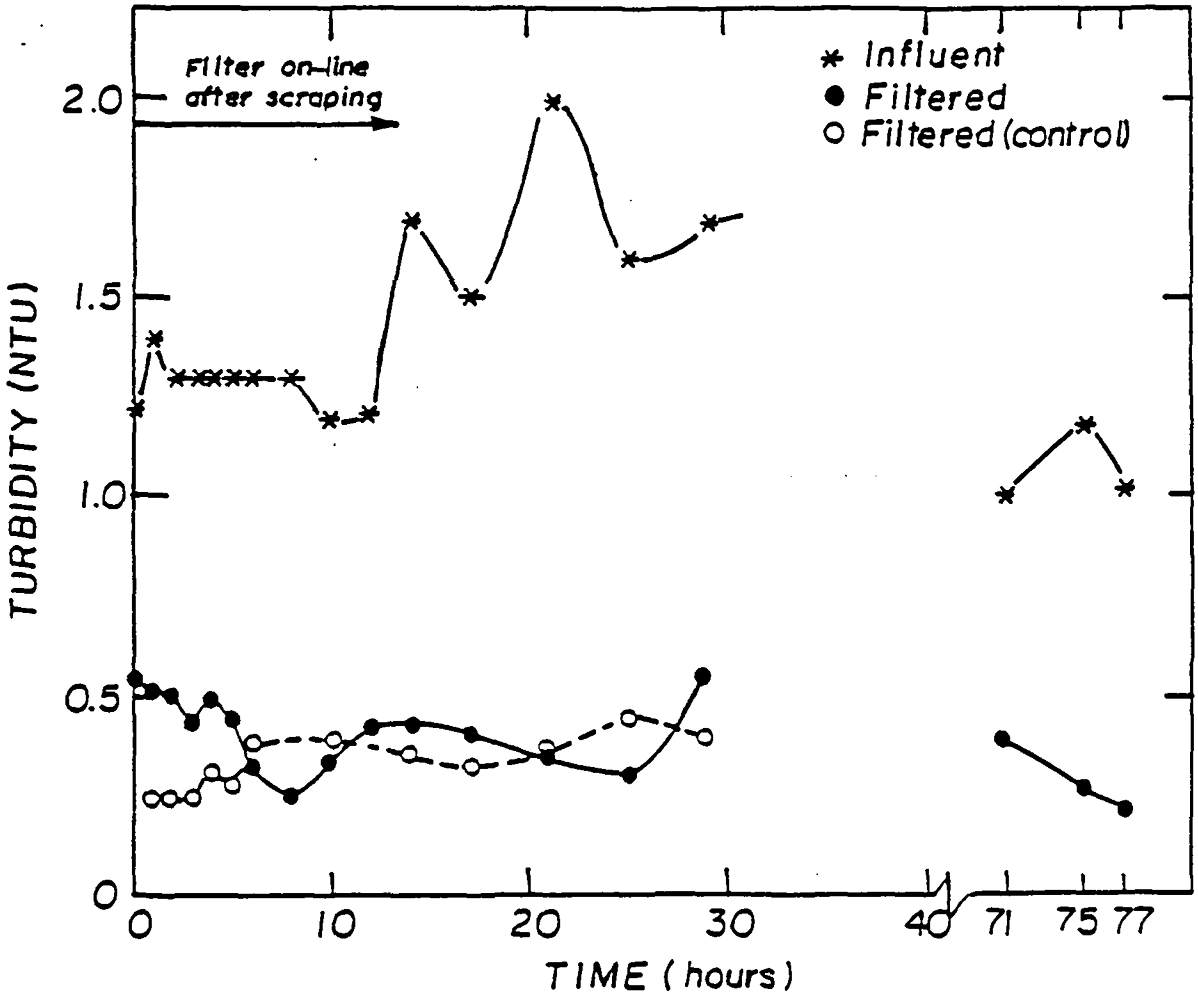

Figure 4. Turbidity versus Time at Auburn, July 1983, Filter #1.

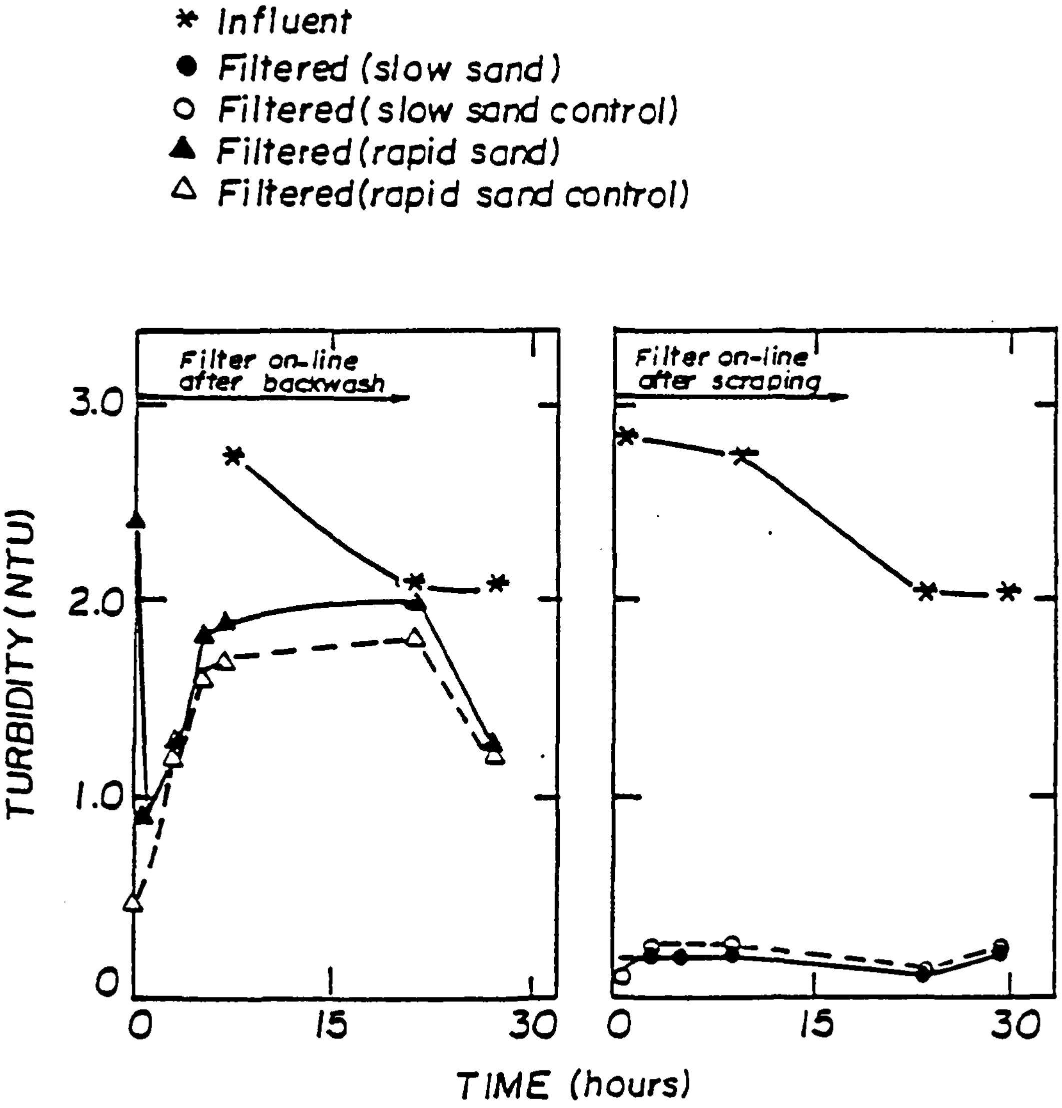

Figure 5. Turbidity versus Time at Auburn, July 1984, Filter #1 (Slow Sand Filter) and a Rapid Sand Filter.

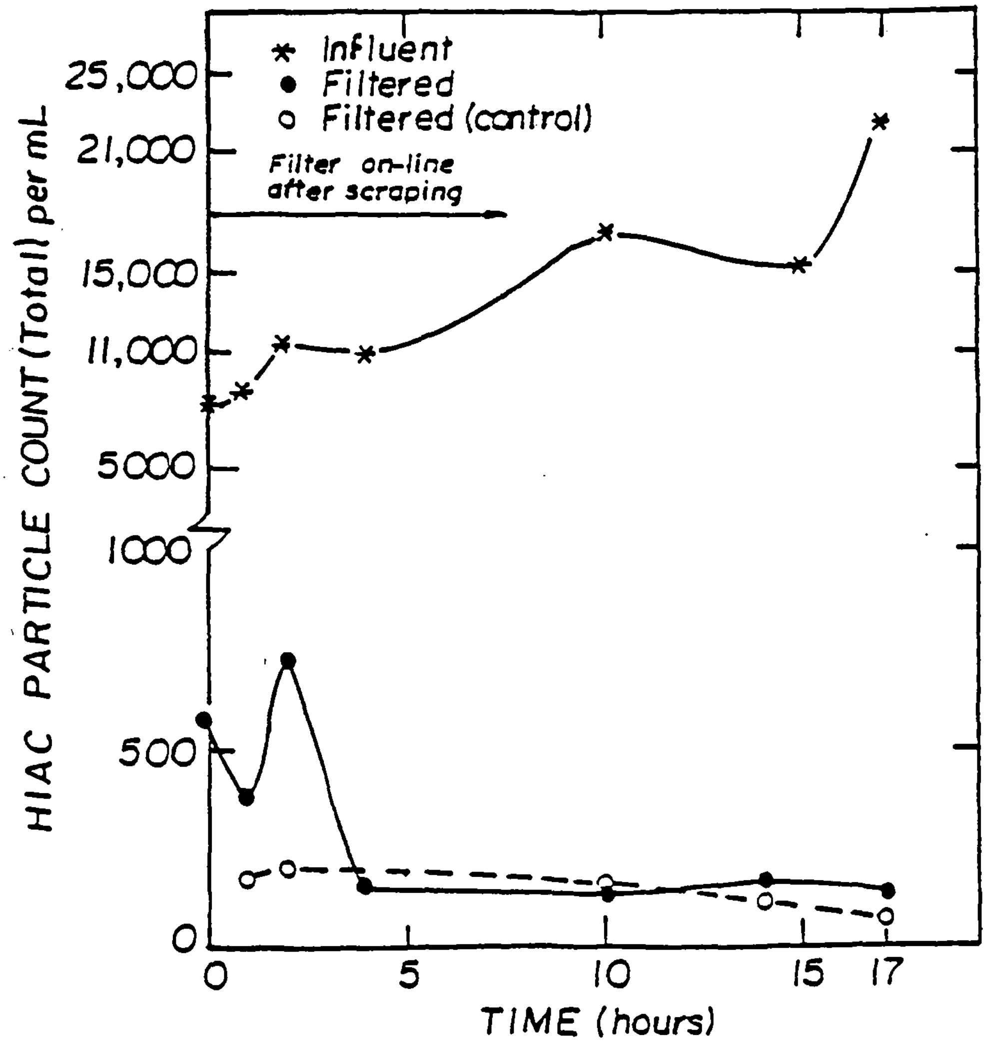

Figure 6. HIAC Particle Count versus Time at Auburn, July 1983, Filter #1.

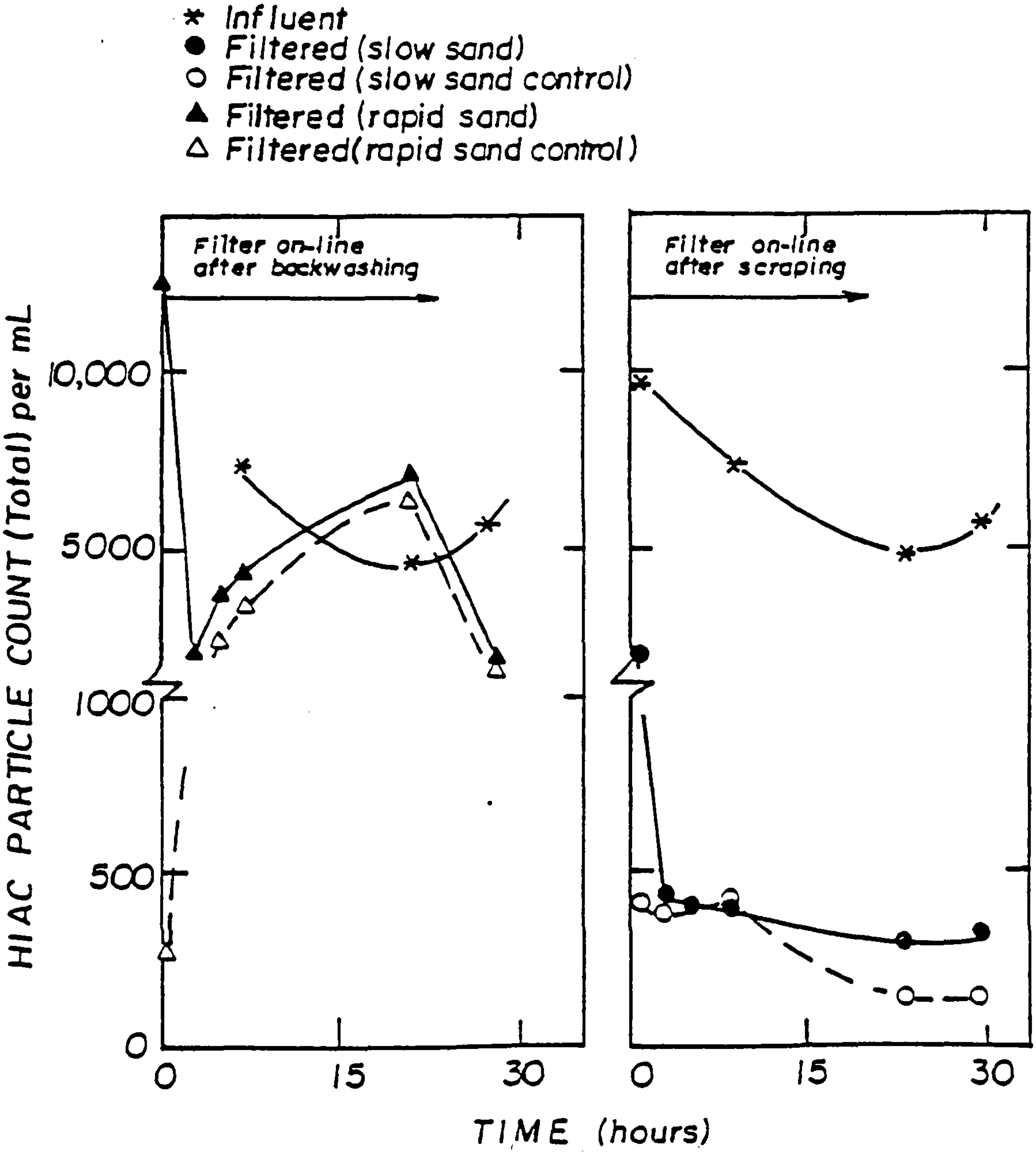

Figure 7. HIAC Particle Count versus Time at Auburn, July 1984, Filter #1 (Slow Sand Filter) and a Rapid Sand Filter.

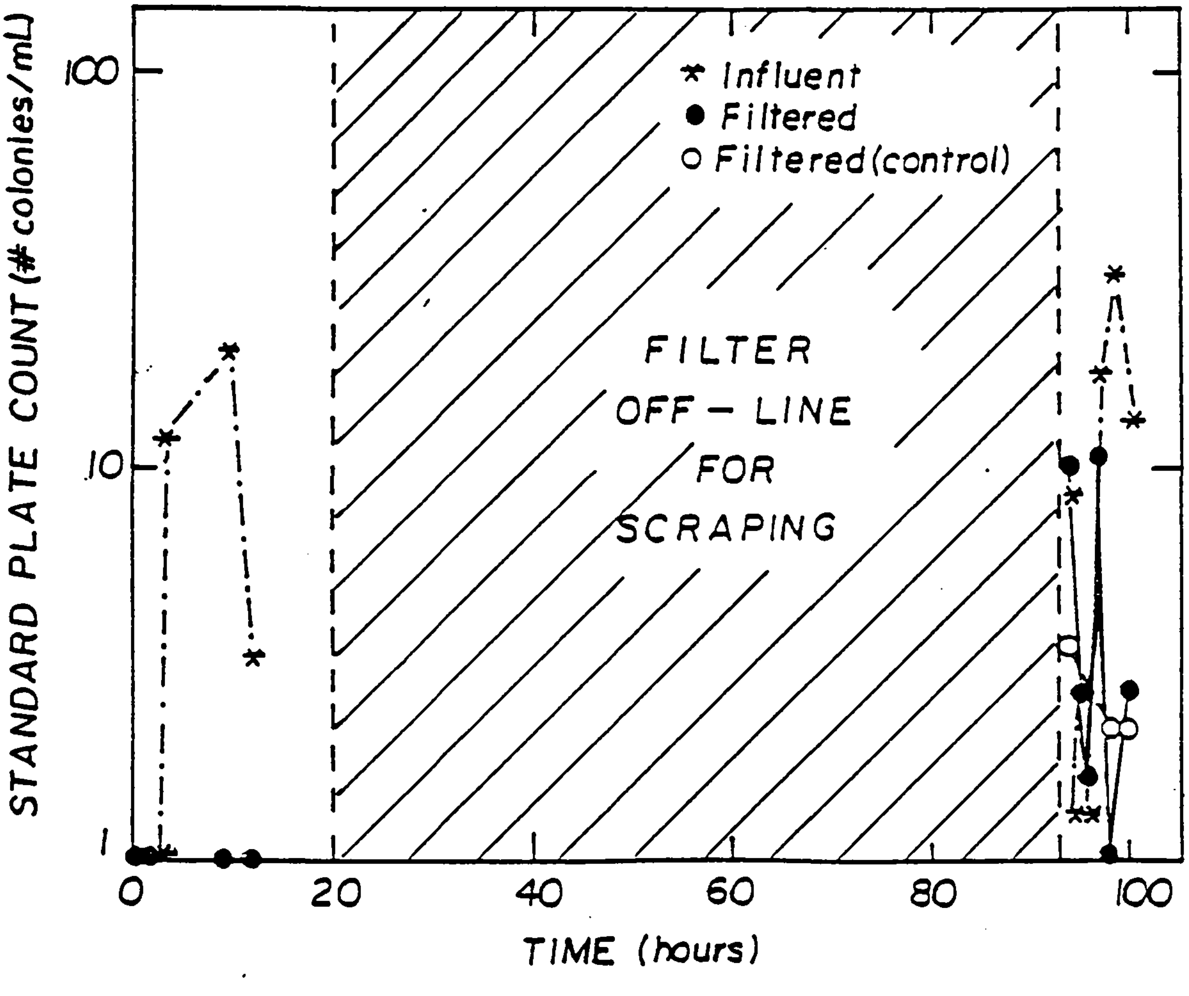

Figure 8. Standard Plate Count Bacteria Density versus Time at Auburn, July 1983, Filter #3.

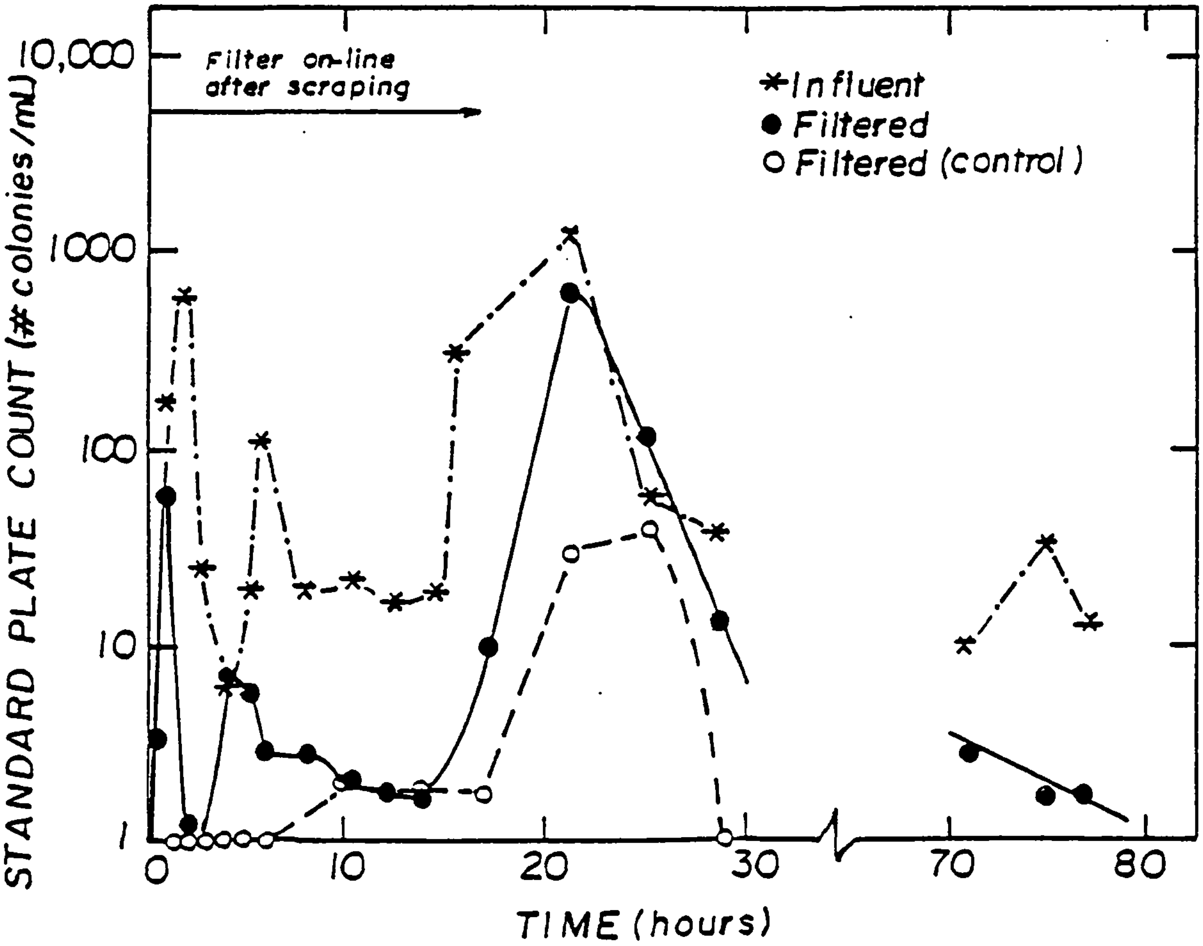

Figure 9. Standard Plate Count Bacteria Density versus Time at Auburn, July 1983, Filter #1.

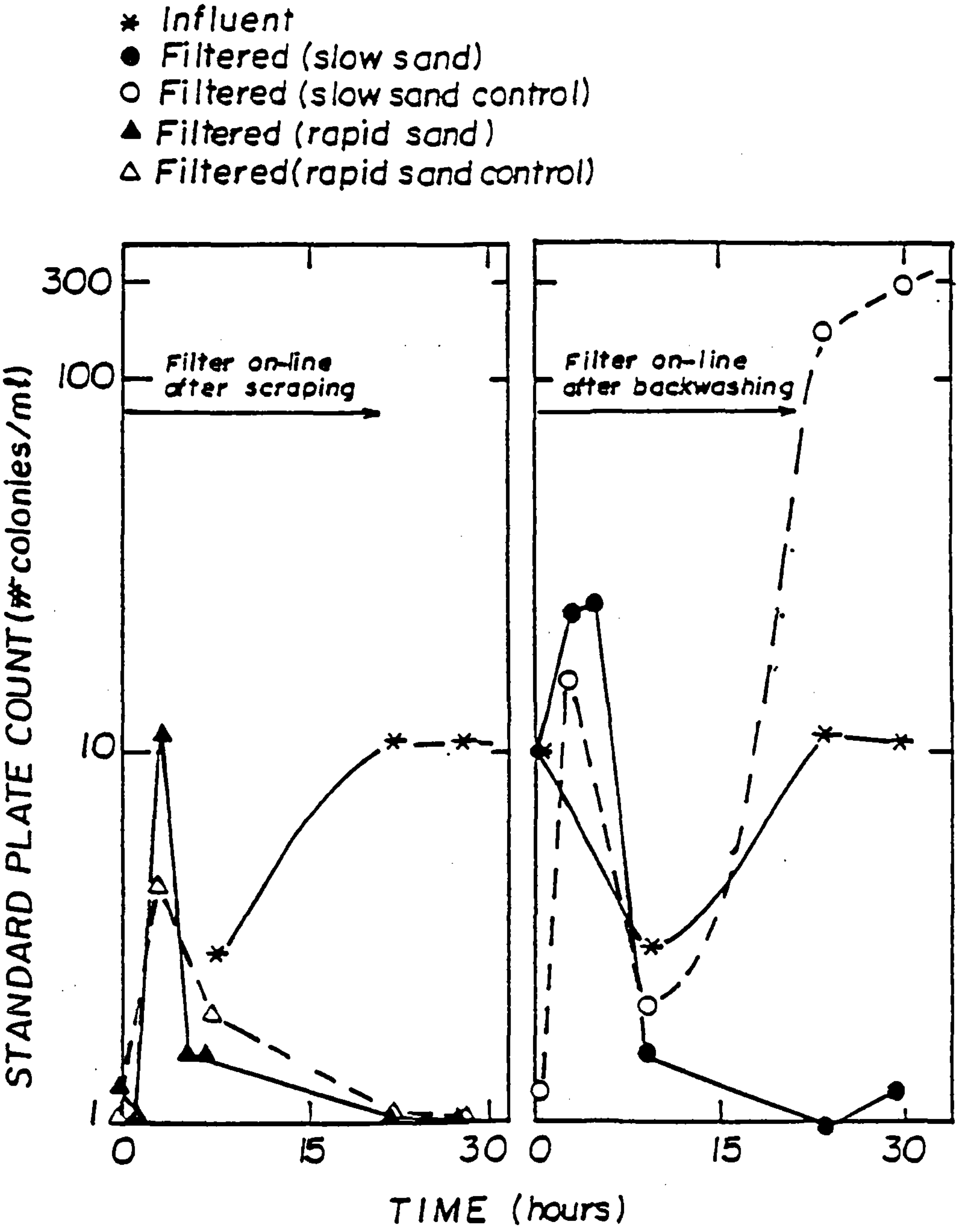

Figure 10. Standard Plate Count Bacteria Density versus Time at Auburn, July 1984, Filter #1 (Slow Sand Filter) and a Rapid Sand Filter.

In Filter #1 (1983) (Figure 9) there is an interesting result. The effluent was at the control level until hour 21. At hour 21 the raw water count peaked at 1500 colonies/mL and the effluent increased abruptly from 10 colonies/mL to 770 colonies/mL. The control filter also peaked, but less dramatically (from less than 10 colonies/mL to 64 colonies/mL). This suggests that although a newly cleaned filter may not exhibit a significant ripening period, if shock inputs arrive it may not be able to handle them as well as an established or "ripened" filter.

Total Coliform Bacteria--

Coliform bacteria were not detected at Auburn except for the day of July 22, 1983. Two filters were being monitored that day: Filter #1 had been operating for 71-75 hours following scraping; Filter #3 was in hours 1-5 of service following scraping. The results are shown below:

Time		Coliforms #/100 mL in raw water	Coliforms #/100 mL in finished water	% Removal
10 AM	Filter #1 Hour 71	1000	15	98.5
7/22/83	Filter #3 Hour 1	1000	10	99.0
	Control filter	1000	15	98.5
Noon 7/22/83	Filter #3 Hour 3	1500	6	99.6
2 PM 7/22/83	Filter #1 Hour 75	300	13	95.7%
	Filter #3 Hour 5	300	1	99.7
	Control filter	300	13	95.7

According to the above table, greater than 95% of the coliforms were removed in all cases. In filter (#3), more than 99% of the coliforms were removed in hours 1-5 after start-up. This is better than the control filter which removed 98.5% of the coliforms. Filter #1 removed 98.5% of the coliforms in its 71st hour of operation and 95.7% of the coliforms during the 75th hour of operation. These numbers are the same as for the control filter. Therefore, although the appearance of coliform bacteria in Auburn's water is rare the slow sand filters removed them effectively with essentially no indication of a ripening period.

Rapid Sand Filtration vs. Slow Sand Filtration

Auburn presented a unique opportunity to compare the performance of slow sand filters with that of rapid sand filters. In July of 1984 a rapid sand and a slow sand filter were backwashed/cleaned simultaneously. Since both filters were receiving the same raw water (the rapid plant was not using coagulation since the raw water turbidities were low) the effects of cleaning on water quality could be compared.

As discussed previously there was, according to the turbidity measurements, no evidence of a ripening period in the slow sand filter plant. The rapid sand filters also did not exhibit a significant ripening period (See Figure 5). The effluent from the clean filters was slightly higher than control levels throughout most of the test, with the exception of the first hour of service. However, while the slow sand filter produced a low turbidity water (0.3 NTU) the rapid sand filter effluent quality was not as good; the turbidity was generally between 1.3 and 2.0 NTU and, therefore, above the 1.0 NTU MCL.

The particle count results were similar to the turbidity data (See Figure 7). After the appearance of a first hour peak, the effluent particle count for both the rapid and slow sand filters decreased to control levels. However, while control levels for the slow sand filter were 100-400 particles/mL, they were much higher for the rapid sand filter, 1000 - 7000 particles/mL.

No conclusions can be drawn from the standard plate count results since the rapid sand plant utilizes prechlorination while the slow sand plant does not (See Figure 10). Coliform bacteria were not detected in the influent or individual plant effluents during these special tests.

It is evident that in this case the slow sand filters yielded a higher quality effluent than the rapid sand filters. This test tends to support the claim of the Auburn plant operators that the slow sand plant is "much better" than the rapid sand plant, however, it also raises questions about the efficacy of operating a rapid sand filter without pretreatment using a coagulant.

SITE 2 - GENEVA

The city of Geneva, New York is located in Ontario County on the north shore of Seneca Lake, fifty miles west of Syracuse. It is the center of an agricultural area and has a population of 17,000.

Water Source

Geneva obtains its water from Seneca Lake, the fourth from Syracuse of the six Finger Lakes. Seneca Lake, the largest and deepest of the Finger Lakes, is 40 miles long and 3.5 miles wide. The turbidity of the raw water which is pumped from the lake at Geneva is usually less than 1.0 NTU (70% of the time) and rarely exceeds 4.0 NTU (only seven times in the past five years). The water chemistry results of a 1973 survey of Seneca Lake are listed in Table 2.

Water Treatment

The original slow sand filter plant at Geneva was placed in service in 1911. At that time there were two covered rectangular filters each 0.20 acres (8712 ft^2) in size. In the 1920's a third, larger covered filter was added. This filter contains 0.30 acres (13,068 ft^2) of filtration area (See Figure 11). The two small filters were designed to treat 1 MGD, while the larger filter was designed to filter 1.5 MGD. The design filtration rate is therefore 0.19 m/hr for all three of the filters. The water is treated with a microstrainer before filtration.

The sand at Geneva is characterized by a uniformity coefficient of 1.9 and an effective size of 0.37 mm. These values are approximately equal to the average values obtained for all of the plants visited. The weight loss in the sand dissolution test was 36%, indicating that the sand is not of high quality and does not meet the AWWA Standard B100-80 requirement that less than 5% dissolve in 1:1 HCl.

Operation

There are five full time operators on duty at Geneva working a swing rotation. During the summer one person is added to the staff to help with groundskeeping and sand scraping.

Scraping and Resanding--

There are no head-loss gauges on the filters at Geneva, therefore, the decision to scrape a filter is guided by the position of a butterfly valve located between the clear well and the distribution system. As the head loss in the filters increases, the valve is opened to maintain a constant flow into the distribution system. When the valve is finally fully opened,

Table 2. Seneca Lake Water Chemistry From U.S. Geological Survey (16)

	mg/L		µg/L
silica	0.10 - 0.50	alumium	21 - 47
calcium	40 - 45	barium	19 - 31
magnesium	9.3 - 10	beryllium	<2.0 - 9.0
sodium	96 - 100	bismuch	<8.0 - 10
potassium	2.7 - 3.0	boron	10 - 17
bicarbonate	105 - 116	chromium	<9.0 - 10
carbonate	0	cobalt	<4.0 - 10
sulfate	42 - 43	copper	5.0 - 30
chloride	160 - 170	gallium	<3.0 - 9.0
fluoride	0.10 - 0.20	germanium	<10 - 19
total kjeldahl N as N	0.23 - 0.52	iron	51 - 590
nitrate as nitrogen	0.20 - 0.50	lead	4.0 - 4.7
ammonia as nitrogen	----	lithium	20 - 40
phosphorous as PO_4	0.02 - 0.06	manganese	<4.0 - 18
sum dissolved solids	403 - 431	molybdenum	<2.0 - 5.0
total hardness	140 - 153	nickel	<4.0 - 17
non-carbonate hardness	54 - 58	silver	<0.90 - 2.0
total organic carbon	7.00	strontium	270 - 320
specific conductance	770 - 835 $\frac{\text{micromhos}}{\text{cm}}$	tin	<9.0 - 19
pH	8.0 - 8.3	titanium	<4.0 - 10
coliforms	---	vanadium	<4.0 - 10
		zinc	<390 - 600
		zirconium	<15 - 20

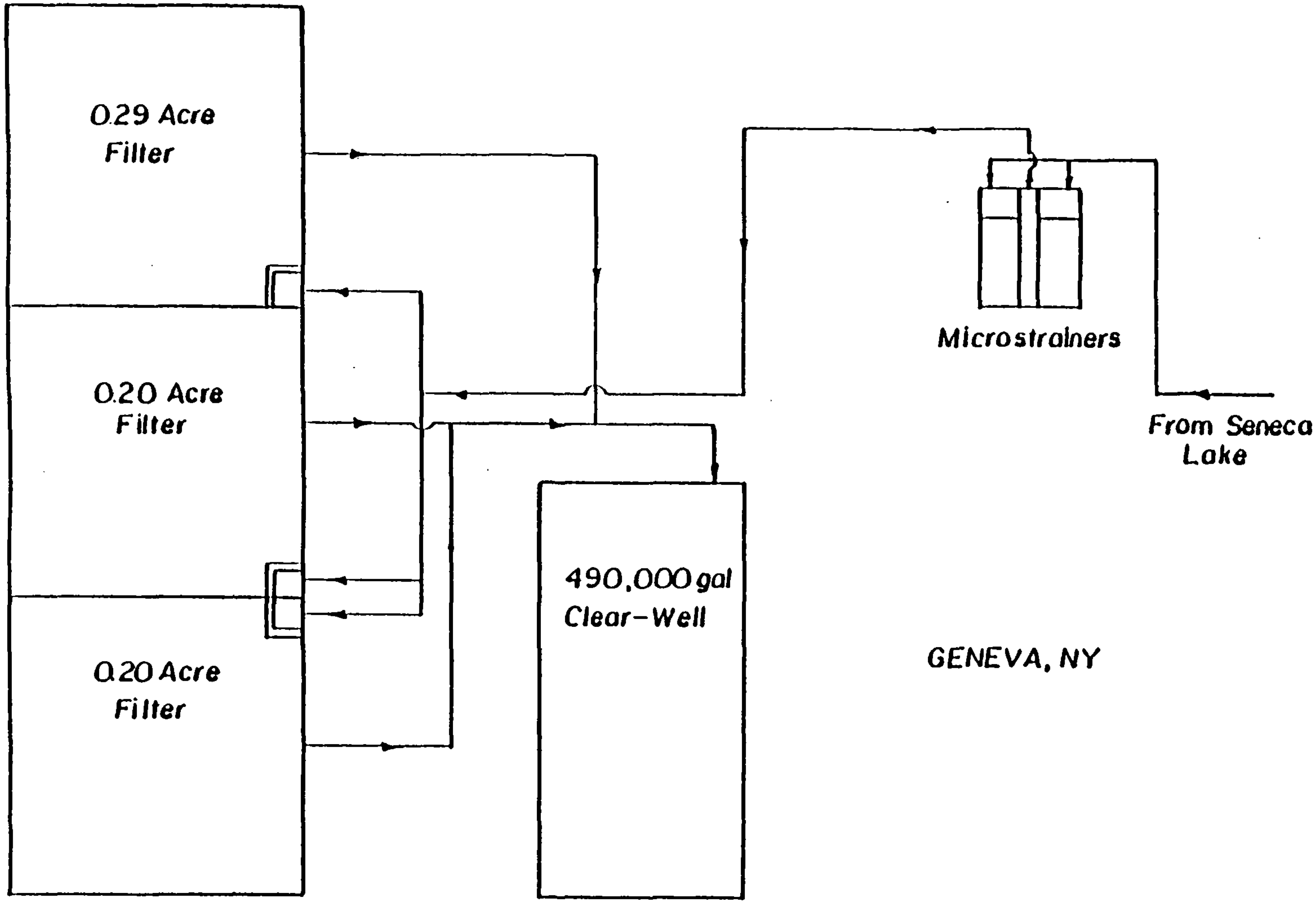

Figure 11. Plan Drawing of the Geneva, N.Y., Slow Sand Filtration Plant.

one of the filters is scraped and the process is repeated. The filters are scraped on a rotational basis. During the past ten years each filter was scraped an average of 2.6 times per year. The average water production per filter run length was 640 m^3/m^3 (15,718 gal/ft^2).

Scraping Process--

The normal scraping process includes 36-38 hours of draining; 4-5 hours of cleaning for the two smaller filters and 6-8 hours of cleaning for the larger filter, followed by 24-48 hours to restore the water to the operating level. (The last step may be done in as little as 12 hours, if needed). Geneva does not run-to-waste after cleaning, however, they will allow the water used to fill the filter remain there under a no-flow condition for 12 hours or more before the valve is opened and filtration is begun.

The scraping operation utilizes eight men, 4.6 man-hours/1000 ft^2 for each of the smaller filters and 4.9 man-hours/1000 ft^2 for the larger filter. Approximately one inch of sand and deposit is removed from the surface of the filter bed using broad shovels. The laborers work back and forth the length of the filter, scraping and shoveling the sand into piles. A second group follows, shoveling the sand into a buggy which is used to haul the sand from the filter. One person follows up the entire operation with a rake.

Resanding Process--

After approximately 18-24 scraping operations the sand depth decreases to approximately two feet and new sand is added to increase the sand depth to 3-4 feet. Since 1970 each filter at Geneva has been resanded twice.

During a normal resanding operation the filter is scraped using normal methods as previously described, except that more than one inch of sand (1.5-2 inches) is removed from the filter surface. Truckloads of sand are brought in and the new sand is dumped on top of the old sand through the hatches in the covered filter. Finally, the sand is spread uniformly throughout the filter by men using rakes. The entire resanding operation removes a bed from service for four to ten days. The out of service time varies greatly depending on the time of year, the amount of sand to be replaced, etc.

Results and Discussion - Geneva

All of the filters in Geneva are connected to a common header and it is not possible to sample the effluent from an individual filter. Therefore, no samples were taken at Geneva. However, an analysis of the daily "combined effluent" turbidity values for the period 1978 to the present showed a number of post-scraping periods in which the turbidity exceeded 0.5 NTU for a day or two. The effluent was continuously less than 0.2 NTU before the filter was scraped. Since these readings were obtained from a header which is connected to 3 filters and only one of these is a recently scraped filter, it is possible that the turbidity of the effluent of the scraped filter exceeded 1 NTU for a short period following scraping.

SITE 3 - HAMILTON

The village of Hamilton, New York is located in Madison County, 35 miles southeast of Syracuse. Hamilton is a rural "college town" community. The total population is 3,500 not including the students of Colgate University.

Water Source

Hamilton receives its water from Woodman's Pond. This is a small spring-fed pond located on a hill outside the village. The turbidity of the raw water pumped from the pond is generally 1-2 NTU and seldom higher. At times coliform bacteria are abundant in the raw water due, according to village Water Department personnel, the presence of birds on the pond. Water chemistry results for the raw water from Woodman's Pond are not available. However, the water chemistry results of a USGS survey of the Hamilton distribution system water are shown in Table 3.

Water Treatment

A slow sand filter was placed in service in Hamilton in 1895. In the 1920's a second filter was added to the original construction. As shown in Figure 12, each filter is circular and both filters are uncovered. The diameter of each filter is approximately ninety feet yielding a total filtration area of 12,724 ft^2. At the present time the Water Department produces an average treated water flowrate of 0.480 MGD, however, only 50-60% of this water (0.264 MGD) passes through the filters. Therefore, the filtration rate is 0.04 m/hr. The 0.264 MGD of water which passes through the two filters receives no pretreatment. After filtration the water is mixed with an almost equal amount of unfiltered water from Woodman's Pond, and the combined flow is chlorinated and distributed to yield the total daily production rate of 0.480 MGD.

The size distribution of the sand used at Hamilton is characterized by an effective size of 0.27 mm and a uniformity coefficient of 2.4. The weight loss in the sand dissolution test was 19%. The sand does not meet the AWWA Standard B100-80 requirement (17) that less than 5% dissolve in 1:1 HCl.

Operation

There are two operators assigned to the Hamilton water plant. Both work the day shift but actually devote very little time to the operation of the plant. Much of their time is spent working on water main breaks and other chores outside the filter plant.

Scraping and Resanding—

There are no headloss gauges or other devices which would help indicate when a filter should be cleaned at Hamilton. Each of the two filters is

Table 3. Village of Hamilton Distribution System Water Quality From U.S. Geological Survey (16)

	mg/L		µg/L
silica	4.3	aluminum	5.0
calcium	56	barium	170
magnesium	16	beryllium	<3.0
sodium	3.5	bismuth	<5.0
potassium	0.90	boron	7.0
bicarbonate	212	chromium	<5.0
carbonate	0	cobalt	<5.0
sulfate	22	copper	660
chloride	6.7	gallium	<3.0
fluoride	0.80	germanium	<8.0
total kjeldahl N as N	0.73	iron	26
nitrate as N	0.80	lead	<5.0
ammonia as N	--	lithium	<10
phosphate as PO_4	0.01	manganese	13
dissolved solids sum	218	molybdenum	3.0
total hardness	206	nickel	<5.0
non-carbonate hardness	32	silver	<4.0
cyanide	0	strontium	130
specific conductance	393 $\frac{\text{micromhos}}{\text{cm}}$	tin	<5.0
pH	7.8	titanium	<5.0
		vanadium	<4.0
		zinc	260
		zirconium	<11
		arsenic	1.0
		cadmium	0
		total mercury	<0.50
		selenium	0

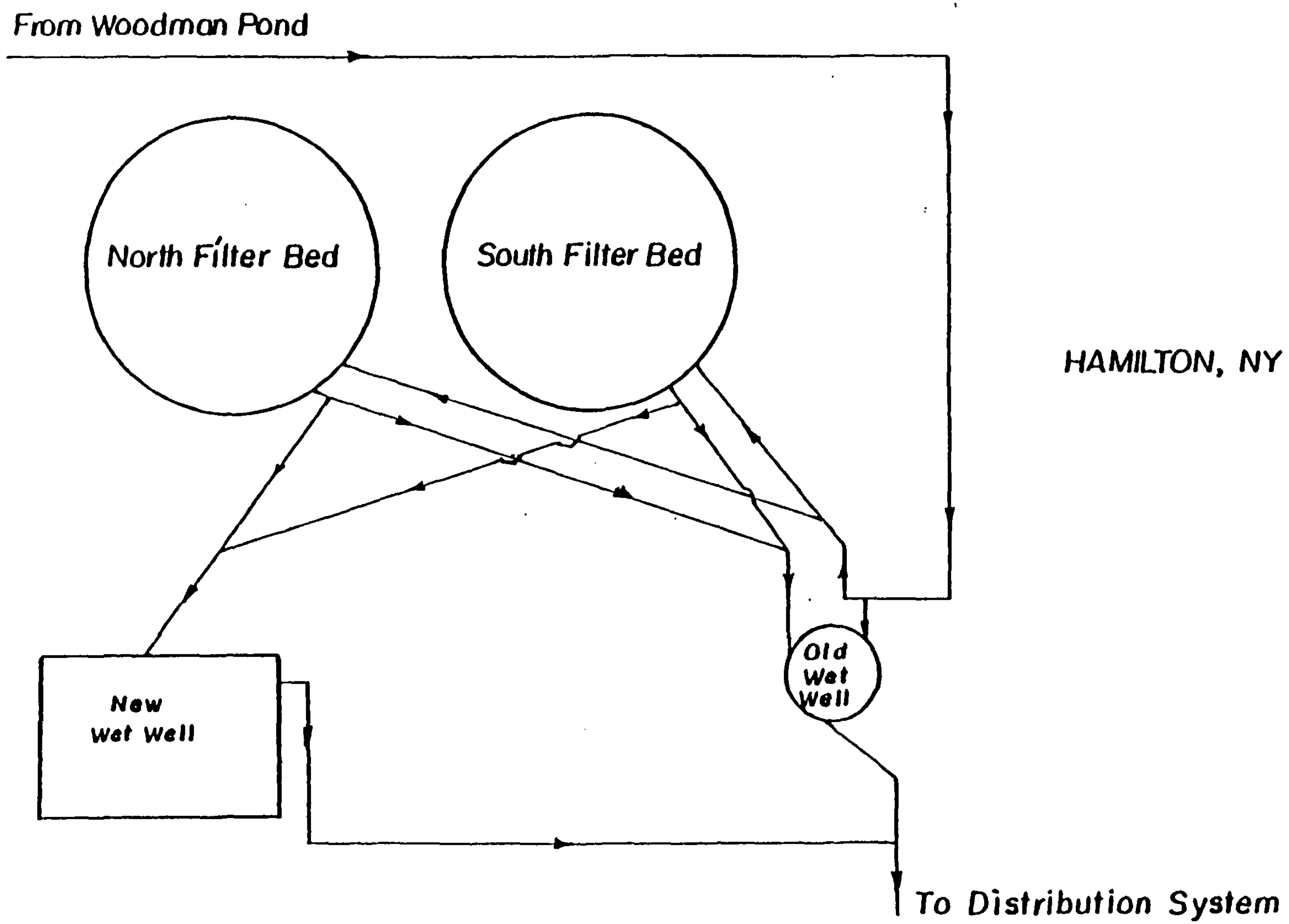

Figure 12. Plan Drawing of the Hamilton, Slow Sand Filtration Plant.

routinely scraped twice per year; once in the spring and once in the fall. The average water production per filter run is therefore 175 m^3/m^2 (4302 gal/ft^2).

Scraping Process--

The amount of time that a filter is out of service during a scraping operation varies greatly. Due to pumping problems it may take Hamilton as long as two weeks to drain a filter prior to cleaning. The cleaning operation itself takes only one day to complete. However, weather is a significant factor since Hamilton has uncovered filters which cannot be scraped during inclement weather. After scraping it takes 24 hours to refill each filter to its operating water level of five feet above the sand. Each filter is put back into service without discharging any water to waste.

The scraping operation takes 7-8 people approximately 7 hours to complete. This corresponds to 7.7-8.8 man-hours/1000 ft^2, which is about 3 man-hours/1000 ft^2 greater than the average for other plants visited. Approximately one inch of sand is scraped from the filter surface with wide shovels and placed in large piles. The sand is then shoveled into 55 gallon drums which are lifted out of the filter bed with a backhoe. The drums are taken by truck to a spot near Woodman's Pond two miles away, and emptied. At the time of the survey it was estimated that the beds contained approximately two feet of sand.

Resanding Process--

There are no records available on resanding at Hamilton. However, according to the operators the filters were resanded in 1972. This operation consisted of simply placing new sand on top of the old sand after a scraping operation. Each filter was out of service for 2-3 weeks. One of the operators has been at the plant for 28 years and this was the only resanding operation that occurred during his tenure.

Sampling

Sample collection at Hamilton posed a special problem since there is no direct way to sample the effluent of individual filters. The first sampling point was at the wet well which contained effluent from both of the filters. Therefore, the effluent from the scraped filter was diverted to an old wet well that is no longer in use so that the samples could be taken. The samples were obtained by attaching the sample bottles to a golf ball retriever and filling them from the pipe entering the old wet well. This method, however, prevented the sampling of a second filter as a control since there was no way to divert a second filter to be sure the effluent was strictly from that filter. The main wet well could not be used as the control sampling point since it was still receiving the flow from both of the filters. Therefore, control samples were not taken in Hamilton. Raw water samples were obtained directly from the top of the uncovered filter beds.

Results and Discussion - Hamilton

A single filter cleaning operation was monitored at Hamilton in May 1984.

Turbidity--

According to the turbidity versus time graph (Figure 13), the raw water turbidity values were within the expected range (1-2 NTU). A check of the Hamilton records showed that the average turbidity of the effluent leaving the plant for the one month period prior to cleaning this filter was 0.47 NTU. The average turbidity of the water from the scraped filter (0.44 NTU) was essentially equal to the average of 0.47 NTU obtained from the plant records. Therefore, there appeared to be no ripening period following filter scraping at Hamilton. Although the effluent turbidity values are somewhat higher than those normally obtained using slow sand filters, the values do not exceed 1 NTU.

Particle Count--

During the first two hours of operation after scraping, the particle number concentrations in the effluent were high (1000-1500 particles/mL) (See Figure 14). After that time period the values became relatively constant at 500-700 particles/mL until they reached a peak at 48 hours (3850 particles/mL). The peak at 48 hours mirrored a peak obtained at 48 hours in the turbidity measurements. There are two possible reasons for this peak. The first is that particles were sloughing off the old pipes leading to the wet well when water was diverted for sampling. The second is that the filter was not operating efficiently. The contention that the filters are not operating efficiently is supported by the turbidity results which show numbers twice as high as are normally found in a slow sand filter effluent (even with a relatively low raw turbidity water).

Standard Plate Count--

The plate count results are scattered as shown in Figure 15. The plate counts appear to decrease with time as the filter run continued. After scraping, the initial plate count values were high (1000 colonies/mL) and tended to decrease to within the range 10-100/mL within several hours. The raw water plate count values were consistently lower than those of the effluent. There was no plate count peak at 48 hr where particle count and turbidity spikes were observed.

Total Coliform Count--

Coliform bacteria were detected in 4 of 23 samples. Three of the four positive samples were raw water. One effluent sample in hour 193 of operation after scraping (noon, 5/15/84) contained 45 coliforms/100 mL. The raw water three hours earlier (9 am, 5/15/83) contained 35 coliforms/100 mL.

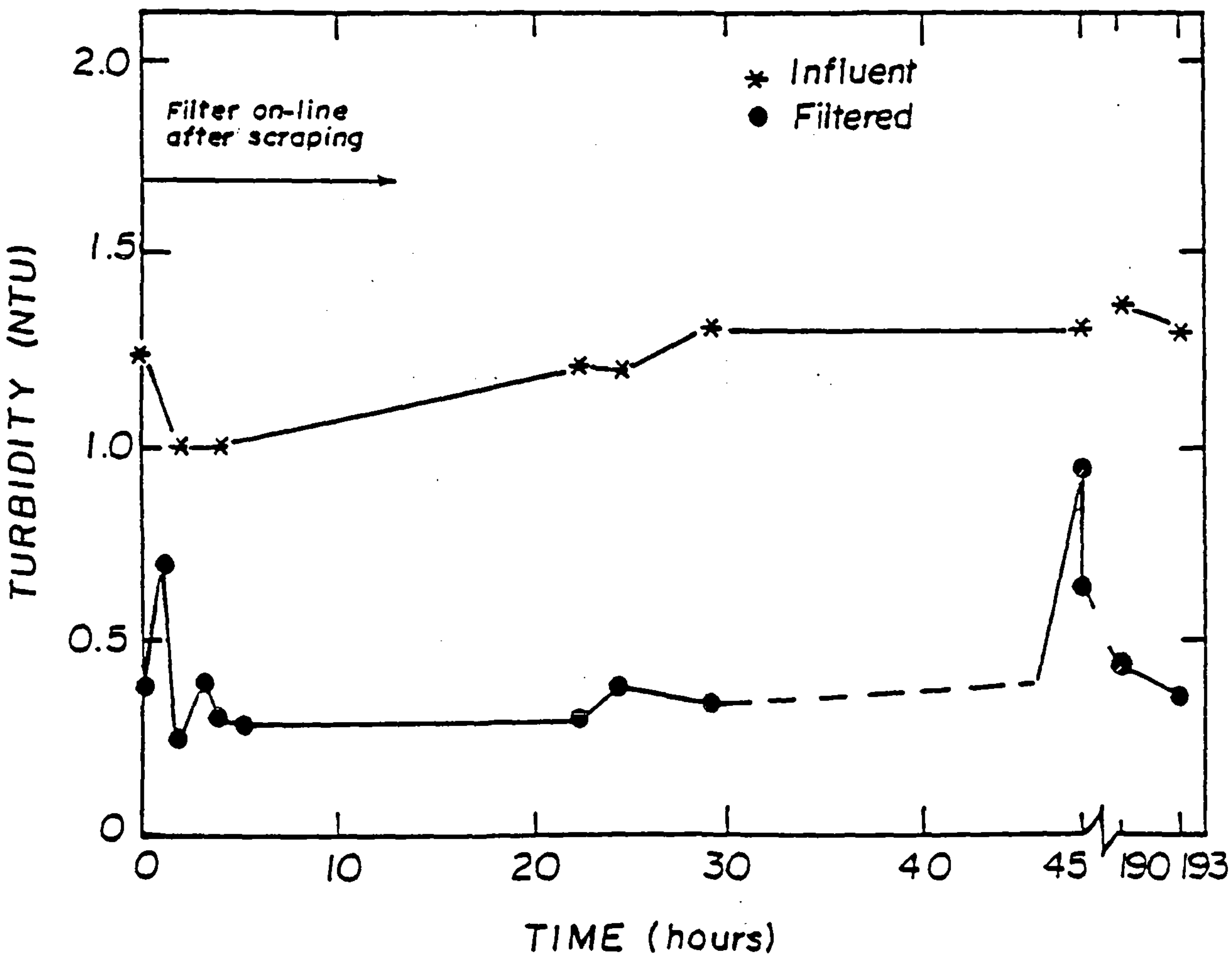

Figure 13. Turbidity versus Time at Hamilton, May 1984.

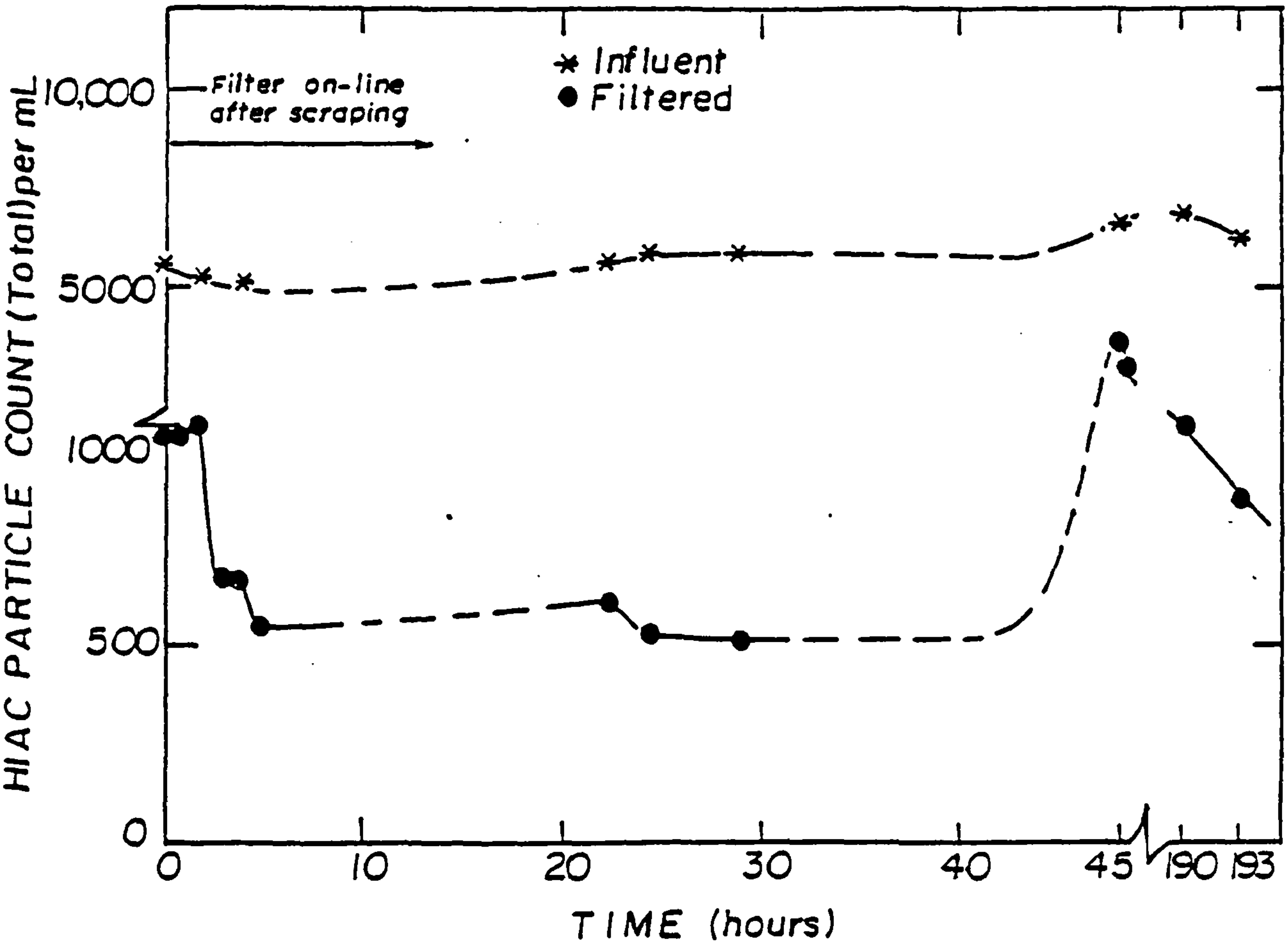

Figure 14. HIAC Particle Count versus Time at Hamilton, May 1984.

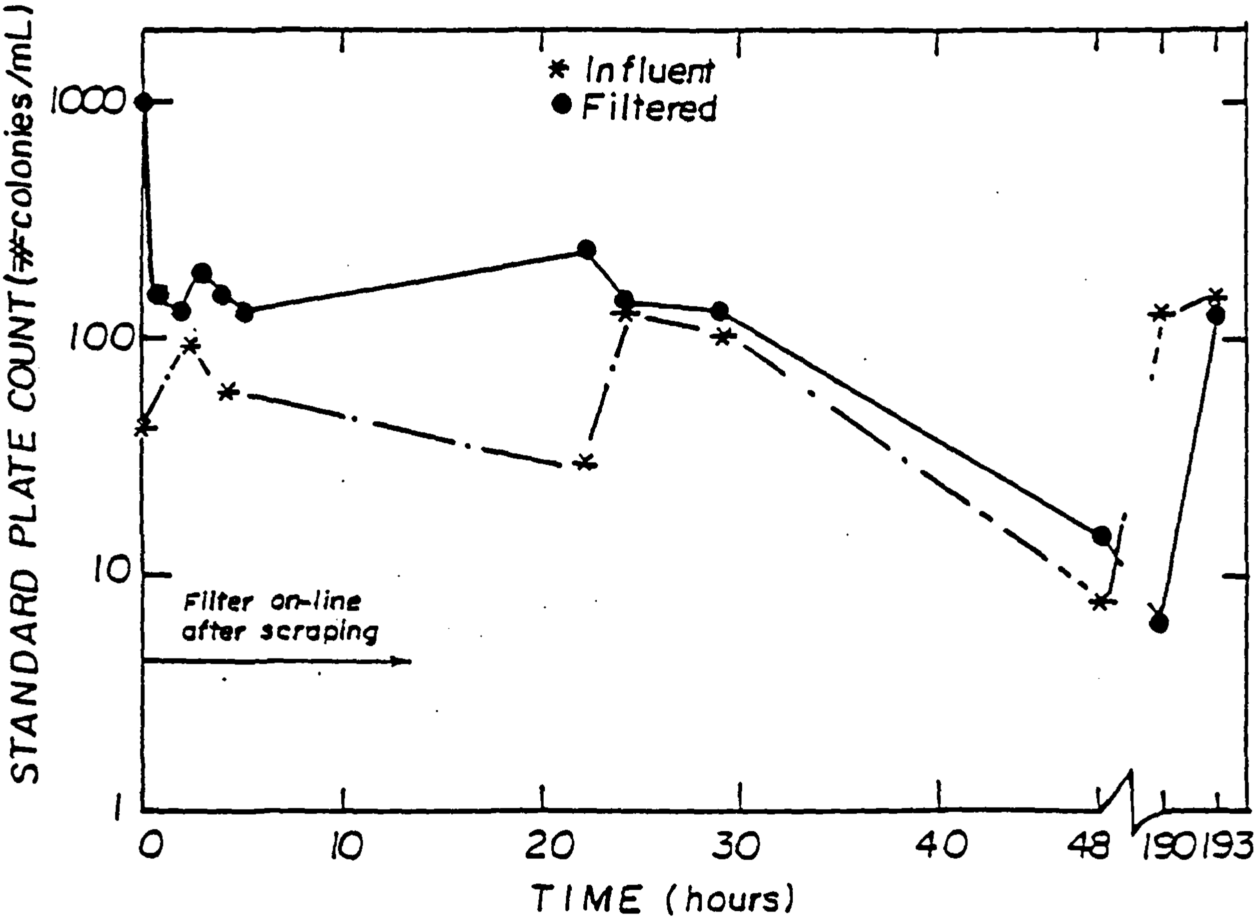

Figure 15. Standard Plate Count Bacteria Density versus Time at Hamilton, May 1984.

SITE 4 - ILION

The village of Ilion, New York is located 60 miles east of Syracuse. Ilion's major industry is the Remington Arms Company and its population is 10,000.

Water Source

The village of Ilion receives its water from three upland reservoirs which are fed by small streams. Several streams flow into the Ilion Gorge which flows into reservoir #1 (15 million gallons capacity), which then flows into reservoir #2 (65 million gallons capacity) at the plant site. A separate 160 million gallon reservoir (#3) receives water from another small watershed. The turbidity of the raw water is generally about 2 NTU, however it may be higher, especially when algae are abundant in the reservoir. USGS or other detailed water chemistry results are not available for Ilion.

Water Treatment

A slow sand filtration plant was placed in service at Ilion in 1893. It consists of two uncovered filters, each is 3040 square feet in area, and still operating today (filters #1 and #2 in Figure 16). In 1912 two filters covered with concrete and earth and measuring 3948 square feet each, were added to the original facility (filters #3 and #4 in Figure 16). Finally in 1917 filters #5 and #6 were added. Both filters were covered and measured 5550 square feet each. However, filter #6 is no longer in service due to excessive leakage through its concrete walls. During normal operation, filters #1, 2, 3, and 4 are used to produce 1.5 MGD of water. This is equivalent to a filtration rate of 0.18 m/hr. During a cleaning operation, filter #5 is put into service in place of the filter being scraped. During this time the filtration rate is 0.15-0.16 m/hr.

The raw water at Ilion is pretreated with chlorine. The chlorine dosage varies with the time of year; 150-160 lb/day (12.0-12.8 mg/L) during the summer, and 50-60 lb/day (4.0-4.8 mg/L) during the winter. These dosages are much higher than those used for post-chlorination; 10-12 lb/day (0.8-1.0 mg/L) during the summer, and 3-4 lb/day (0.2-0.3 mg/L) during the winter.

A microstrainer is in place to provide additional pretreatment for the water from reservoir #3, however, it is no longer used (18).

The sand used at Ilion is characterized by an effective grain size of 0.37 mm and a uniformity coefficient of 2.2. The weight loss in the sand dissolution test was 5%. Ilion is one of the two sites where the sand met the AWWA Standard B100-80 requirement (17) that less than 5% dissolve in 1:1 HCl.

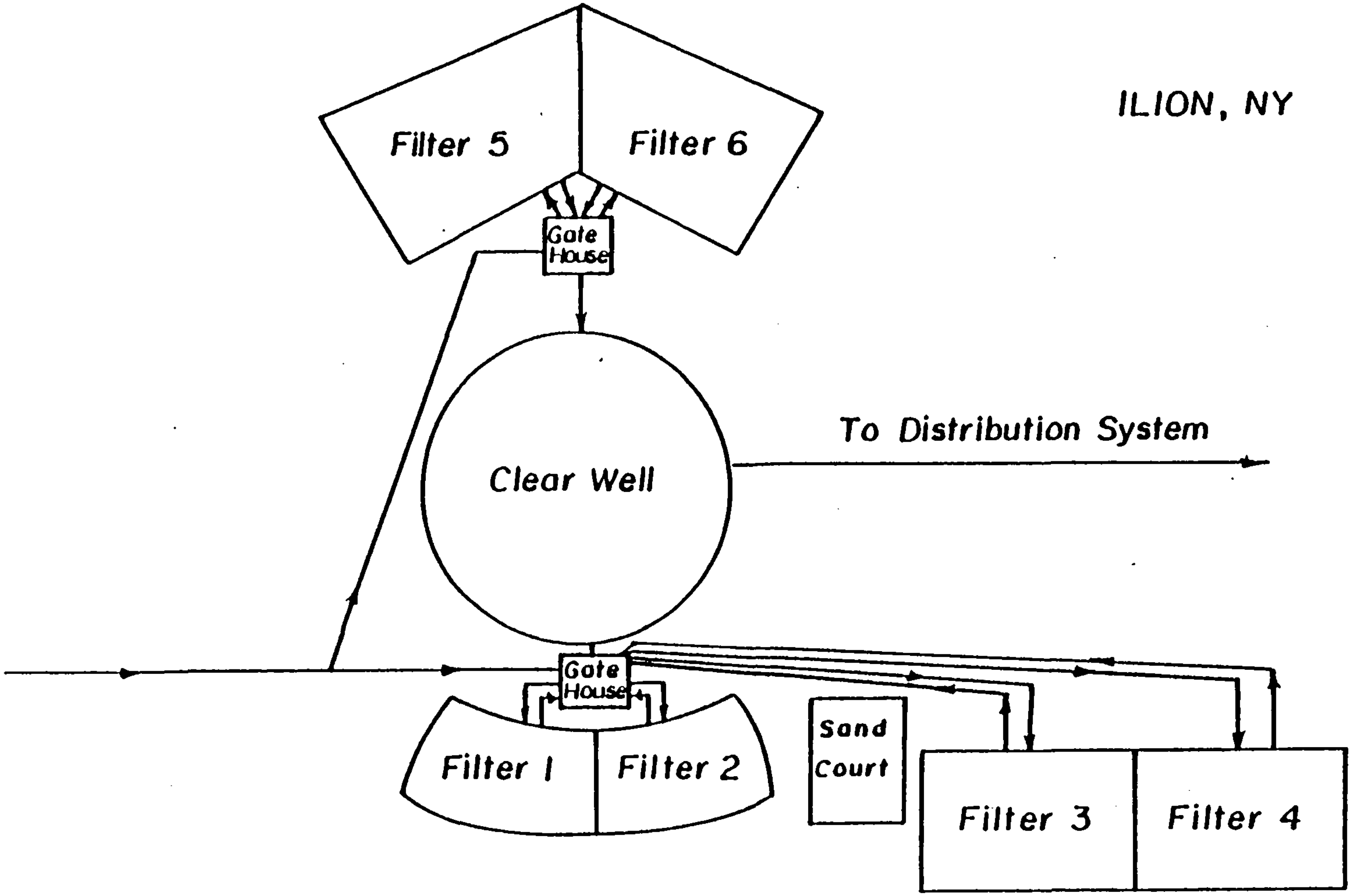

Figure 16. Plan Drawing of the Ilion, Slow Sand Filtration Plant.

Operation

One chief operator and two full-time operators work during the day time, five days a week, at Ilion. However, with the exception of the scraping and resanding operations, very little of the operators' time is consumed by specific attention to the slow sand filters. Much of their time is devoted to maintenance of the distribution system and groundskeeping.

Scraping and Resanding--

Normally, each filter is operated with approximately three feet of sand and four to five feet of water on top of the sand.

There are no headloss gauges at Ilion, therefore, the decision to scrape is based on past experience and observation of the quantity of water in the clearwell. In the past the two open filters (#1 and #2) have been scraped an average of 2.5 times per year. The three covered filters (#3 4, 5) are cleaned less often for an average of 1.25 times per year. Therefore, the average run lengths are 631 m^3/m^2 (15,487 gal/ft^2) for the uncovered filters, and 1261 m^3/m^2 (30,973 gal/ft^2)for the covered filters.

Scraping Process

During a normal scraping operation a filter will be out of service for approximately 12 days. First the raw water valve is closed and the water allowed to drain to the top of the sand. Although this only takes one day, a total of three days are required before the sand is dry enough to scrape. It then takes 4-5 workers four days to scrape the filter, after which the filter is refilled (approximately 6-8 hours). Finally, Ilion wastes water for 3-4 days before feeding the filter bed effluent back into the distribution lines. Bad weather can slow this cleaning process, especially for the uncovered filters.

Approximately 3-4 inches of sand is scraped from the filter bed and placed in a hopper. This unusually large scraping depth (0.5 inches is more common) is an unexplainable tradition at Ilion. High pressure fire hoses are connected to the hopper so that the sand is transported hydraulically to a sand washer and finally to the outdoor sand storage court. Headroom is a problem in Filters #3 and #4 since there is only 5 feet 10 inches of space between the sand and the ceiling. This, according to plant personnel, hampers scraping operations. Filter #5 has seven feet of headroom and along with the uncovered filters, presents no such problem.

As a consequence of the large depth of sand taken from the filter and the headroom problems, the scraping time is unusually long. The total man-hours per 1000 square feet ranges from 23-42 depending on filter conditions (head room, etc.)

Resanding process--

Each filter bed is resanded every other year. At this time the sand depth has decreased to 2-2.5 feet. The resanding operation returns the sand depth to the original three feet. In this operation the sand depth scraped is one to two inches more than the usual. Hardened sand areas are removed and pockets of penetration are cleared of sand to allow workers to check the effluent trenches. The washed sand is returned to the filter bed hydraulically. The hopper is placed in the sand court and the sand is shoveled into it. The sand travels through the fire hoses, passes through the sand washer and finally arrives in the filter bed. Here it is spread with rakes and shovels on top of the existing sand until the total sand depth reaches three feet.

During the resanding operation the uncovered filters are out of service for two weeks before the filters are refilled and the wasting period begins. Filters #3 and #4 are out of service for 2-3 weeks and the largest filter (#5) is out of service for 3-4 weeks.

Sampling

Filter effluent samples were obtained from sample valves located near the main floor of the gate house. Raw water samples were taken directly from the top of the open filters.

Results and Discussion - Ilion

Turbidity--

As shown in Figure 17, the turbidity of the scraped filter effluent was essentially the same as that of the control filter. There was no evidence of a turbidity ripening period at Ilion.

Particle Count Data--

The particle count data (plotted in Figure 18) are in agreement with the turbidity results in that there was no evidence of a particle count ripening period. The scraped filter particle count was at control levels except for hour 6 when filter #1 effluent contained 789 particles/mL and the control filter effluent contained 319 particles/mL. The influent particle count during this period ranged between 8000 and 11,000 particles/mL.

Standard Plate Count Data--

The Standard Plate Count Data for influent and scraped and control filters are plotted in Figure 19. The raw water densities were essentially the same as those of the control filter. This may have been a consequence of the use of prechlorination at Ilion. The scraped filter SPC density peaked at hours 2-3 (174-178 colonies/mL) and gradually returned to the control filter level by hour 10. Since these levels were not measured in the raw water, it is possible that the source was the sand layer. It is possible that shoveling

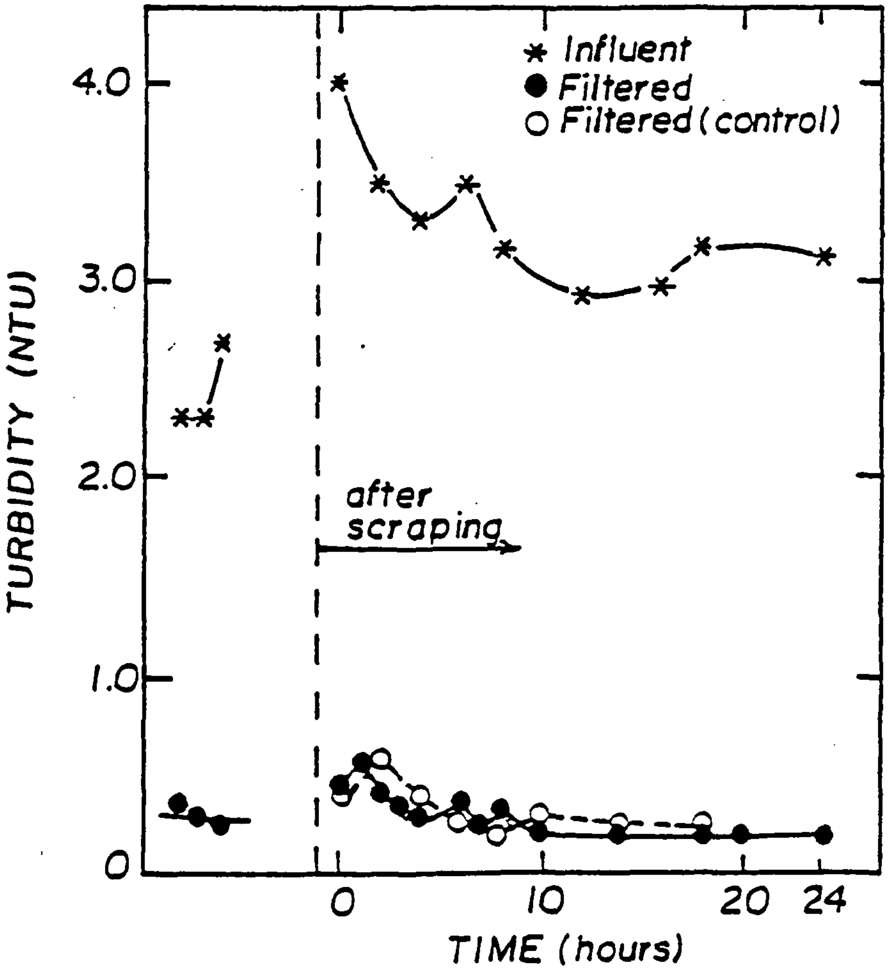

Figure 17. Turbidity versus Time at Ilion, August 1983, Filter #1.

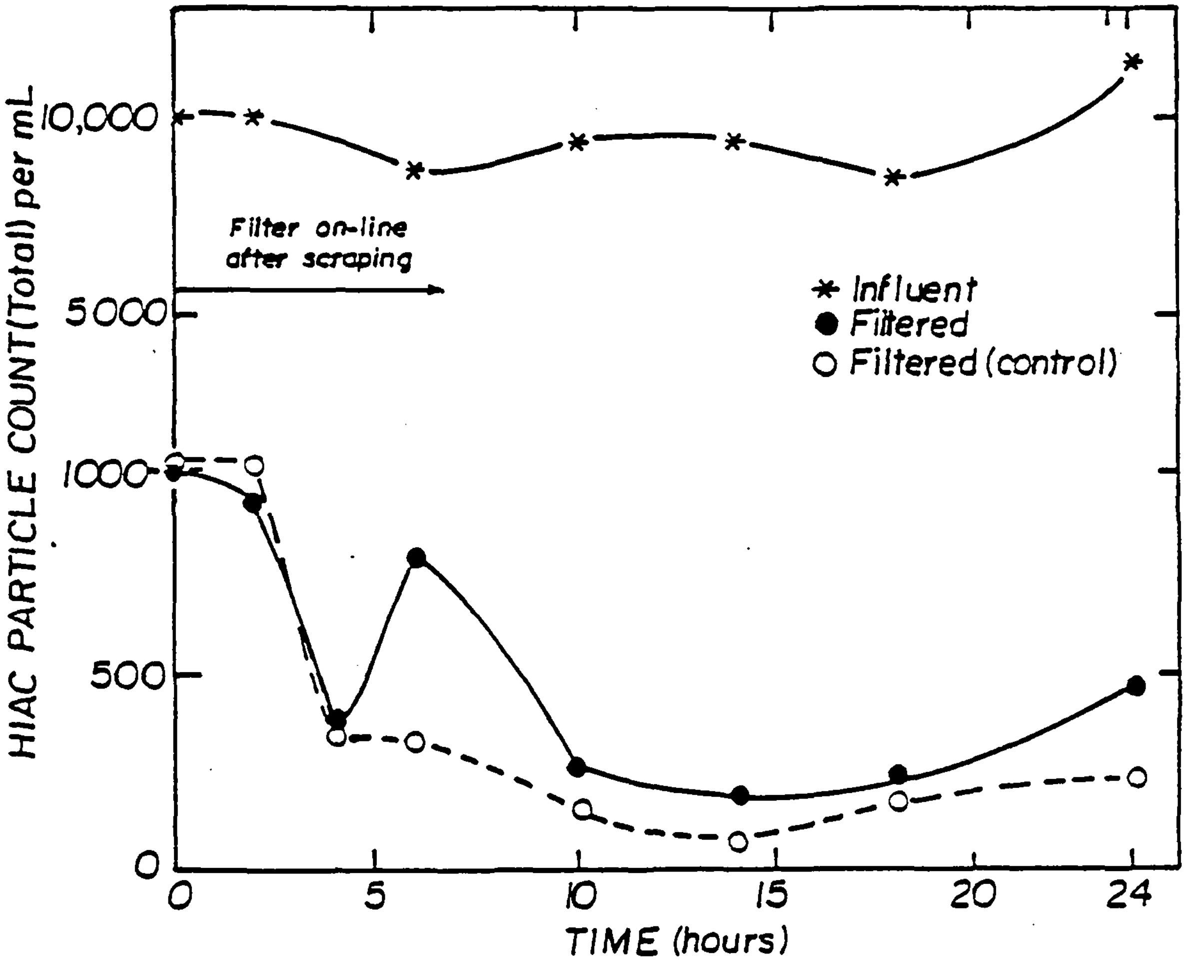

Figure 18. HIAC Particle Count versus Time at Ilion, August 1983, Filter #1.

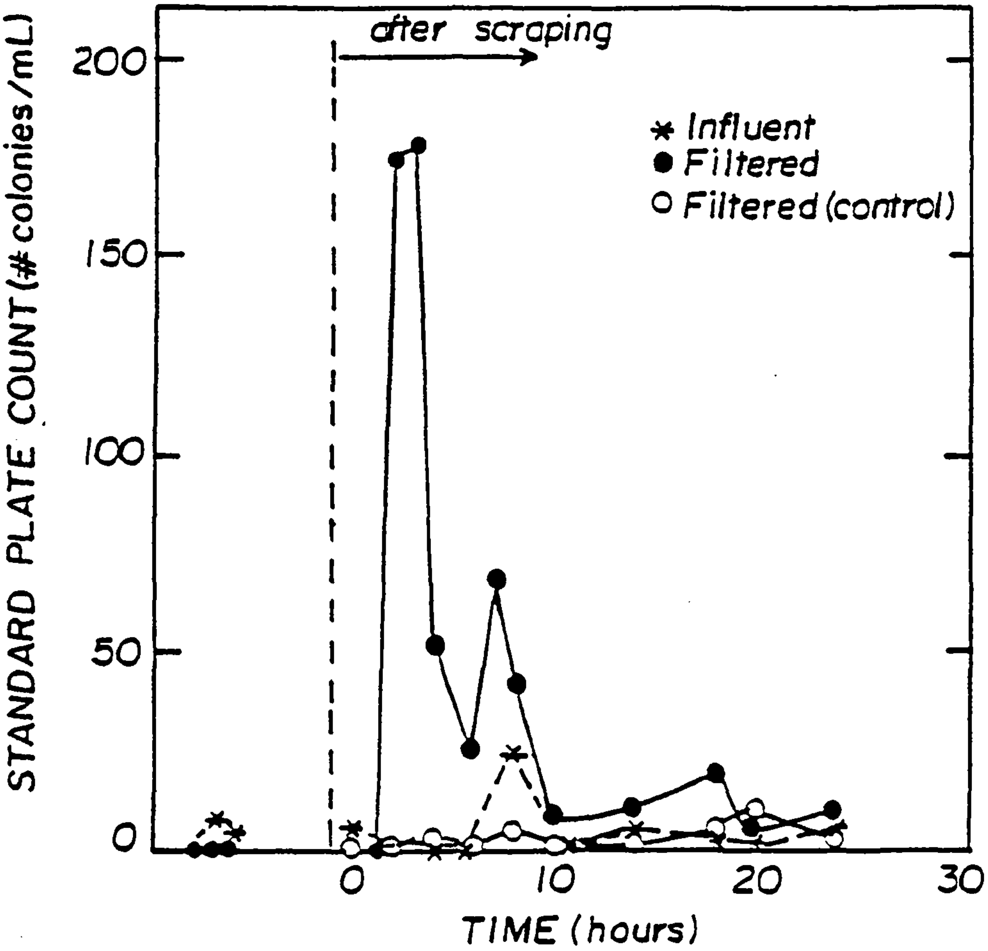

Figure 19. Standard Plate Count Bacteria Density versus Time at Ilion, August 1983, Filter #1.

and walking on the filters caused some of the microbial population to be released. However, these numbers never exceeded 200 organisms/mL and, in general, are considered to be low.

Total Coliform Bacteria--

Coliform bacteria were not detected in any of the samples taken at Ilion.

SITE 5 - NEWARK

The village of Newark, New York is located on the New York State Barge Canal, 55 miles west of Syracuse. The Newark water treatment plant, which serves a population of 12,000, is located ten miles southwest of the village in the small community of Shortsville.

Water Source

Newark obtains its water from Canandaigua Lake. The lake is located 18 miles southwest of the village and is the sixth (from Syracuse) of the long, narrow Finger Lakes. Canandaigua Lake is approximatley 18 miles long and 1.5 miles wide. The turbidity of the raw water being pumped from the lake is usually 1-3 NTU. A comprehensive water chemistry survey of Canandaigua Lake is not available.

Water Treatment

Newark's slow sand filter plant was built in 1950-51. According to the plan diagram in Figure 20, there are four identical covered filters each 39 feet x 139 feet. The total filtration area is 21,684 ft^2 (0.5 acre). The plant operates at its design value of 2.0 MGD, or a filtration rate of 0.16 m/hr.

The raw water from Canadaigua Lake is pretreated with chlorine before it is pumped to the water treatment plant. The primary reason for chlorine pretreatment is to prevent algae from affecting the transmission pipeline, especially during the summer months. Fifteen pounds of chlorine are used daily for pretreatment (0.9 mg Cl_2/L). Post chlorination is accomplished with 25 pounds of chlorine (1.5 mg Cl_2/L) per day.

The effective size and uniformity coefficient for the sand at Newark are 0.35 mm and 1.7, respectively. The weight loss in the sand dissolution test was 36% indicating that the sand at Newark does not meet the AWWA Standard B100-80 requirement (17) that less than 5% dissolve in 1:1 HCl.

Operation

Two full-time operators work the day shift at the Newark plant. Most of their time is consumed by routine groundskeeping and traveling to check pumps, etc. Except during scraping and resanding operations, only a couple of hours each day are spent on actual plant operations such as water sampling and performing routine maintenance. One of the operators lives in a house situated on the plant site, thereby remaining available should any problems arise during non-working hours.

Scraping and Resanding--

Originally each filter is filled with sand to a depth of 36 inches. During normal operation there is six feet of water on top of the sand. When the filter bed is drained for scraping there is 7-8 feet of head room between the sand layer and the cover.

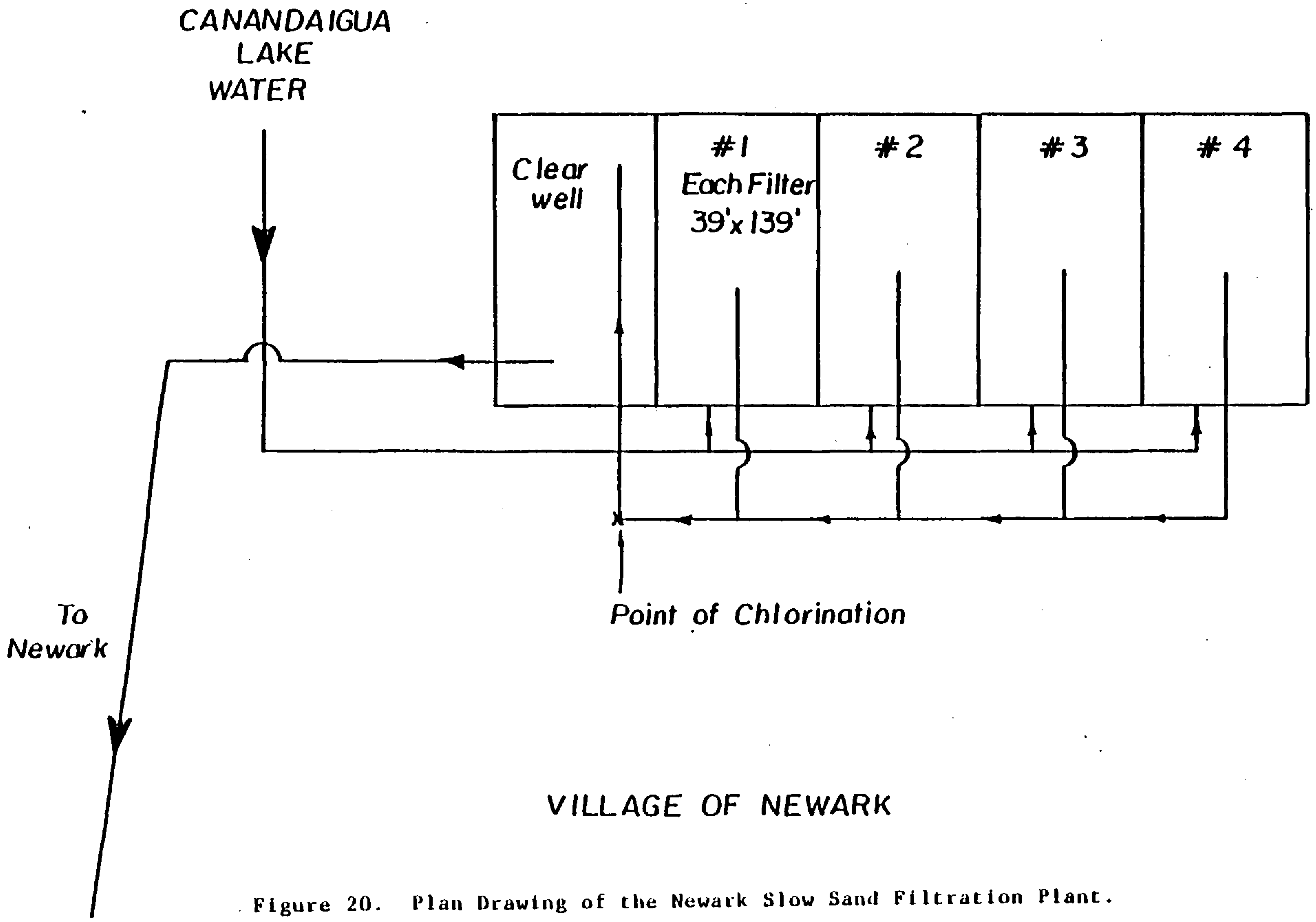

Figure 20. Plan Drawing of the Newark Slow Sand Filtration Plant.

The total plant output is 2 MGD. This is achieved using four identical filters with 0.5 MGD capacity each. The decision to scrape a filter is made with the guidance of headloss guages. A filter is normally scraped when the headloss reaches three feet of water. Three feet of headloss represents a 20% decrease in flowrate through the filter, i.e., a decrease from 0.5 MGD to 0.4 MGD.

Over the past five years each filter was scraped an average of 3.4 times per year. The durations of the filter runs lengths vary greatly, depending primarily on the time of year. Runs may be as short as two months during the summer or as long as eight months at other times.

Scraping Process--

During a normal scraping operation a filter is out of service for approximatley 24 hours. The operation begins at 3 p.m. the day before scraping. At this time the filter stops receiving raw water and is allowed to drain overnight. The following morning workers are borrowed from the Department of Public Works so that a total of five people are available to scrape the filter.

A motorized, four-wheel buggy with a capacity of one cubic yard is driven onto the filter bed and parked in a central area. The workers skim approximatley one-half inch of sand from the surface using long handled, flat bladed shovels and pitch the sand into the buggy. When the buggy is full, one person drives it out of the filter, dumps the sand and drives back. This routine is continuous for the two hour period required to completely scrape the filter.

To finish the scraping operation one person drives the buggy with a piece of chain link fence attached to the rear. Two other men rake the corners and other areas that can not be smoothed by the buggy. This finishing operation takes about ten minutes to complete. The entire scraping operation using five men to scrape the filter and three men to smooth the surface corresponds to 2 man hours/1000 ft^2.

Finally, the filter is refilled with water in a period of approximately three hours and put back into service. No water is discharged to waste. The used sand is piled at the plant site and used by the Village of Shortsville for sanding streets in winter.

Resanding Process--

Approximately every five years the filter beds are resanded to keep the depth of the sand greater than a two foot minimum. At the beginning of this operation a filter bed is scraped using the procedure described above. Then, 6-12 inches of sand is added to the filter using the buggy and workers with shovels. The sand is increased to approximately three feet total depth. This operation takes 7-8 days and 52-59 man hours/1000 ft^2 to complete.

The filter is refilled with water and the effluent is discharged to waste for the next 3.5 to 4.5 days. During this wasting period the amount of chlorine added to the filter bed is increased to 50-60 pounds per day to disinfect the new sand. This amount is greater than the normal prechlorination dose of 15 pounds per day. After the wasting period the filter is put back on line, the total time out of service for the resanding operation is 10-13 days.

Sampling

Since the Newark facility is a relatively new slow sand filtration plant, sampling was not as complicated as in some of the other plants visited. Each filter bed and the raw water line were equipped with taps.

Results and Discussion - Newark

A filter cleaning operation was monitored in August of 1983 and a resanding operation was monitored in January of 1984.

Turbidity--

Figure 21 is a plot of turbidity versus time after the filter was scraped. Turbidity values were plotted for the raw water, the scraped filter and a control filter which had been on line for at least one month. The control and scraped filter effluent turbidities were essentially the same, suggesting that, in this case, a ripening period did not exist. The scraped and control filters had average turbidities of 0.31 NTU. The average raw water turbidity for this period was 2.5 NTU. An analysis of turbidity records back to 1978 showed no evidence of a ripening period following filter scraping.

The turbidity results were somewhat different for the resanding operation (See Figure 22). In this case the resanded filter turbidity (0.3-0.4 NTU) was higher than that of the control filter (0.10-0.15 NTU). The resanded filter turbidity values gradually approached those of the control filter over the 24 hour period after the resanding operation was completed.

An interesting observation is that the average August raw water turbidity was 2.54 NTU, while the average January raw water turbidity was 0.96 NTU. This difference was most likely due to the absence of algae during the winter months, and may account for the apparent ripening period observed during the winter resanding. Since the water turbidity is lower during the winter it takes longer to form a schmutzdecke on the sand surface, therefore, giving a ripening period.

Another explanation for the slight ripening period observed after resanding may be related to the chlorine dose. As mentioned previously Newark increases the prechlorination dosage in the water supplied to a resanded bed in order to disinfect the new sand. However, while achieving this result, beneficial organisms in the old sand that may help to remove turbidity may also be killed and temporarily reduce the efficiency of the filter.

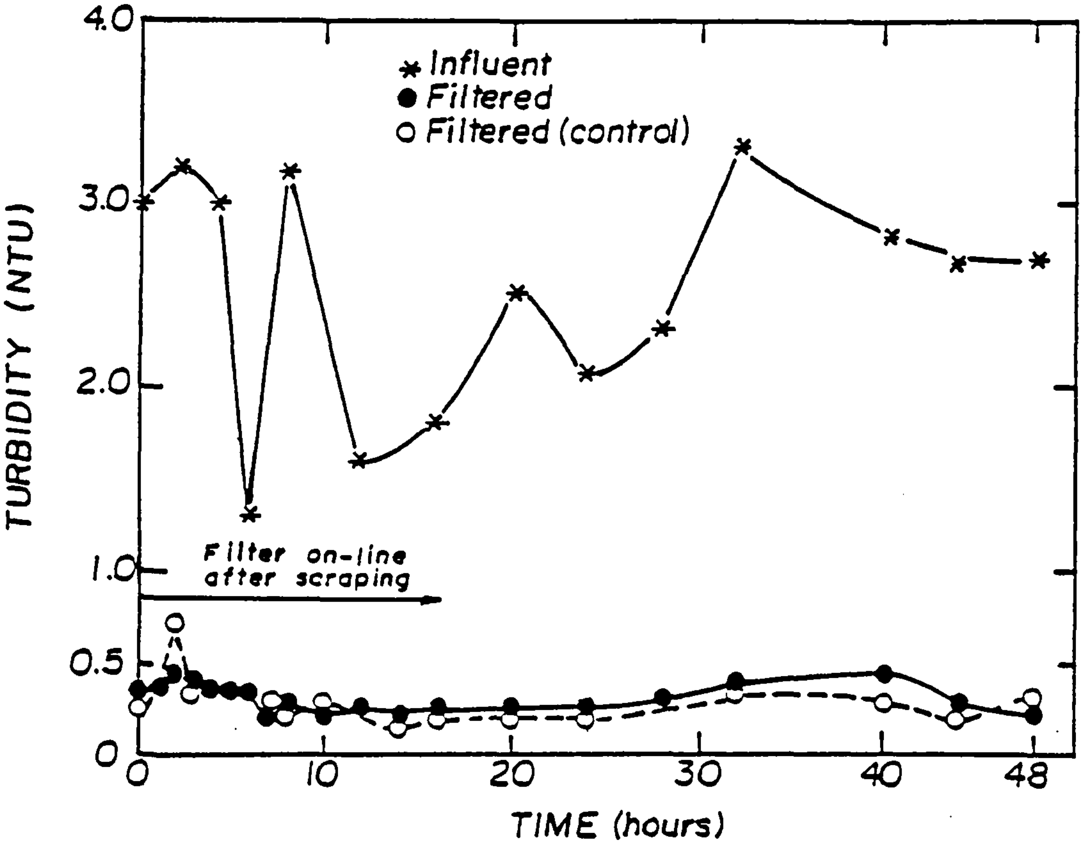

Figure 21. Turbidity versus Time at Newark, August 1983, Scraping Operation, Filter # 1.

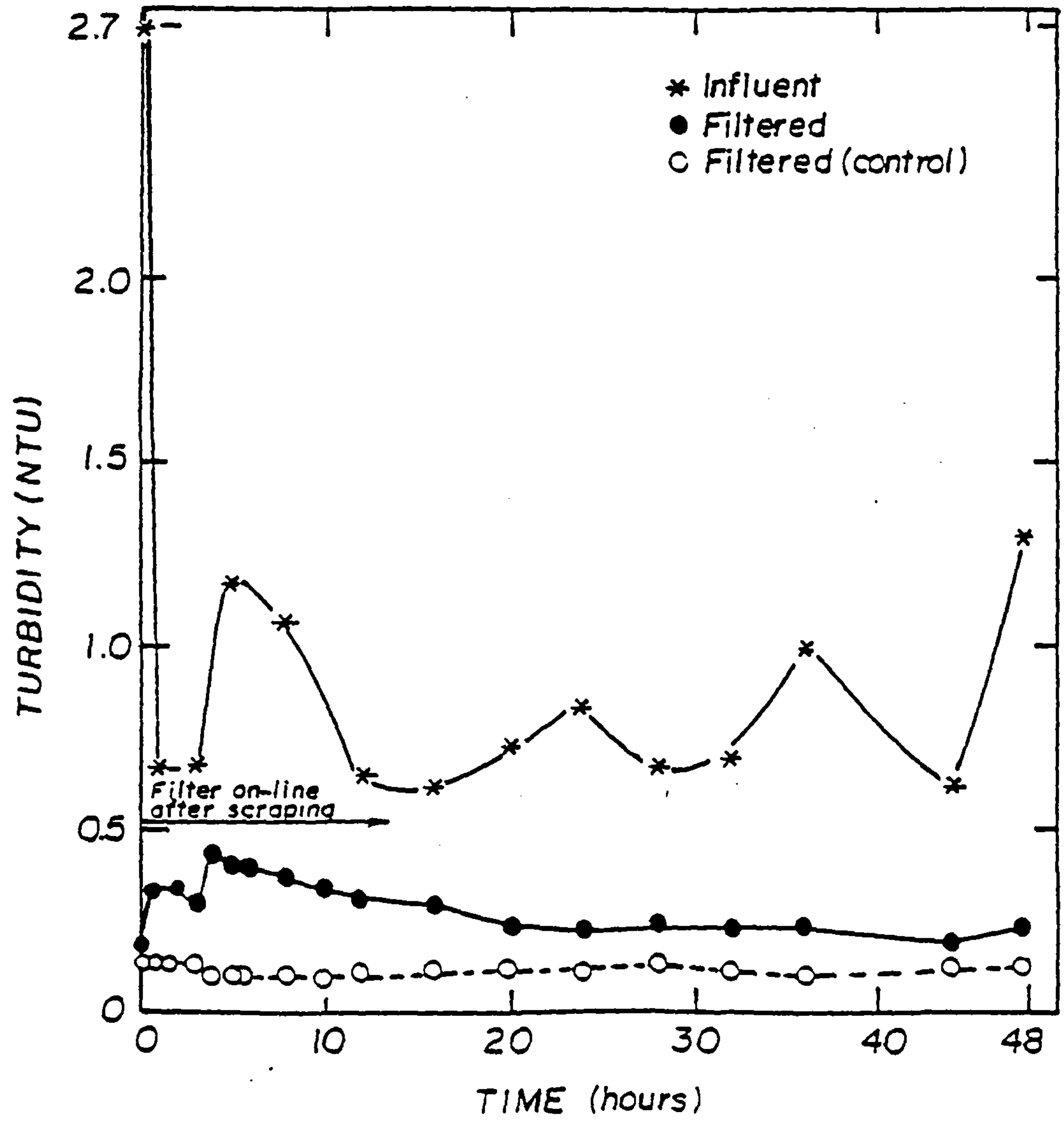

Figure 22. Turbidity versus Time at Newark. January 1984, Resanding Operation, Filter #1.

A third possibility is the decreased water temperature during the winter resanding operation. During the summer scraping operation the water temperature was approximately 11-13°C. However, the water temperature was 4°C during the resanding operation. This lower water temperature may decrease the activity of the organisms in the sand, thus, decreasing the efficiency of the filter.

Finally, a combination of all three of the above may result in the apparent ripening period after resanding.

Particle Count Data--

The results obtained using the HIAC particle size analyzer generally correlated with the turbidity results. After the August scraping operation, the particle counts for the scraped filter were similar to the values for the control filter (Figure 23). In the case of resanding, the particle analysis indicates that the resanded filter particle counts (500-900 particles/mL) were higher than those of the control filter (140-200 particles/mL) during the first twenty hours of operation (see Figure 24).

The one exception to this trend was during the first hour of operation. This may be because Newark backfills its filters with clean water after scraping and resanding, and it may take an hour or two before raw water is actually filtered.

Standard Plate Count--

The Standard Plate Count data for the scraped filter (Figure 25) shows two peaks; one after two hours of operation (27 colonies/mL) and one after twenty hours of operation (380 colonies/mL). The twenty hour peak follows four hours after a raw water peak of 310 colonies/mL. It is interesting to note that the control filter also peaked at twenty hours but the peak height was much less (25 colonies/mL) than the cleaned filter peak height. This result, which was also seen at the Auburn plant, suggests that a very recently scraped filter cannot handle slugs of poor quality water as effectively as an established filter.

There were no apparent trends in the plate count data at Newark. This may be due to the prechlorination practiced there, especially during a resanding operation when the prechlorination dose used is comparatively high. The resanding plate count graph (Figure 26) does, however, suggest the presence of a slight ripening period. The resanded filter plate count values were initially high (690 colonies/mL) and then scatter for the first eight hours before decreasing to the 2-3 colonies/mL range. The control filter generally remained between two and ten colonies/mL.

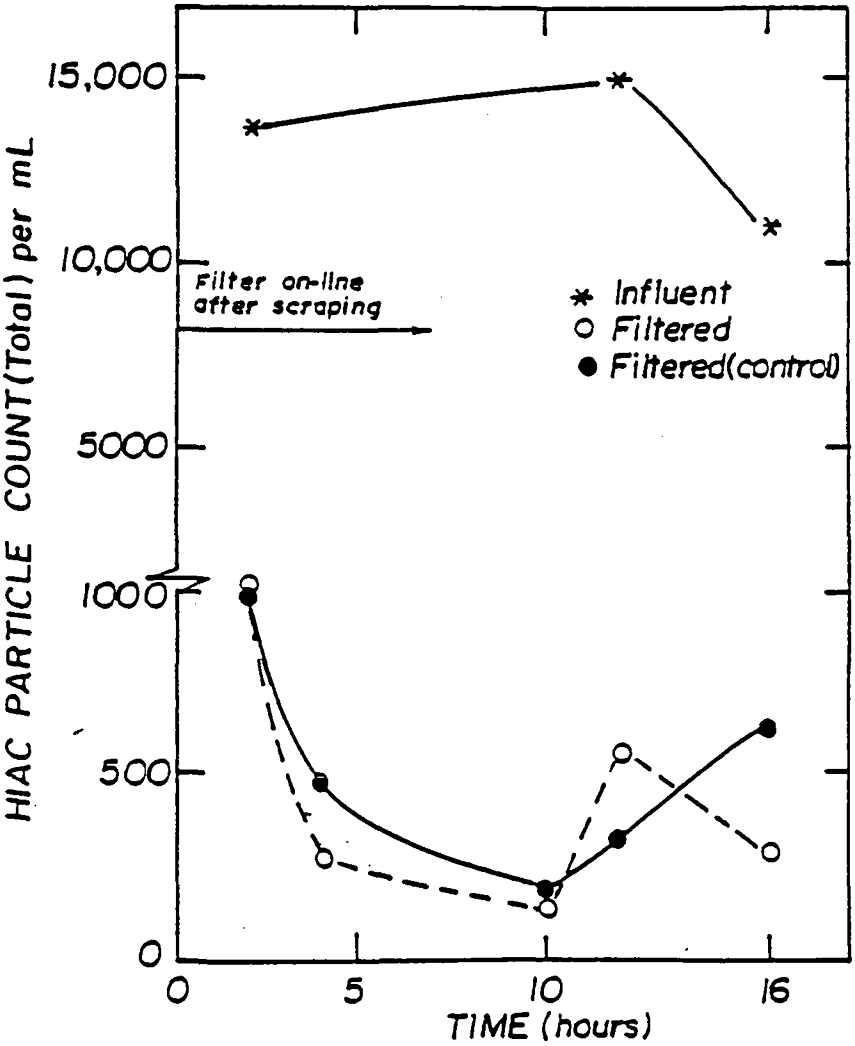

Figure 23. HIAC Particle Count versus Time at Newark, August 1983, Scraping Operation, Filter # 1

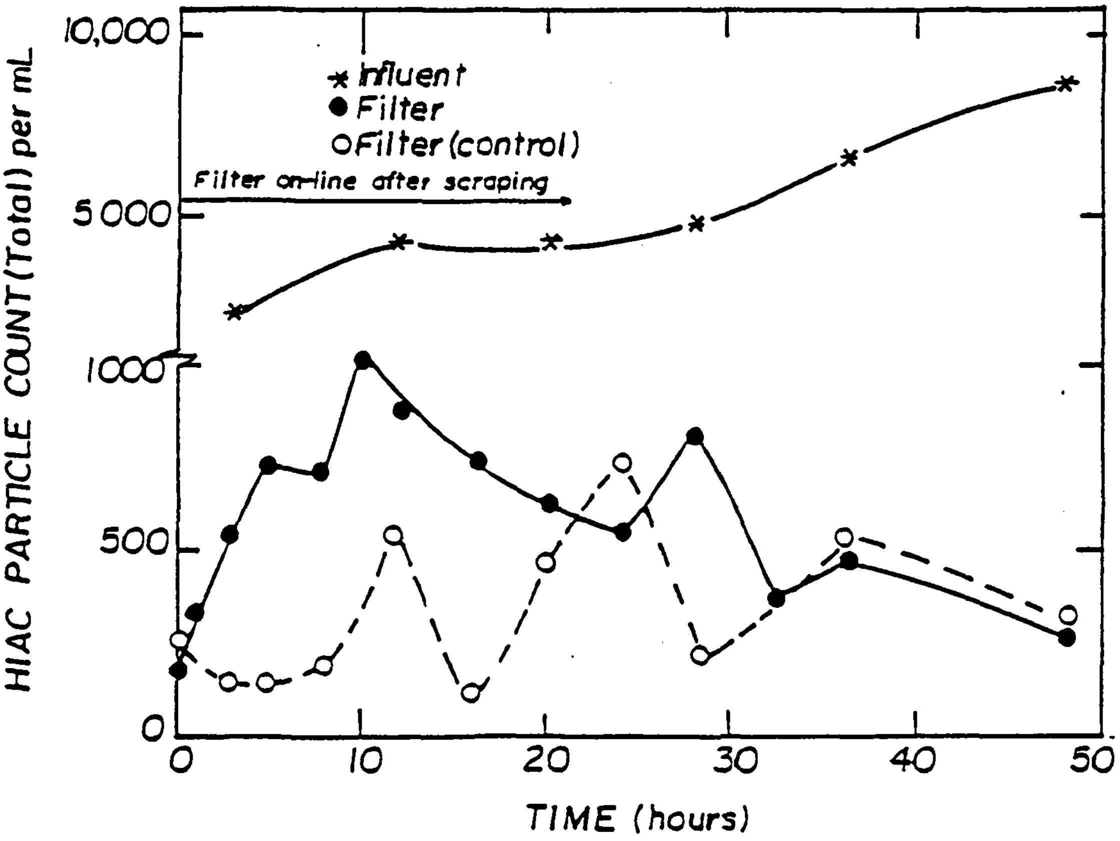

Figure 24. HIAC Particle Count versus Time at Newark, January 1984, Resanding Operation, Filter #1.

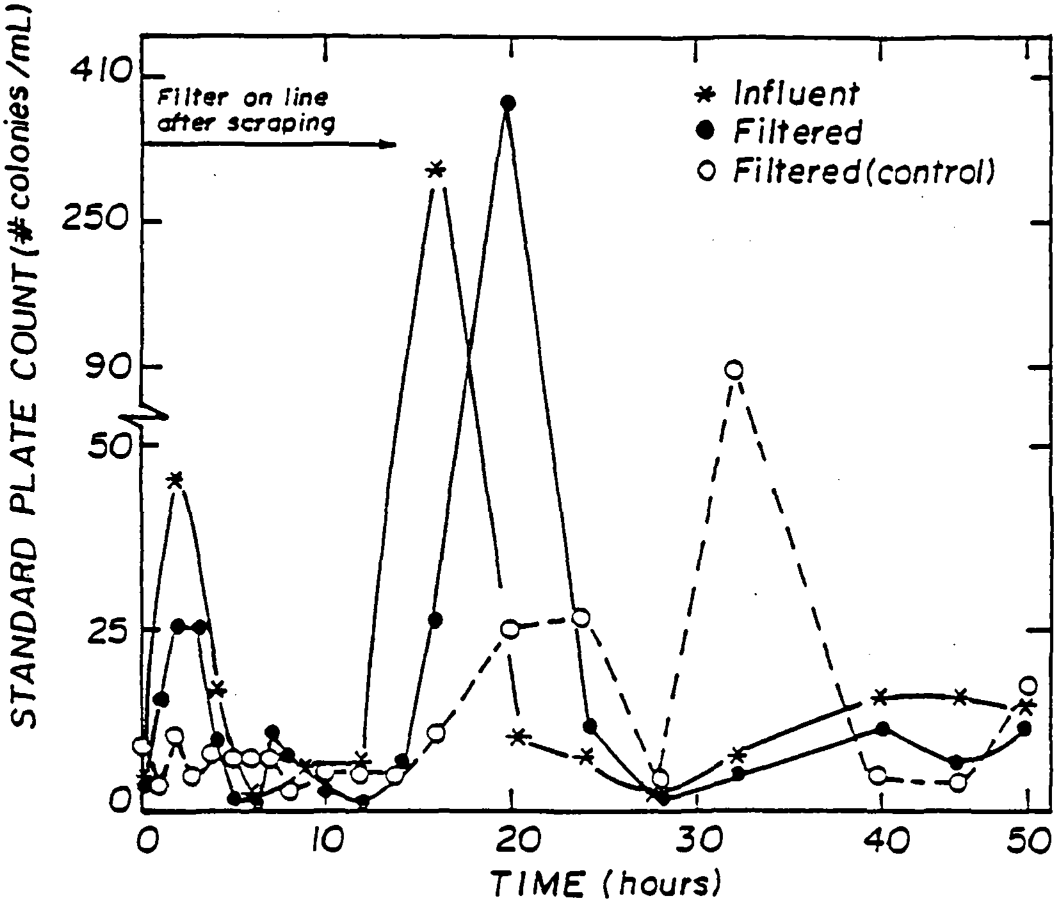

Figure 25. Standard Plate Count Bacteria Density versus Time at Newark, August 1983, Scraping Operation, Filter #1.

The plate count results seem to support the turbidity and particle analysis results. No ripening period is seen during filter cleaning operations at Newark. A check of turbidity history records (back to 1978) supported this observation. However, a ripening period of approximately one day was seen after a resanding operation.

Total Coliform Bacteria--

Coliform bacteria were not detected in the samples taken at Newark during this study.

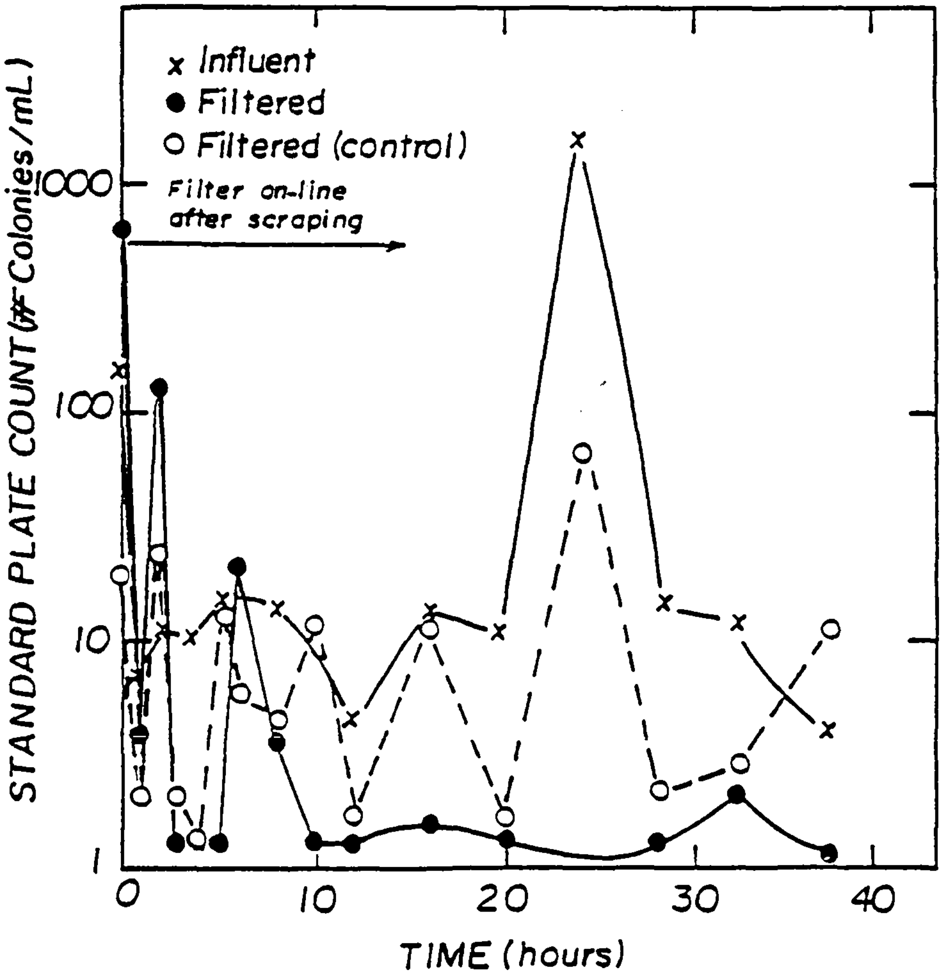

Figure 26. Standard Plate Count Bacteria Density versus Time at Newark, January 1984, Resanding Operation, Filter # 1.

SITE 6 - OGDENSBURG

The city of Ogdensburg, New York (population 15,000) is located 130 miles northeast of Syracuse on the St. Lawrence River at its confluence with the Oswegatchie River opposite Prescott, Ontario. It is the manufacturing center in one of the most productive dairy regions in northern New York and is the site of an international harbor.

Water Source

The city of Ogdensburg receives its water from the St. Lawrence River. The raw water is of very high quality with turbidity consistently less than 1.5 NTU and often less than 1.0 NTU. Water chemistry results for the St. Lawrence River are shown in Table 4. The water chemistry results in this table are from samples taken at Massena, New York (30 miles northeast of Ogdensburg).

Water Treatment

A slow sand filter plant was put into service at Ogdensburg in 1911. As shown in the accompanying diagram, Figure 27, there are four identical covered filters and a sand washing apparatus. Each filter is 140 ft. x 60 ft giving a total filtration area of 33,600 ft^2 (0.8 acre). The plant produces an average of 3.6 MGD which corresponds to an average filtration rate of 0.18 m/hr. According to plant personnel the design value for the filtration rate is 0.20 m/hr. The water supplied to the filters receives no pretreatment.

The sand at Ogdensburg has an effective size of 0.35 mm and a uniformity coefficient of 1.7. The sand dissolution test results showed that the sand is of high quality, only 0.4% dissolved in 1:1 HCl.

Operation

There is an operator on duty at Ogdensburg twenty-four hours a day. Three operators are used to operate the plant and pump station from 8 a.m. to 4 p.m. Three additional operators share the duties from 4 p.m. to 8 a.m., with only one operator on duty at a time.

Scraping and Resanding--

When the filter beds are in operation there is seven feet of water on top of three feet of sand. When a bed is drained for cleaning there is approximatley ten feet of clear space between the sand and the filter cover.

There are no headloss gauges at Ogdensburg. One filter is scraped every Friday. Therefore, each filter is scraped every four weeks. This corresponds

Table 4. St. Lawrence River Water Chemistry at Massena, N.Y. From U.S. Geological Survey (16)

	mg/L		µg/L
silica	0.20 - 1.0	alumium	14 - 290
calcium	41	barium	24 - 33
magnesium	7.5 - 8.1	beryllium	<0.80 - 2.0
sodium	12 - 13	bismuth	<4.0 - 8.0
potassium	1.2 - 1.5	boron	8.0 - 16
bicarbonate	109 - 113	chromium	<4.0
carbonate	0	cobalt	<4.0
sulfate	26 - 29	copper	30 - 110
chloride	24 - 28	gallium	<2.0 - 4.0
fluoride	0.10 - 0.80	germanium	<4.0 - 8.0
total kjeldahl N	.20 - .43	iron	10 - 380
nitrate as N	.08 - .20	lead	3.0 - 4.0
ammonia as N	---	lithium	10
phosphate as PO_4	.05 - .09	manganese	3.0 - 36
dissolved solids sum	170 - 176	molybdenum	<1.0 - 2.0
total hardness	133 - 136	nickel	4.0
non-carbonate hardness	41 - 46	silver	<.40 - .80
cyanide	0 - .01	strontium	150 - 190
specific conductance	313-325 $\frac{\text{micromhos}}{\text{cm}}$	tin	<4.0
pH	7.8 - 8.3	titanium	3.0 - 26
		vanadium	<2.0 - 4.0
		zinc	26 - 380
		zirconium	<6.0 - 9.0
		arsenic	0 - 10
		cadmium	0
		total mercury	.50
		selenium	0 - 2.0

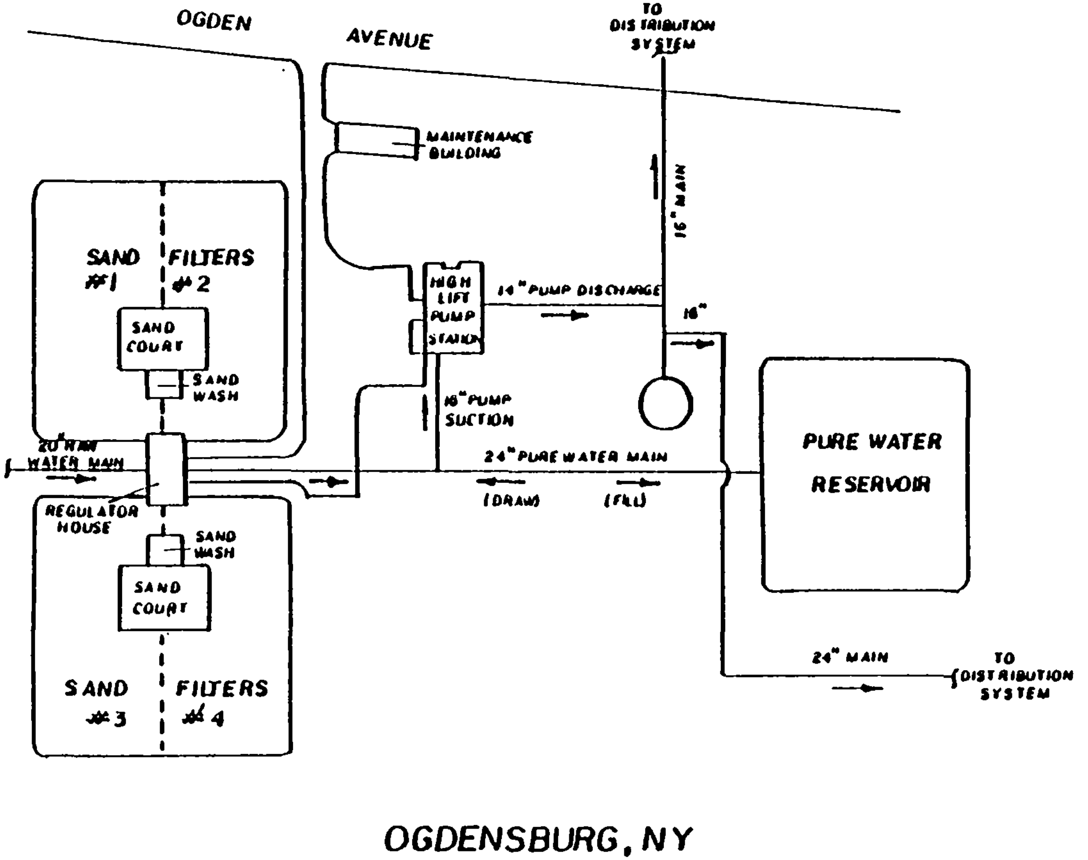

Figure 27. Plan Drawing of the Ogdensburg Slow Sand Filtration Plant.

to a water production per filter run of 121 m^3/m^2 (2978 gal/ft^2). Past experience has shown that at the end of each four week run a filter bed is producing only 10-20% of its maximum capacity (1 MGD) or may not be producing water at all. This varies depending on the time of year, demand for treated water, etc.

Scraping and Resanding Process--

Ogdensburg is unique in that for a given filter the cleaning and resanding operations are conducted at the same time. The bed is drained the night before and is ready for cleaning in 6-10 hours.

The scraping/resanding operation begins at 8 a.m. Friday morning. Six to seven city employees are brought in to do the job, which takes six hours. This corresponds to 4.3-5.0 man hours per 1000 square feet. Approximately one inch of sand is scraped from the filter bed with broad shovels and placed in a hopper. The hopper is connected to a permanent eductor system which pipes the sand slurry to a sand washer (a sand agitator with a settling tank) located above the filter bed.

The sand is stored in the sand court until the scraping operation is complete. Hard spots in the filter bed are spaded. Next the washed sand is conveyed hydraulically back into the filter bed where it is spread and smoothed using rakes and shovels. Finally the filter is filled with raw water (not filtered water as in most plants) and put back in service after being out of operation for approximately twenty-four hours. Ogdensburg usually does not run to waste after cleaning, however, they will do it occasionally for a maximum of two hours during nonsummer months.

Sampling

As in Auburn, each filter emptied into its own wet well. Samples were taken by attaching bottles to a string and dropping the bottles into the wells. Raw water samples were taken by dipping bottles directly into water on the tops of the filter beds at the points where the raw water entered.

Results and Discussion - Ogdensburg

Two filter scraping/resanding operations were monitored at Ogdensburg, one in August 1983 and a second in February 1984.

Turbidity--

According to the turbidity versus time data plotted in Figures 28 and 29 there was no evidence of a ripening period. The control and scraped filter turbidity values were essentially the same. The raw water

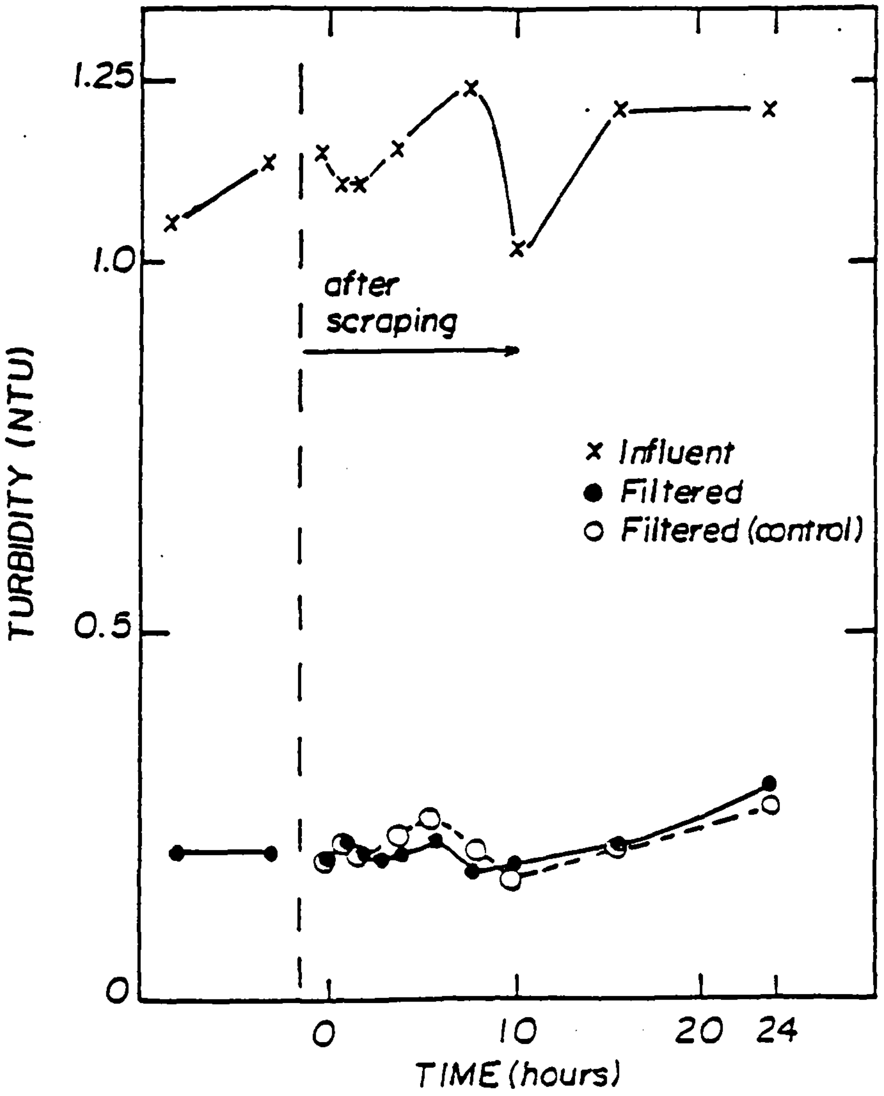

Figure 28. Turbidity versus Time at Ogdensburg, August 1983, Filter #1 . Scraping and Resanding.

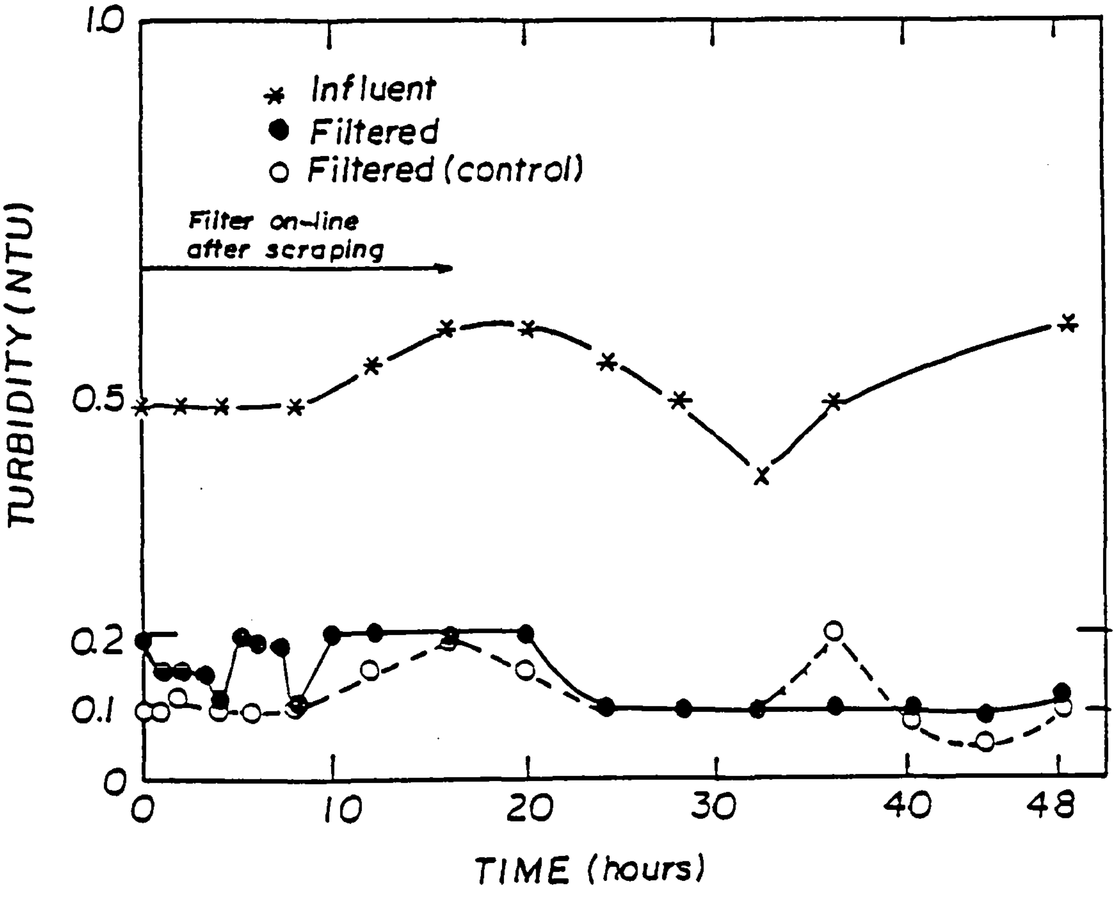

Figure 29. Turbidity versus Time at Ogdensburg, February 1984, Filter #3, Scraping and Resanding.

and the filtered water were both of high quality. The raw water never exceeded 1.25 NTU while the filtered water was consistently in the range 0.1-0.2 NTU during testing in August and February.

Particle Count--

Due to the long travel distance, samples could not be brought back to Syracuse University for particle analysis in a reasonable amount of time. Therefore, HIAC Particle Count data could not be collected for Ogdensburg.

Standard Plate Count--

There were no obvious trends in the Standard Plate Count data. The scatter in the data for the just scraped filter is greater than the scatter in the control filter data (Figures 30 and 31). This suggests that a recently cleaned filter may not be as able to effectively treat slugs of lower quality water as well as an established filter. It is obvious that the plate count values obtained during the winter are much lower (1-20 colonies/mL) than during the summer (80-250 colonies/mL). During the summer (water temperature approximately 11°C) the raw water plate count values were lower than the filtered water plate counts. This is not the case during the winter (water temperature 1.5°C), indicating that the warmer summer water is more conducive to organism growth in the filter bed.

Total Coliform Bacteria--

Coliform bacteria were not found in any of the winter samples. However, coliforms were found during the summer in seven out of 37 of the scraped filter effluent samples and one raw water sample. The apparent absence of coliforms in the control filter samples indicates that there may have been a ripening period in the filter. The reason the turbidity and plate count results did not show this may have been due to the exceptionally high raw water quality.

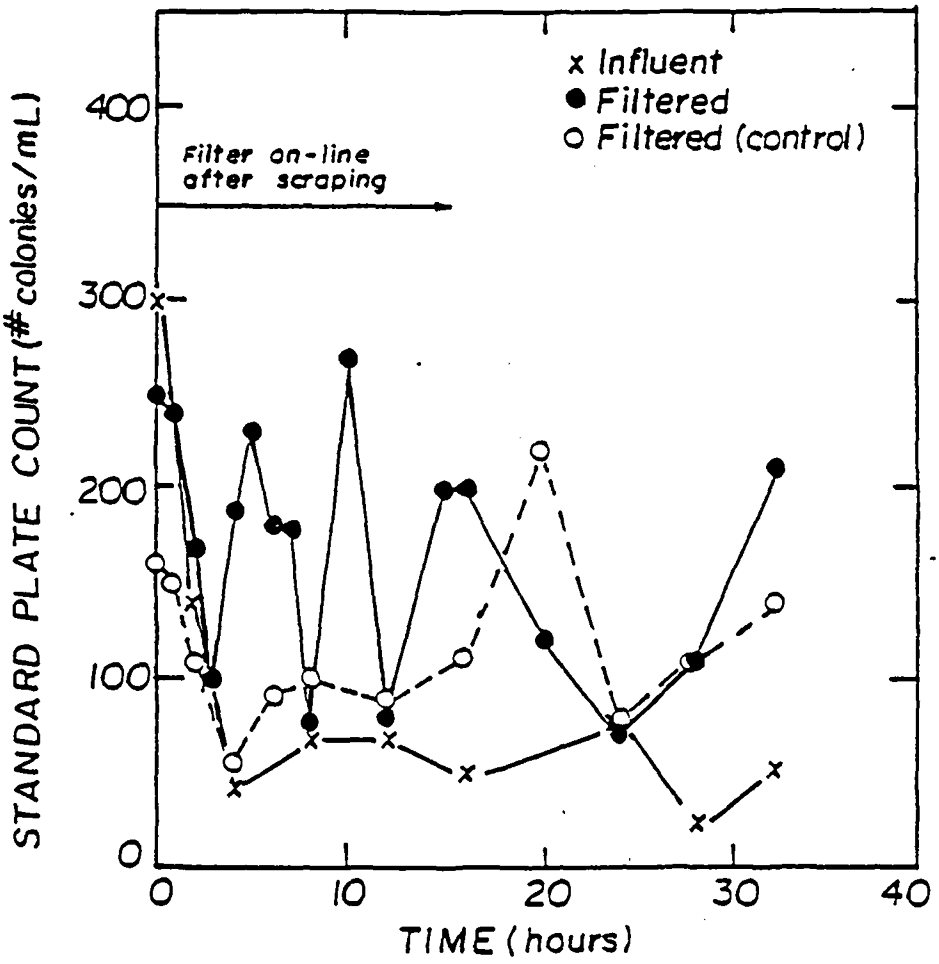

Figure 30. Standard Plate Count Bacteria Density at Ogdensburg, August 1983, Filter #1, Scraping and Resanding.

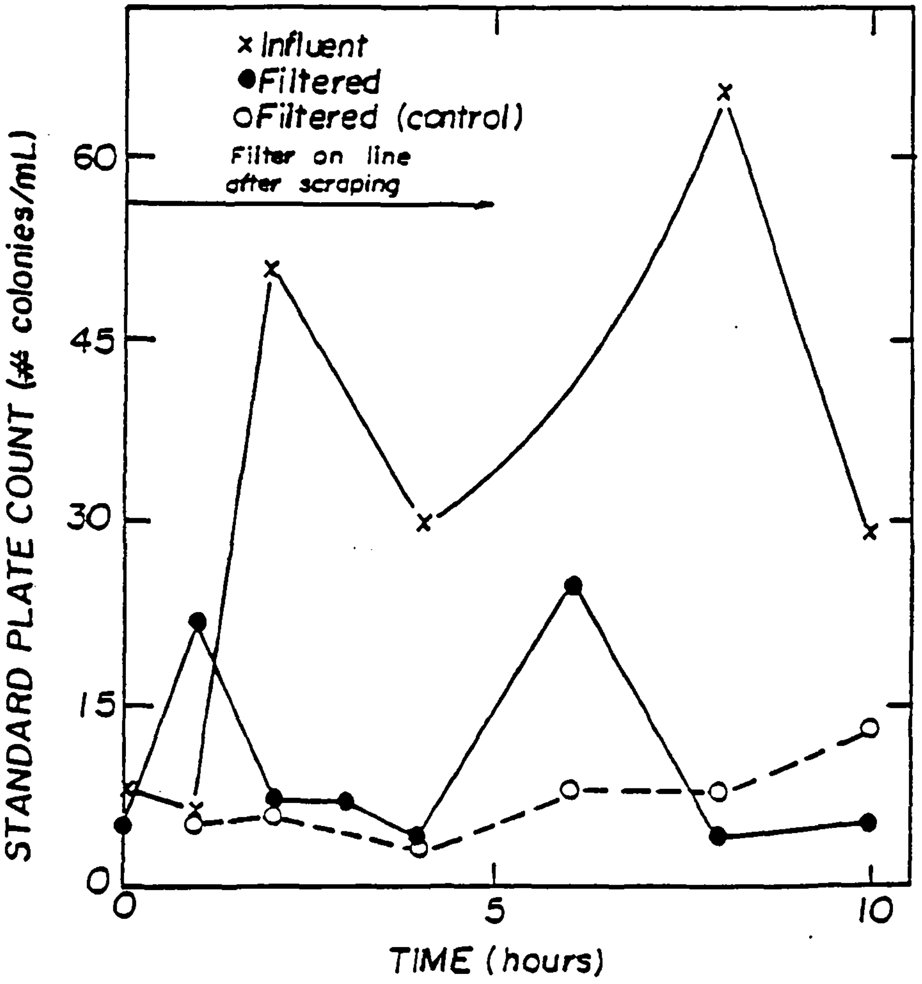

Figure 31. Standard Plate Count Bacteria Density at Ogdensburg, February 1984, Filter # 3, Scraping and Resanding.

SITE 7 - WAVERLY

The village of Waverly (population 5,000) is 90 miles southwest of Syracuse on the New York-Pennsylvania border. It is near the city of Sayre, Pennsylvania and midway between the cities of Binghamton and Elmira, New York.

Water Source

The village of Waverly has two sources of water. One source is a set of three deep wells that meets the Village's average demand flowrate when operating continuously. A second source is surface runoff impounded in two, 45 million gallon earthen, uncovered reservoirs.

The well water is hard (250-300 mg/L as $CaCO_3$) but is otherwise of good quality and needs no treatment other than chlorination. Water from the reservoir generally has a high turbidity (8-20 NTU). The turbidity peaks during the spring runoff at values which are sometimes as high as 40 NTU. In addition the reservoir water occasionally contains significant amounts of iron and manganese. Total iron concentrations as high as 0.9 mg Fe/L and total manganese concentrations greater than 3 mg Mn/L have been measured.

Water Treatment

In the summer of 1982 a new slow sand filtration plant went on line in Waverly to treat the reservoir water. This plant was designed without the benefit of a pilot plant study. As illustrated in Figure 32, the plant has four identical covered filters each 100 ft x 30 ft and therefore a total filtration area of 12,000 square feet. The plant treats 1.2 MGD at a filtration rate of 0.16 m/hr.

Originally the plant was operated with no pretreatment. However, the filtered water turbidity frequently exceeded 5 NTU, a value which is well above the MCL of 1.0 NTU. An expert hired by the village's consulting engineer concluded that in addition to the presence of iron and manganese, the Waverly raw water contains silica. According to the expert the silica is in what is essentially a soluble form before treatment and therefore not readily removed by filtration. After the silica passes through the filters it "polymerizes" forming particles which scatter light and contribute to the turbidity of the filtered water.

In February of 1982 prechlorination was begun at Waverly. With prechlorination and raw water turbidity less than 15 NTU the filtered water turbidity could be maintained below 1.5 NTU. Consequently the New York State Department of Health requires Waverly to take the slow sand filtration plant off-line when the raw water turbidity exceeds 12.5 NTU and to rely entirely on its well water supply.

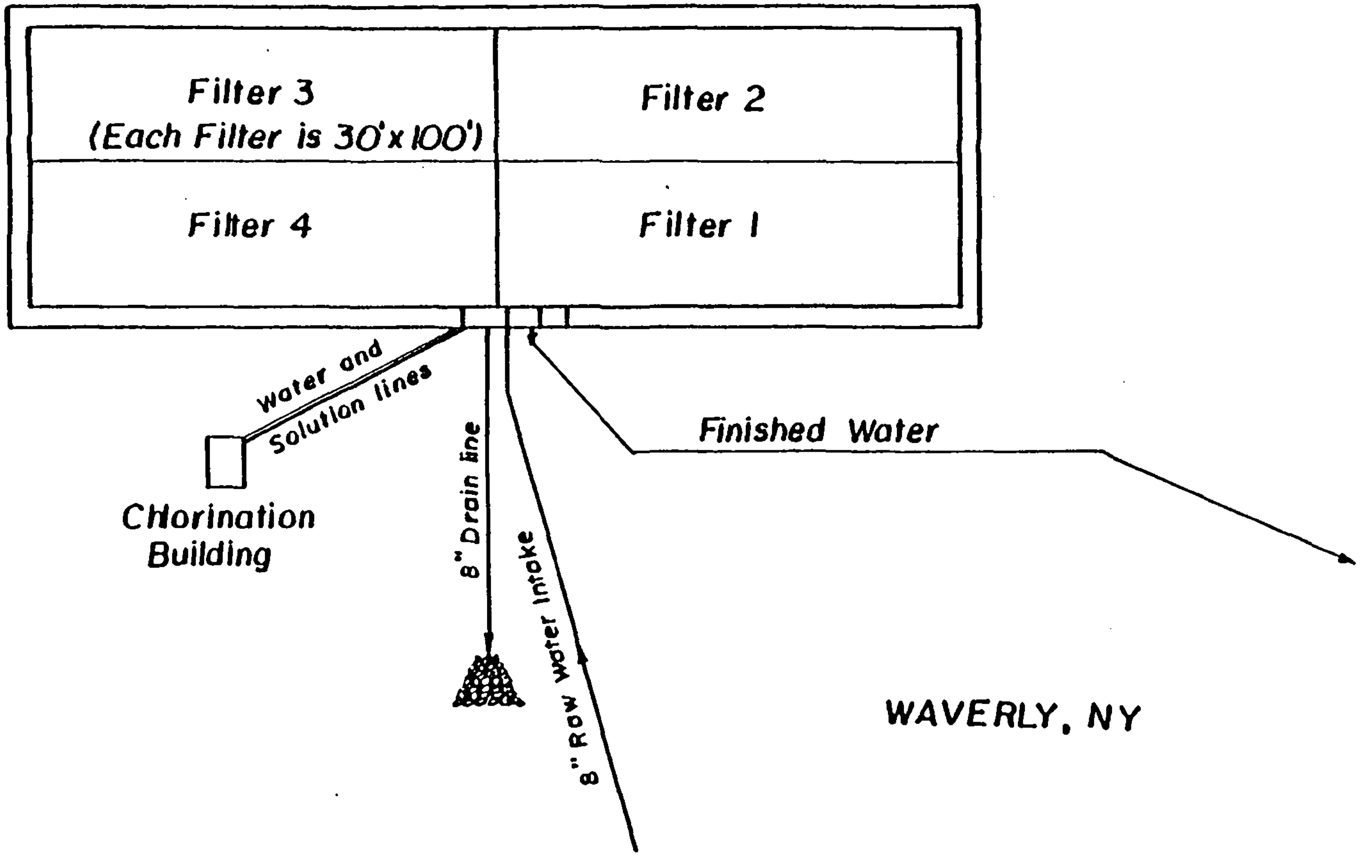

Figure 32. Plan Drawing of the Waverly Slow Sand Filtration Plant.

It is not known exactly why prechlorination has affected lower filtered water turbidities. Two explanations are offered by plant personnel. One is that the chlorine slows or prevents the "polymerization" of the submicron siliceous particles which are detectable as turbidity after filtration.

The second explanation is that the chlorine promotes particle aggregation which in turn increases the efficiency of removal by filtration.

Prechlorination has had the added benefit of helping to control iron and manganese at Waverly. The chlorine apparently oxidizes the iron and manganese and promotes the formation of metal hydroxides and oxides which are removed by filtration. Iron as high as 0.9 mg Fe/L has been reduced to <0.1 mg Fe/L and manganese as high as 3.0 mg Mg/L has been reduced to <0.05 mg Mn/L with prechlorination.

The prechlorination chlorine dosage at Waverly is 5 mg Cl_2/L. For postchlorination a dosage of 1.5-2.0 mg Cl_2/L is used. In addition to chlorine, soda ash is added to the raw water. The soda ash increases the pH and alkalinity of the water, thus tending to make it more compatible with the water with which it may become mixed. The soda ash dosage of 10-13 mg Na_2CO_3/L according to Waverly personnel, prevents "a precipitate from forming" when the two waters are blended.

The sand used at Waverly has an effective size of 0.15 mm and a uniformity coefficient of 2.4. This effective size is the smallest of any plant visited. The uniformity coefficient is slightly higher than the average (2.4) for all plants. The sand dissolution test results (weight loss = 17%) indicated that the sand is not of high quality and does not meet the AWWA Standard B100-80 requirement (17) that less than 5% dissolve in 1:1 HCl.

Operation

One person is responsible for the plant eight hours per day on weekdays and four hours per day on the weekends. However, very little of his time is spent at the plant. The operator is responsible for taking samples and adjusting flow rates, etc. Normally this takes no more than one hour per day. The remainder of his time is spent working with other water department employees on the distribution system.

Scraping and Resanding --

The depth of sand in each filter is initially 36 inches, and there is approximately ten feet of head room in the filter building. When the filter is in operation, the depth of water above the sand surface is approximately six to eight feet.

The decision to scrape a filter is made with the guidance of a differential headloss gauge. Waverly normally scrapes a filter when the headloss is 6.0 -7.5 feet. During a filter run the flowrate in a filter will drop from 200 gallons per minute (0.29 MGD) to approximately 170 gallons per minute (0.24 MGD).

Due to the variable quality of the Waverly raw water, the filter run lengths vary significantly. A filter run may last as long as six weeks or be as short as two days. When the plant was designed it was estimated that the average run length would be 4 months (2800 hours). As noted, the plant is taken off-line when the raw water turbidity exceeds 15 NTU.

Scraping Process--

During a normal scraping operation the filter is out of service for 2 to 3 days. It takes 24 hours to drain the filter, 8 hours to scrape, 24 hours to backfill the filter, and finally the water is wasted for approximately three hours before the filter is put back into service.

The scraping operation requires two laborers who complete the job in eight hours. This corresponds to 5 man hours/1000 ft^2. Approximately one inch of sand is removed from the filter bed with long-handled flat-bladed shovels. The sand is loaded into a standard four cubic foot wheelbarrow which is pushed outside the filter bed and dumped near the filter building. Due to the small volume of the wheelbarrow, a significant amount of time is spent by one worker using it, while the other worker continues to scrape. This process is inefficient since the second worker must sometimes wait for the wheelbarrow to return. Finally, the filter bed is smoothed with rakes and refilled with water.

Resanding Process --

The filter beds at Waverly were resanded during the summer of 1983. One foot of sand (100 tons) was added to each filter. The resanding operation was very similar to the filter scraping operation. First, a filter was scraped in the normal manner. Next, the workers brought in sand with wheelbarrows and spread it on top of the existing sand with shovels and rakes. Each filter was out of service for approximately three and one half weeks during resanding.

Sampling

Filter effluent and raw water samples were obtained using taps installed in the pipelines. However, raw water samples taken after prechlorination but before the filter were obtained from the water on top of the filter beds. Taking these samples involved climbing down through a roof hatch to the water surface on a permanent ladder. The sample was taken by dipping a bottle directly into the water on the surface of the filter.

Results and Discussion - Waverly

One filter scraping operation was monitored in June of 1984.

Turbidity --

According to Figure 33, the filtered water turbidity for the scraped filter was initially rather high (6.7 NTU versus 1.5 NTU for the control filter). After approximately one hour of operation the turbidity decreased to 2.9 NTU and eventually leveled off in the 2.0-2.2 NTU range after eight hours of operation. The filtrate turbidity remained at this level until hour 127 (approximately 5.3 days of operation) when regular sampling was terminated. The control filter effluent turbidity remained at approximately 1.5 NTU during this entire time period.

Experience at Waverly has shown that it usually takes approximately two weeks for the effluent turbidity of a recently scraped filter to become essentially equal to that of the control filters ($\leq$ 1.5 NTU). In the case of the scraping of June, 1984, plant personnel continued to take daily turbidity readings. After ten days (240 hours) of operation the effluent turbidity in the recently scraped filter decreased to 1.1 NTU. (The raw water turbidity was essentially constant at 7.0 NTU during this period).

What we observed at Waverly in June of 1984 seems to be more or less standard for this plant. A lengthy (2 week) ripening period is the rule rather than the exception. The reasons for this situation are not known although it appears likely that the raw water source contains particulate matter (or precursors to the formation of particulate matter) which is difficult to remove by slow sand filtration.

Particle Count Data --

The HIAC particle count data is plotted in Figure 34. The initial particle count after scraping was approximately 2300 particles/mL. The count data for the scraped filter approached that of the control filter after approximately 27 hours of operation. An extensive ripening period is not seen in the particle count data. It is possible that the particles in the Waverly supply are simply too small to be detected by the HIAC unit.

Figure 35 is a plot of turbidity versus particle concentration for all the samples collected during this study for which both turbidity and HIAC particle counts were measured. Both raw and filtered water samples are included.

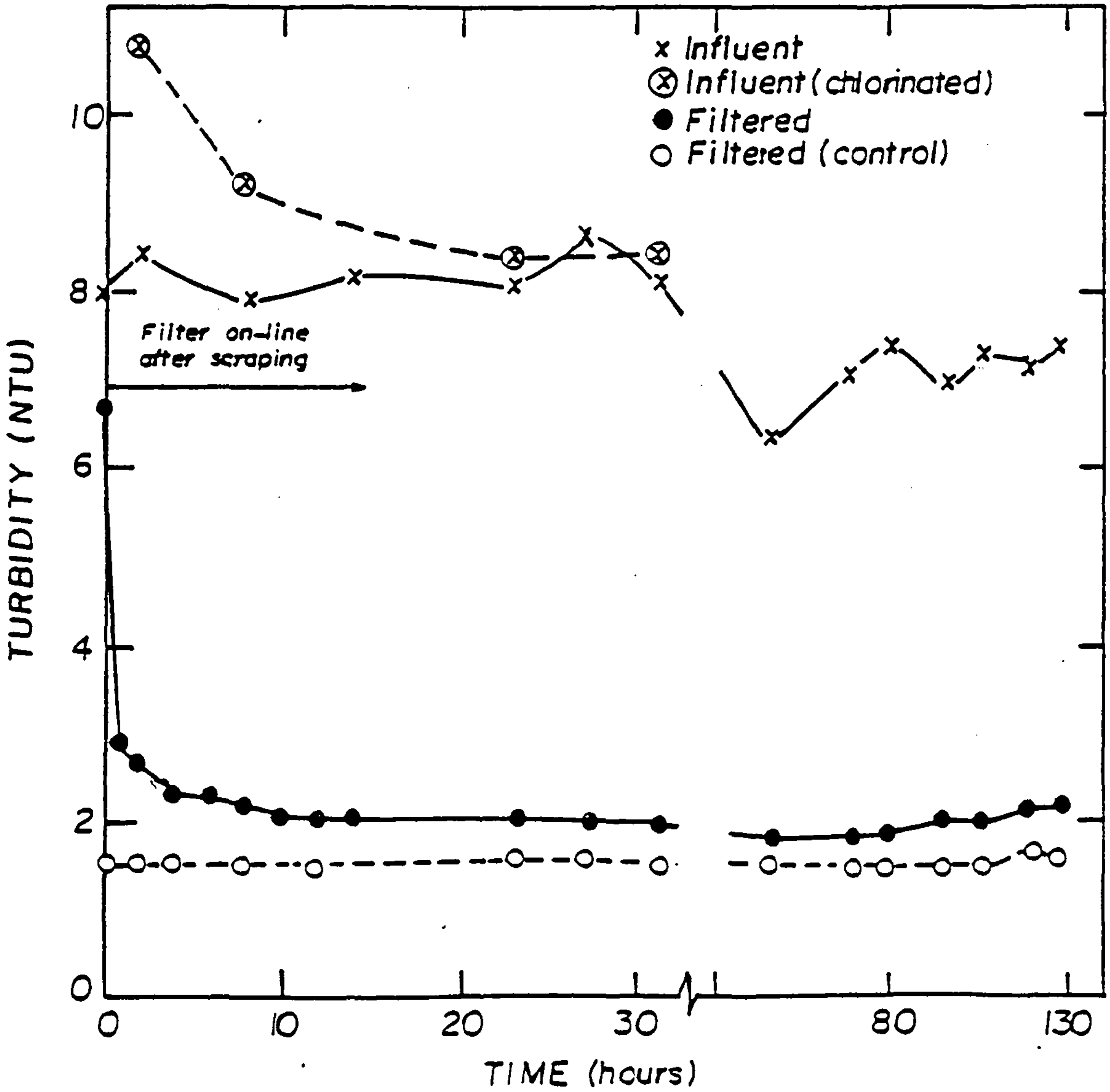

Figure 33. Turbidity versus Time at Waverly, June 1984, Filter #2.

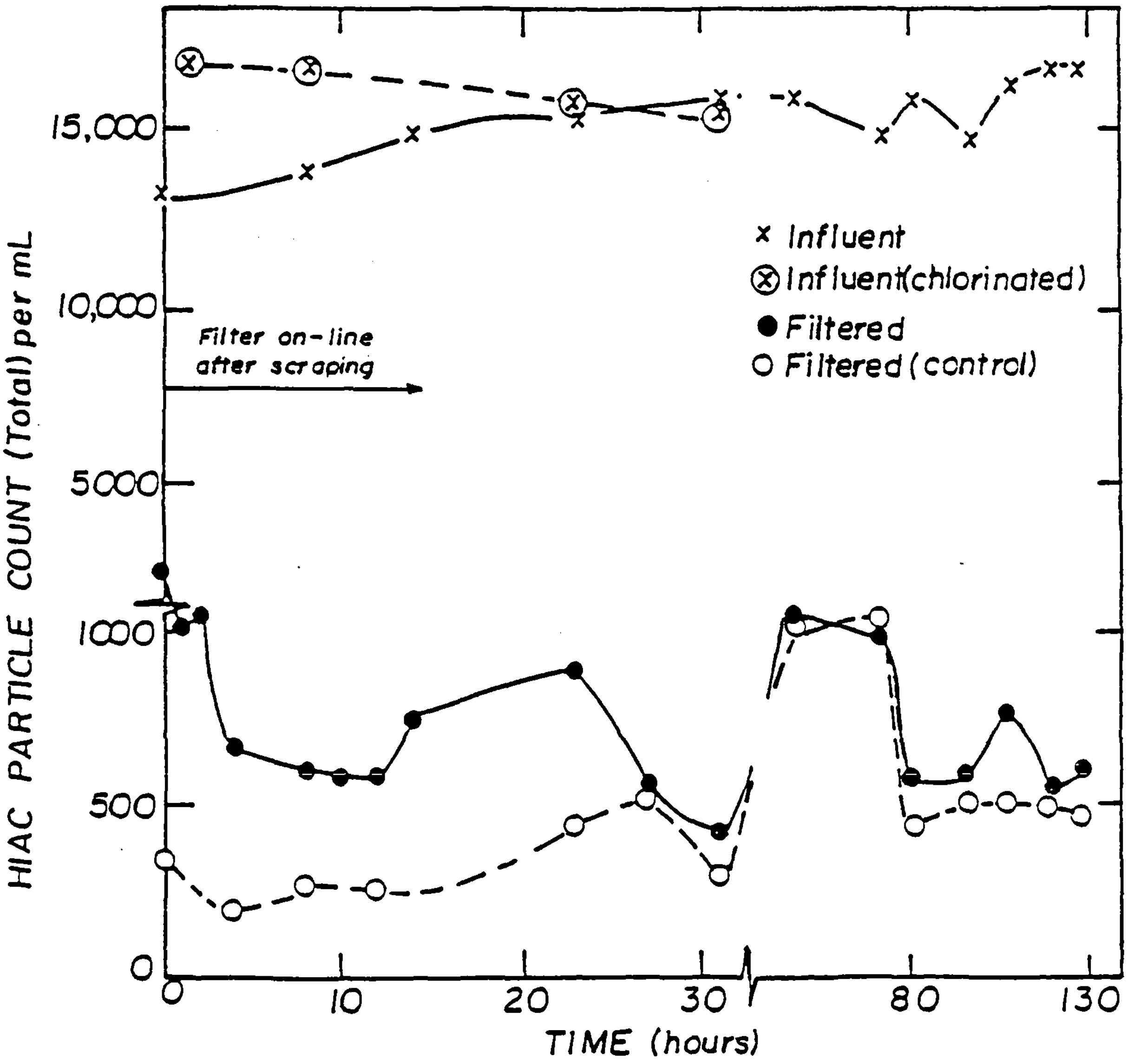

Figure 34. HIAC Particle Count versus Time at Waverly, June 1984, Filter # 2.

In Figure 35 the results obtained for the samples collected at Auburn, Hamilton, Newark and Ilion appear to cluster around the same trend line. The data collected at Waverly plot significantly above the points which correspond to the other sites. For example, at Auburn, Hamilton, Newark and Ilion a particle concentration of 1000/mL corresponded to turbidity values in the range 0.3 to 0.7 NTU. At Waverly a particle concentration of 1000/mL corresponded to turbidity values in the range of 1.8 to 3.0 NTU.

The results plotted in Figure 35 suggest that in terms of the removal of particles greater than 2 μm in diameter the filters at Waverly were as efficient (or more so) than the filters at the other sites. Apparently, particles smaller than 2 μm passed through the filters at Waverly and had a significant effect on turbidity.

Standard Plate Count --

Treatment at Waverly includes prechlorination and therefore the standard plate count is not an effective means to detect the presence of a ripening period. As can be seen in Figure 36, the plate count data for the control and recently scraped filters were very similar until hour 47. After this time the plate count for the recently scraped filter became substantially greater than that of the control. Since the same raw water was pumped to both the just scraped and control filters, the high number of plate count organisms in the recently scraped filter effluent may have come from the sand within the filter bed.

Total Coliform Bacteria --

Out of the 52 samples tested for coliform bacteria, 10 samples were positive. Six of the ten positive samples were raw water samples and the total coliform concentrations ranged from one to three coliforms/100 mL. The remaining four positive samples were from the recently scraped filter effluent. In all four of these cases one coliform/100 mL of water was found. The positive samples were obtained at 1, 2, 80 and 106 hours after scraping.

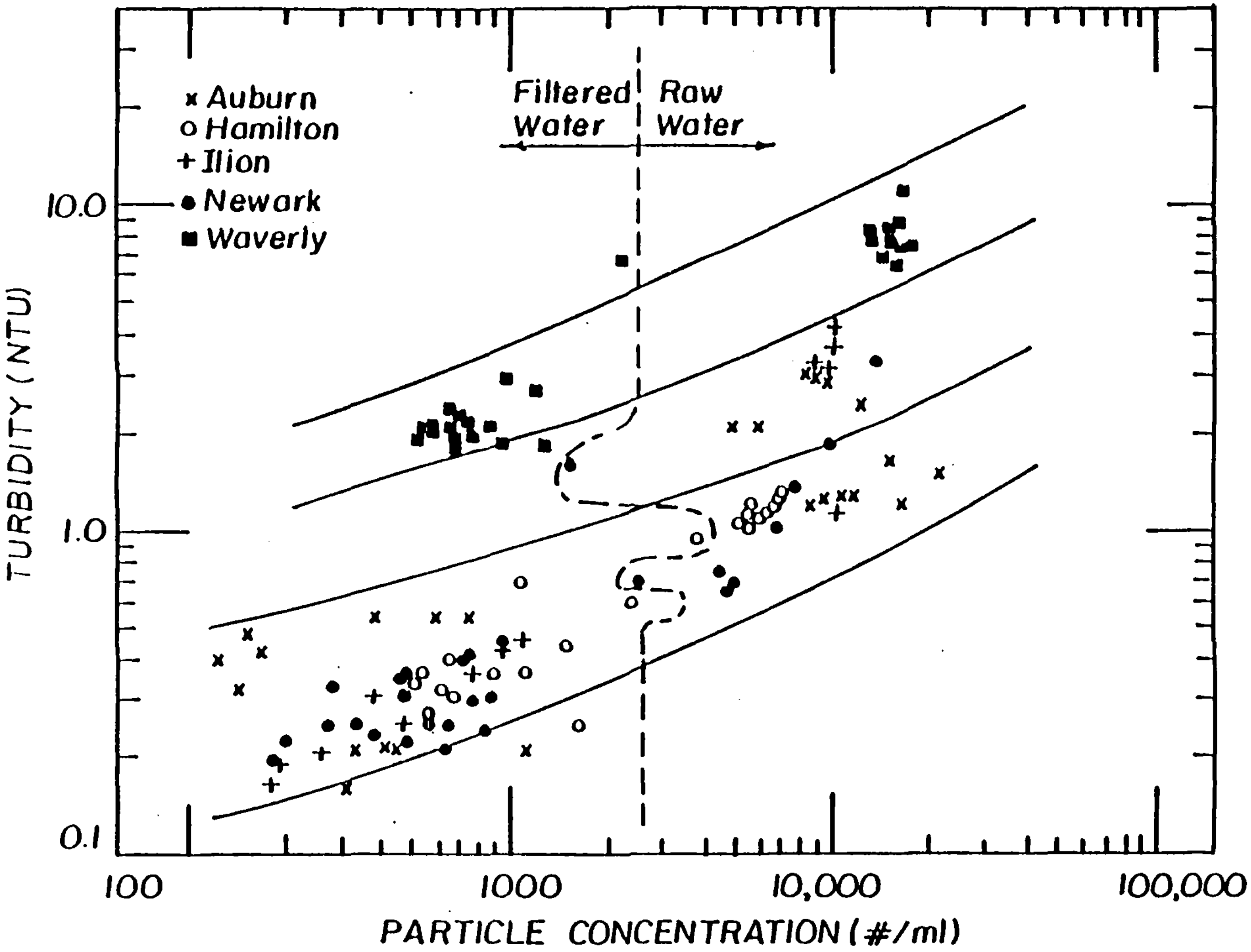

Figure 35. Turbidity versus HIAC Particle Count for all Sites Visited Except Geneva and Ogdensburg.

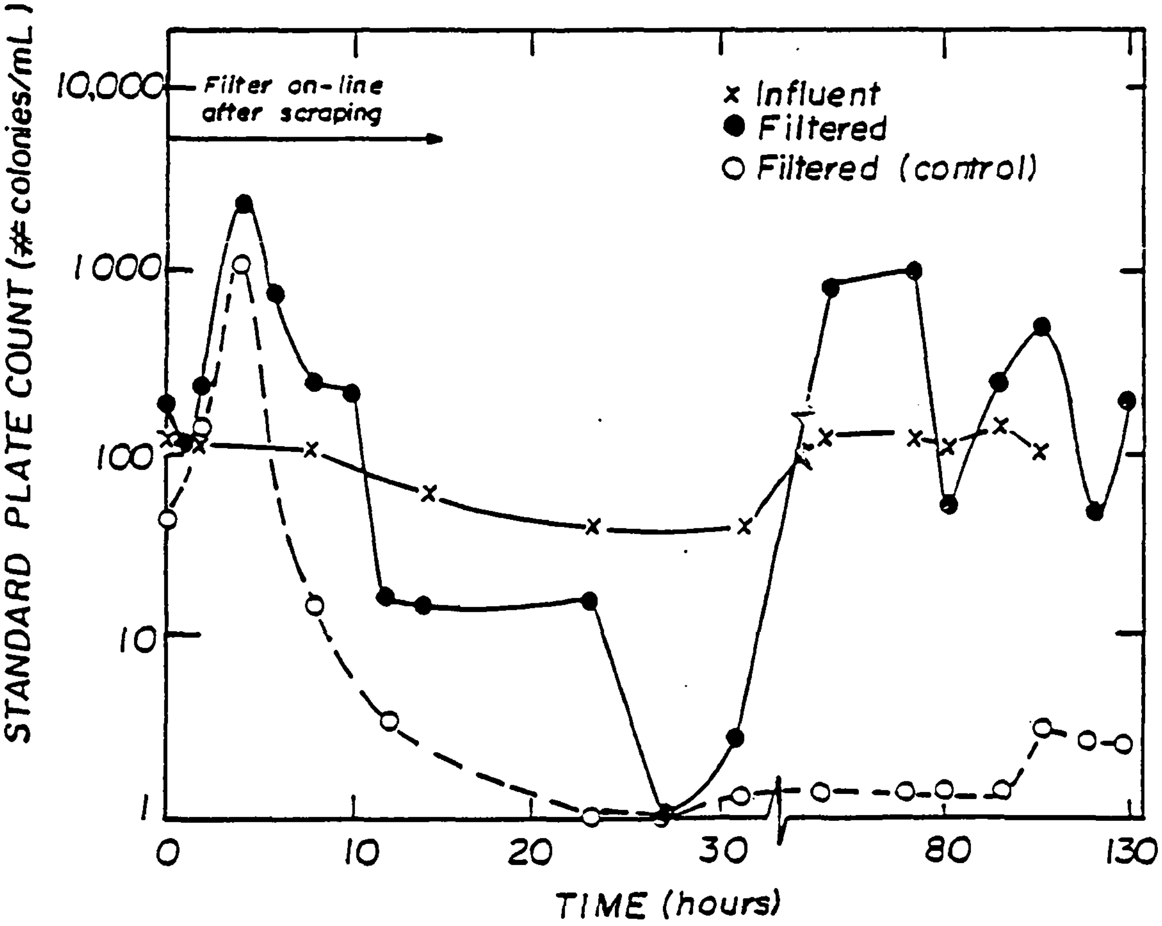

Figure 36. Standard Plate Count Bacteria Density versus Time at Waverly, June 1984, Filter #2.

SECTION 6

SUMMARY

The following tables summarize the principal results of this study. Table 5 lists characteristics of the sites visited including raw water source and average operating filtration rate. Table 6 gives the effective size, uniformity coefficient and percent weight loss in the dissolution test for the sand sample obtained at each of the sites. Tables 7 and 8 summarizes the results obtained in the analysis of the filter scraping data (manpower requirements, etc.) and Table 9 lists where and under what conditions ripening periods were observed.

According to Table 5 the average operating flowrate for the sites visited ranged from approximately 0.3 MGD at Hamilton to 6.0 MGD at Auburn. The average raw water turbidity for every site was less than 3.0 NTU, except at Waverly, where the average was approximately 8 NTU. All of the sites visited have covered filters except at Hamilton, and two filters at Ilion which are uncovered.

The average operating filtration rate is the average operating flowrate 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.

It is usually assumed that the efficiency of filtration in a slow sand filter is determined, at least in part, by the presence of viable microorganisms within the filter bed and, therefore, the use of a prechlorination step in these systems would be detrimental to filter performance. The effluent volume weighted average turbidity (for the control filter) was compared with the influent volume weighted average turbidity at each site and monitoring period where a control filter was sampled. The values were averaged for the entire length of each sampling period and used to calculate the percent turbidity remaining in the effluent. The average and standard deviation of the values of the percent turbidity remaining for the three cases in which prechlorination is used (4 sets of data) are 17% and 7.9%, respectively. For the three cases (6 sets of data) in which there is no prechlorination step, the average and standard deviation of the values of the

Table 5. Characteristics of the Slow Sand Filtration Plants Visited in the Study

Location	Slow Sand Filtration Average Operating Flowrate (MGD)	Raw Water Source	Average Raw Water Turbidity from plant records (NTU)	Total Slow Sand Filter Plan Area (ft^2)	Design Filtration Rate (m/hr)	Average Operating Filtration Rate (m/hr)	Pre-chlorination?	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 (1 not used
Newark	2.0	Canandaigua 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

percent turbidity remaining are 21% and 7.6%, respectively. Although other factors may have obscured the true significance of the addition of chlorine before slow sand filtration these results do not give a clear indication that prechlorination is detrimental to performance. In fact, in the plants sampled it may have a slightly positive effect on turbidity removal.

The effective size of the filter sand ranged from 0.15 mm at Waverly to 0.45 mm at Auburn (see Table 6). The average effective size for all sites was 0.33 mm. The uniformity coefficient had an average value of 2.1 and ranged from 1.7 at Newark and Ogdensburg to 2.4 at Auburn, Hamilton and Waverly. The 1982 Edition of Recommended Standards for Water Works (19) states in Section 4.2.4.6 that for slow rate gravity filtration the effective size should be between 0.30 and 0.45 mm and the uniformity coefficient should not exceed 2.5.

Standard B100-80 of the American Water Works Association (17) 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. According to Table 6 the only sites with filter sand which meets the AWWA Standard are Ilion and Ogdensburg. 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. It is, possible however, that converting to a more expensive, higher quality silica sand would have a significant economic impact on many of the utilities visited, especially those which do not wash and reuse their sand.

Table 7 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 7 for Auburn includes scraping (i.e., sand removal) and raking. Slezak, et al. (20) in a survey of slow sand filtration practice in the U. S. noted a mean filter cycle length of 44 days in spring, summer and fall and 60 days in winter.

The water production (3200 gal/ft^2) and scraping frequency (9.7/year) listed for Waverly in Table 7 are based on an estimate that in the future their average filter run length will be 900 hours. This average run length estimate is based on data obtained in a 9 month study in which Waverly personnel developed an operational strategy for effectively dealing with the high raw water turbidity and high iron and manganese concentrations which frequently occur in their reservoir supply. In the past Waverly operators experienced filter run lengths as short as two days. In the future when

Table 6. Sand Characteristics at the Slow Sand Filtration Plants Visited

Location	Effective Size (mm)	Uniformity Coefficient	% dissolved in 1:1 HCl
Auburn	0.45	2.4	35
Geneva	0.37	1.9	35
Hamilton	0.27	2.4	19
Ilion	0.37	2.2	5
* Newark	0.35	1.7	36
Ogdensburg	0.35	1.7	9.4
Waverly	0.15	2.4	17
Average:	0.33	2.1	21

* Results at Newark were obtained from plant personnel

Table 7. Filter Scraping Data - Summary

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 (inches)	Method(s) used in removing sand from Filter Surface	Man hours per 1000 square feet to scrape filters
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, hydraulic	4-5
Waverly	3,200 **	9.7 **	1.0	Shovels, wheelbarrows	5

* At Auburn, 2 scraping operations per year are actually occasions when the filters are raked and no sand is removed

** Water Production and scraping frequency which the Waverly personnel have estimated for the future using data from a 9 month operations study. Waverly has had runs as short as two days.

high turbidity (>12.5 NTU) and/or high total iron (>3.0 mg Fe/L) and manganese (>1.0 mg Mn/L) are present in the raw water the New York State Department of Health, Bureau of Public Water Supply, 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 7 summarize the methods used and manpower requirements for filter scraping at the sites visited. Most of the sites remove approximately one inch of sand from the filter surface using broad shovels. The one exception is Ilion where, for unexplained reasons, over three inches of sand is removed.

The depth of sand scraped has an effect on the man hours required for scraping per 1000 ft^2 of filter surface. In the cases where 0.5 to 1.0 inch was removed the labor requirement ranged from 2 to 9 man hours/1000 ft^2. At Ilion where 3-4 inches was removed the labor requirement was significantly greater, 23-42 man hours/1000 ft^2.

The method used to convey the dirty sand from the filter area also has an effect on the labor requirement. For example, the lowest labor requirement was at Newark (2 man hours/1000 ft^2) where an efficient motorized buggy was used to haul the dirty sand form the filter. The greatest labor requirement (for the plants which scrape between one-half and one inch of sand) was at Hamilton (8-9 man hours/1000 ft^2) where the dirty sand removal process involved filling 55 gallon drums and hauling them away with a tractor.

In general, under typical conditions, i.e., removal of about 1 inch 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 8 compares the estimated slow sand filter operational costs for the treatment plants visited. It was assumed that day-to-day activities devoted exclusively to the filters (collecting samples, checking the filters etc.) require one man-hour per day. The labor requirement for scraping is based on the scraping frequency listed in Table 7. Resanding was assumed to require, based on data from Auburn, 50 man-hours per 1000 ft^2.

The estimated operational unit costs range from 0.5¢/1000 gal at Auburn to 5.3¢/1000 gal at Hamilton. The mean value for all plants is 2.4¢/1000 gal. The exceptionally low value at Auburn is due, in part, to their use of low wage ($3/hr) summer help for most scraping and resanding operations.

Table 9 summarizes the results that pertain to the presence of a ripening period. A ripening period is an interval of time immediately after a scraped and/or resanded filter is put back on line in which the turbidity or particle count results for the scraped/resanded filter are significantly greater than the corresponding values for a control filter.

Table 8. Estimated Slow Sand Filter Operation and Maintenance Cost

Location	Average Operational Flow (MGD)	Labor for Scraping (manhours/ year)	Labor for Resanding (manhours/ year)	Day-to-Day Activities (manhours/ year)	Total Labor Costs ($/year)	Total Operation & 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

*Ogdensburg scrapes and resands simultaneously.

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

Table 9. Filter Ripening Data - Summary

Location	* Type of Operation During Visit	Date of Site Visit	Raw Water Turbidity During Site Visit (NTU)	Water Temperature during site visit	Filtrate Turbidity Approximately 5 Hours 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°C	0.43	0.27	YES	0.25
Auburn	(1)	July, 83	1.2-2.0	~ 19°C	0.28	0.27	NONE	--
Auburn	(1)	July 84	2.0-2.8	~ 18°C	0.22	0.23	NONE	--
Geneva	(1)	July 83	-	-	-	-	-	--
Hamilton	(1)	May 84	1.0-1.5	~ 12°C	0.28	NONE	NONE	--
Ilion	(1)	July 83	2.0-4.0	~ 23°C	0.30	0.40	minimal (particle count only)	0.5
Newark	(1)	Aug. 83	1.2-3.5	~ 13°C	0.35	0.35	NONE	--
Newark	(2)	Jan. 84	0.6-2.7	~ 4°C	0.41	0.12	YES	2
Ogdensburg	(3)	Aug. 83	0.3-0.6	~ 15°C	0.12	0.10	NONE	--
Ogdensburg	(3)	Feb. 84	1.0-1.2	~ 2°C	0.22	0.24	NONE	--
Waverly	(1)	June 84	6.0-11.0	~ 15°C	2.3	1.6	YES	10

* (1) Scraping operation

(2) Resanding operation

(3) Scraping combined with resanding

** Control Filter - filter on-line at least one month, except Ogdensburg where the filter was on line one week

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 hours 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 less than the 1.0 NTU, MCL.

The measurements made at Ilion are difficult to interpret with respect to indicating the presence of a ripening period. The scraped and control filters gave very similar turbidity results after scraping, but, approximately 6 hours after the scraped filter was brought back on line the particle count results for the scraped filter began to exceed the values of the control filter by a factor of about 2. The length of time required before this disparity essentially disappeared was about 12 hours.

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, however, a ripening period was clearly evident in both the turbidity and particle count results when resanding was the case. During the ripening period the filtrate turbidity of the scraped filter exceeded that of the control by a factor of about 3. However, the effluent turbidity of the control and scraped filters never exceeded 0.5 NTU. 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 two 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; the scraped and control filter particle count data appeared to coincide after about 30 hours while the turbidity values converged after about 10 days.

It is not known exactly why Waverly has problems. It appears that the raw water contains sub-micron particles which 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.

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APPENDIX

ANALYTICAL RESULTS

DATA SHEET

LOCATION: Auburn - Filter #1

DATE: 7/19/83; 7/20/83; 7/22/83

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100 mL)	HIAC Particle Count(#/mL)
Location*	Time					
	7/19					
E	11 am	19	0.55	1	<1	588
I	11 am	20.5	1.20	1	<1	8364
E	12 am	19.5	0.52	88		376
EC	12 am	19	0.24	0		178
I	12 am	18	1.40	137		9102
E	1 pm	19	0.52	2	<1	723
EC	1 pm	19	0.25	1	<1	200
I	1 pm	18	1.30	800	<1	11468
E	2 pm	19.5	0.43	1		
EC	2 pm	19	0.25	1		
I	2 pm	17	1.30	57		
E	3 pm	19.5	0.48	9	<1	152
EC	3 pm	19	0.32	1		
I	3 pm	17	1.30	8	<1	10918
E	4 pm	19	0.43	8		
EC	4 pm	18.5	0.27	1		
I	4 pm	18	1.30	37		
E	5 pm	19	0.32	5	<1	
EC	5 pm	18.5	0.38	0		
I	5 pm	18	1.30	130	<1	
E	7 pm		0.25	5		
I	7 pm		1.30	37		
E	9 pm		0.33	4	<1	147
EC	9 pm		0.38	4	<1	154
* I	9 pm		1.20	42	<1	16803

I = influent
E = scraped filter effluent
EC = control filter effluent

Note: On all tables in this appendix a blank space indicates that the test was not conducted on that sample.

DATA SHEET

LOCATION: Auburn - Filter #1

DATE: 7/19/83; 7/20/83; 7/22/83

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
	7/19					
E	11 pm		0.43	4		
I	11 pm		1.20	28		
	7/20					
E	1 am		0.43	3	<1	170
EC	1 am		0.35	4	<1	109
I	1 am		1.70	32	<1	14979
E	4 am		0.40	10	<1	123
EC	4 am		0.32	3	<1	57
I	4 am		1.50	500	<1	22322
E	8 am	19.5	0.34	770	<1	
EC	8 am	18.5	0.35	54		
I	8 am	21	2.00	1500	<1	
E	Noon	19.5	0.29	170	<1	
EC	Noon	18.5	0.44	64	<1	
I	Noon	19.0	1.60	71	<1	
E	4 pm	19.5	0.55	21	<1	
EC	4 pm	19	0.40	1		
I	4 pm	17.5	1.70	53	<1	
	7/22					
E	10 am	19	0.38	5	15	
I	10 am	19	1.00	9	1000	
E	2 pm	18.5	0.27	3	13	
I	2 pm		1.20	57	300	
E	2 pm		0.22	3		
* I	2 pm		1.00	21		

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Auburn - Filter #3			DATE: 7/18/83 - 7/22/83			
Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
Pre-Scraping						
	7/18					
E	11 am	18.5	0.40	0	<1	
I	11 am	21	1.30	1	<1	
E	1 pm	18.5	0.32	1	<1	
I	1 pm	20.5	1.40	0	<1	
E	2 pm	18.5	0.30	0		
I	2 pm	21	1.50	18		
E	8 pm		0.22	1	<1	
I	8 pm		1.60	41	<1	
E	11 pm		0.20	0	<1	
I	11 pm		1.30	5	<1	
**Post-Scraping						
	7/22					
E	10 am	19	0.39	11	10	
EC	10 am	19	0.38	5	15	
I	10 am	19	1.00	9	1000	
E	11 am	18	0.31	4		
I	11 am	19	0.90	2		
E	12 pm	18	0.45	2	6	
I	12 pm	19	0.90	2	1500	

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Auburn - Filter #3

DATE: 7/22/83

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
E	1 pm	17.5	0.32	14		
I	1 pm	18.5	0.80	31		
E	2 pm	17.5	0.28	1	1	
EC	2 pm	18.5	0.27	3	13	
I	2 pm	18.5	1.20	57	300	
E	4 pm	17.5	0.30	4		
EC	4 pm	18.5	0.22	3		
I	4 pm	18.5	1.00	21		

*

I = influent

E = scraped filter effluent

EC = control filter effluent

**(Filter 3 put back in service at 9 am, 7/22/83)

DATA SHEET

LOCATION: Auburn - Filter #1

DATE: 7/13/84

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count(#/mL)
Location*	Time					
	7/13					
E (rapid)	10 am	17	2.40	2	<1	12,233
EC(rapid)	10 am	17	0.44	1	<1	272
E (slow)	9 am	18	0.21	10	<1	1142
EC(slow)	9 am	18	0.16	2	<1	407
I	9 am	18	2.85	10	<1	9733
E (rapid)	9 am	17	0.87	1	<1	986
E (slow)	11 am	18	0.22	43	<1	429
EC(slow)	11 am	18	0.23	28	<1	382
E (rapid)	1 pm	17	1.30	15	<1	2060
EC(rapid)	1 pm	17	1.19	7	<1	
E (slow)	1 pm	18	0.21	47	<1	401
E (rapid)	3 pm	18	1.80	3	<1	3714
EC(rapid)	3 pm	18	1.60	3	<1	2640
E (rapid)	5 pm	19	1.92	3	<1	4508
EC(rapid)	5 pm	19	1.70	4	<1	3412
E (slow)	5 pm	18	0.22	3	<1	407
EC(slow)	5 pm	18	0.23	4	<1	420
I	5 pm	19	2.75	5	<1	7650

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Auburn - Filter #1

DATE: 7/14/84

Sample		Water Temp.	Turbidity	Std. Plate Count	Coliform Bacteria	HIAC Particle Count(#/mL)
Location*	Time	(°C)	(NTU)	(colonies/mL)	(#/100mL)	
	7/14					
E (rapid)	7 am		2.00	1	<1	7040
EC(rapid)	7 am		1.81	1	<1	6627
E (slow)	7 am		0.16	1	<1	300
EC(slow)	7 am		0.16	210	<1	141
I	7 am		2.05	14	<1	4728
E (rapid)	1 pm		1.30	1	<1	1689
EC(rapid)	1 pm		1.23	1	<1	1454
E (slow)	1 pm		0.22	2	<1	330
EC(slow)	1 pm		0.24	310	<1	142
I	1 pm		2.10	14	<1	5636

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Hamilton				DATE: 4/16/84 - 5/7/84		
Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
Pre-Scraping	4/16					
	1 pm	8	0.50	14	<1	3162
	1 pm	8	1.02	500	<1	5484
Post-Scraping	5/7					
E	11 am	13	0.37	1000	<1	1096
I	11 am	13	1.25	67	<1	5592
E	Noon	13	0.70	280	<1	1107
E	1 pm	13	0.25	210	<1	1593
I	1 pm	13	1.00	98	2	5293
E	2 pm	12.5	0.40	370	<1	664
E	3 pm	13	0.30	280	<1	678
I	3 pm	14	1.05	82	<1	5024
E	4 pm	13	0.28	220	<1	546

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Hamilton

DATE: 5/8/84 - 5/9/84 - 5/15/84

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
	5/8					
E	9:30a	12.5	0.31	430	<1	613
I	9:30a	12.5	1.20	57	<1	5714
E	11:30a	12.5	0.37	250	<1	526
I	11:30a	12.5	1.20	200	<1	5906
E	4 pm		0.34	230	<1	506
I	4 pm		1.30	100	<1	5982
	5/9					
E	11 am	12	0.95	26	<1	3852
I	11 am	12	1.30	9	<1	6666
E	11:15a	12	0.65			2998
	5/15					
E	9 am		0.43	7	<1	1475
I	9 am		1.37	230	35	6899
E	Noon		0.36	170	45	880
I	Noon		1.30	200	10	6317

* I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Ilion				DATE: 7/28/83, 8/4/84, 8/5/83		
Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Pre-Scraping	7/23					
E	9 am		0.35	0	<1	
I	9 am		2.30	0	<1	
E	10 am		0.30	1	<1	
I	10 am		2.30	7		
E	11 am		0.25	2	<1	
I	11 am		2.70	5	<1	
Post-Scraping	8/4					
E	2 pm		0.45	0	<1	1060
EC	2 pm		0.40	0	<1	1327
I	2 pm		3.8	3	<1	10,139
E	3 pm		0.55	0		
E	4 pm		0.40	174	<1	942
EC	4 pm		0.60	0	<1	1191
I	4 pm		4.00	0		10,158
E	5 pm	22.5	0.35	178		
E	6 pm	22.5	0.30	51	<1	370
EC	6 pm	22.5	0.40	3	<1	347
I	6 pm	22.5	3.50	0	<1	
E	8 pm		0.35	26	<1	789
EC	8 pm		0.30	1	<1	318
I	8 pm		3.30	0	<1	8678
*						

I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Ilion				DATE: 8/4/83, 8/5/83		
Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
	8/4					
E	9 pm		0.25	69		
E	10 pm	22.5	0.30	42	<1	
EC	10 pm	22.5	0.23	5	<1	
I	10 pm	22.5	3.50	26	<1	
E	Mid.		0.22	7		259
EC	Mid.		0.31	1		165
I	Mid.		3.15	1		9447
	8/5					
E	4 am		0.18	11	<1	194
EC	4 am		0.22	1	<1	79
I	4 am		2.90	4	<1	9423
E	8 am	22.5	0.16	17	<1	235
EC	8 am	22.5	0.26	6		180
I	8 am	22.5	2.95	5		8474
E	10 am		0.21	4	<1	
EC	10 am		0.21	10	<1	
I	10 am		3.15	2	<1	
Iv (before Cl_2)			1.20	27	<1	
E	2 pm		0.25	9	<1	459
EC	2 pm		0.25	3	<1	222
I	2 pm		3.10	4	<1	10,306
I (before Cl_2)			1.10	700	<1	

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Newark

DATE: 1/11/84, 1/12/84, 1/13/84

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
	1/11					
E	12:30p	4.5	0.19	690	<1	181
EC	12:30p	4.5	0.15	38	<1	259
I	12:30p	4.5	2.70	320	<1	
E	1:30p	4.5	0.34	6	<1	335
EC	1:30p	4.5	0.14	4	<1	
I	1:30p	4.5	0.67	8	<1	
E	2:30p	4.5	0.34	200		
EC	2:30p	4.5	0.14	14		
E	3:30p	4.5	0.31	2	<1	561
EC	3:30p	4.5	0.14	4	<1	146
I	3:30p	4.5	0.69	12	<1	2479
E	4:30p	4.0	0.45	2		
EC	4:30p	4.5	0.11	5		
E	5:30p	4	0.41	2	<1	738
EC	5:30p	4	0.12	11	<1	145
I	5:30p	4	1.18	20	<1	
E	6:30p	4	0.41	42		
EC	6:30p	4	0.11	8		
E	8:30p	4	0.38	6	<1	711
EC	8:30p	4	0.12	7	<1	197
I	8:30p	4	1.03	32	<1	
E	10:30p	4	0.36	2		1140
EC	10:30p	4	0.11	18		

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Newark

DATE: 1/11/84, 1/12/84, 1/13/84

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
	1/12					
E	12:30a	4	0.32	2	<1	886
EC	12:30a	4	0.12	3	<1	547
I	12:30a	4	0.64	7	<1	4542
E	4:30a	4	0.30	3	<1	744
EC	4:30a	4	0.14	12	<1	112
I	4:30a	4	0.65	16	<1	
E	8:30a	4	0.26	2	<1	623
EC	8:30a	4	0.13	3	<1	480
I	8:30a	4	0.72	11	<1	4365
E	12:30p	4	0.25	1	<1	564
EC	12:30p	4	0.11	84	<1	738
I	12:30p	4	0.84	1600	<1	
E	4:30p	4	0.24	2	<1	820
EC	4:30p	4	0.14	4	<1	213
I	4:30p	4	0.68	22	<1	4874
E	8:30p		0.24	4	<1	375
EC	8:30p		0.12	5	<1	
I	8:30p		0.70	15	<1	
	1/13					
E	12:30a		0.23	0	<1	484
EC	12:30a		0.11	10	<1	533
I	12:30a		0.99	6	<1	6574

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Newark

DATE: 8/22/83, 8/24/83, 8/25/83, 8/26/83

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Pre-Scraping	8/22					
E	8 am		0.40	1	<1	
I	8 am		1.80	6	<1	
E	12:30a		0.50	5	<1	
I	12:30a		3.00	1	<1	
Post-Scraping	8/24					
E	3 pm		0.35	3	<1	
EC	3 pm		0.30	8	<1	
I	3 pm		3.00	4	<1	
E	4 pm		0.35	16		
EC	4 pm		0.35	4		
E	5 pm		0.45	27	<1	982
EC	5 pm		0.75	11	<1	1093
I	5 pm		3.20	45	<1	13685
E	6 pm		0.40	25		
EC	6 pm		0.35	5		
E	7 pm		0.35	9	<1	483
EC	7 pm		0.35	8	<1	280
I	7 pm		3.00	17	<1	
E	8 pm		0.35	2		
EC	8 pm		0.35	7		

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Newark

DATE: 1/11/84, 1/12/84, 1/13/84

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
	1/13					
E	8:30a	4	0.20	1	<1	
EC	8:30a	4	0.12	7	<1	
I	8:30a	4	0.61	12	<1	
E	12:30p	4	0.26	0	<1	270
EC	12:30p	4	0.13	5	<1	317
I	12:30p	4	1.30	19	<1	7680

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Newark

DATE: 8/22/83, 8/24/83, 8/25/83, 8/26/83

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
	8/24					
E	9 pm		0.35	2	<1	
EC	9 pm		0.35	8	<1	
I	9 pm		1.30	2		
E	10 pm		0.23	12		
EC	10 pm		0.30	7		
E	11 pm		0.30	7	<1	
EC	11 pm		0.25	3	<1	
I	11 pm		3.20	7	<1	
	8/25					
E	1 am		0.23	3		199
EC	1 am		0.30	5		149
E	3 am		0.25	2	<1	329
EC	3 am		0.24	5	<1	562
I	3 am		1.60	7	<1	1495
E	5 am		0.20	7		
EC	5 am		0.18	5		
E	7 am		0.24	27	<1	622
EC	7 am		0.22	11	<1	299
I	7 am		1.80	310	<1	9596
E	11 am		0.25	380	<1	
EC	11 am		0.22	25	<1	
I	11 am		2.50	10	<1	

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Newark				DATE: 8/22/83, 8/24/83, 8/25/83, 8/26/83		
Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
	8/25					
E	3 pm		0.25	12	<1	
EC	3 pm		0.20	27	<1	
I	3 pm		2.10	7	<1	
E	7 pm		0.30	2	<1	
EC	7 pm		0.30	4	<1	
I	7 pm		2.30	3	<1	
E	11 pm		0.40	5	<1	
EC	11 pm		0.30	85	<1	
I	11 pm		3.30	7	<1	
	8/26					
E	7 am		0.45	12	<1	
EC	7 am		0.30	5	<1	
I	7 am		2.80	15	<1	
E	11 am	13	0.30	6	<1	
EC	11 am	13	0.20	4	<1	
I	11 am	11	2.70	15	<1	
E	3 pm		0.25	12	<1	
EC	3 pm		0.30	18	<1	
I	3 pm		2.70	13	<1	

*
I = influent
E = scraped filter effluent
EC = control filter effluent

LOCATION: Ogdensburg - Filter #4

DATE: 8/18/83; 8/20/83; 8/21/83; 8/22/83

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Pre-Scraping	8/18					
E	1 pm		0.15	190	<1	
I	1 pm		0.55	5800	<1	
E	2 pm		0.30	260		
I	2 pm		0.60			
E	3 pm		0.15	260	<1	
I	3 pm		0.45	560	<1	
Post-Scraping	8/20					
E	8:30a		0.18	250	<1	
EC	8:30a		0.10	160	<1	
I	8:30a		0.50	300	<1	
E	9:30a		0.15	240		
EC	9:30a		0.10	150		
E	10:30a		0.15	170	7	
EC	10:30a		0.12	110	<1	
I	10:30a		0.50	140		
E	11:30a		0.15	100		
E	12:30p		0.12	190	<1	
EC	12:30p		0.10	54	<1	
I	12:30p		0.50	41	<1	
E	1:30p		0.20	230		

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Ogdensburg - Filter #4			DATE: 8/18/83; 8/20/83; 8/21/83; 8/22/83			
Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count(#/mL)
Location*	Time					
	8/20					
E	2:30p		0.18	180	<1	
EC	2:30p		0.10	89	<1	
E	3:30p		0.18	180		
E	4:30p		0.10	55	1	
EC	4:30p		0.10	100	<1	
I	4:30p		0.50	70	<1	
I(C_2)	4:30p		0.15	220		
E	6:30p		0.20	270		
E	8:30p		0.20	79	<1	
EC	8:30p		0.15	86	<1	
I	8:30p		0.55	66	<1	
I(C_2)	8:30p		0.20	300		
E	11:30p			200		
	8/21					
E	12:30a		0.20	200	9	
EC	12:30a		0.20	110	<1	
I	12:30a		0.60	52	<1	
I(C_2)	12:30a		0.18	56		
E	4:30a		0.20	120	6	
EC	4:30a		0.15	220		
I	4:30a		0.60			
I(C_2)	4:30a		0.25	340		

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Ogdensburg - Filter #4

DATE: 8/18/83; 8/20/83; 8/21/83; 8/22/83

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count(#/mL)
Location*	Time					
	8/21					
E	8:30a		0.10	67	2	
EC	8:30a		0.10	73	<1	
I	8:30a		0.55	78	5	
I(C_2)	8:30a		0.10	12		
E	12:30p		0.10	110	6	
EC	12:30p		0.10	110		
I	12:30p		0.40	11		
I(C_2)	12:30p		0.10	48		
E	4:30p		0.10	210	<1	
EC	4:30p		0.10	140	<1	
I	4:30p		0.40	57		
I(C_2)	4:30p		0.10	190		
E	8:30p		0.10		3	
EC	8:30p		0.20			
I	8:30p		0.50		<1	
	8/22					
E	12:30a		0.10		2	
EC	12:30a		0.08		<1	
E	8:30a		0.12		<1	
EC	8:30a		0.10		<1	
I	8:30a		0.60		<1	

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Ogdensburg - Filter #3				DATE: 2/23/84, 2/25/84, 2/26/84		
Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
Pre-Scraping	2/23					
E	11 am		0.20	4	<1	
I	11 am		1.06	54	<1	
E	4 pm		0.19	9	<1	
I	4 pm		1.14	28	<1	
Post-Scraping	2/25					
E	8 am	1.5	0.18	5	<1	
EC	8 am	1.5	0.18		<1	
I	8 am	1.5	1.15	8	<1	
E	9 am	1.5	0.22	22	<1	
EC	9 am	1.5	0.21	5	<1	
I	9 am	1.5	1.11	6	<1	
E	10 am	1.5	0.19	7	<1	
EC	10 am	1.5	0.18	6	<1	
I	10 am	1.5	1.12	51	<1	
E	11 am	1.5	0.18	7	<1	
E	Noon	1.5	0.19	5	<1	
EC	Noon	1.5	0.22	4	<1	
I	Noon	1.5	1.15	30	<1	
E	2 pm		0.22	25		
EC	2 pm		0.24	8		

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Ogdensburg - Filter #3

DATE: 2/23/84, 2/25/84, 2/26/84

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
	2/25					
E	4 pm	1.5	0.17	4	<1	
EC	4 pm	1.5	0.19	8	<1	
I	4 pm	1.5	1.23	65	<1	
E	Mid.		0.20			
EC	Mid.		0.20			
I	Mid.		1.30			
	2/26					
E	8 am		0.28			
EC	8 am		0.26			
I	8 am		1.20			

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Waverly

DATE: 6/18/84, 6/20/84, 6/21/84 6/22/84, 6/23/84, 6/24/84, 6/25/84

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
Pre-Scraping	6/18					
E	8 am		2.50	550		
E	4 pm		2.50	600		
Post-Scraping	6/20					
E	9 am	14.5	6.70	370	<1	2312
C	9 am	14.5	1.55	67	<1	337
I	9 am	14.5	8.00	190	1	13126
E	10 am	14.5	2.87	150	1	960
E	11 am	14.5	2.69	450	1	1161
EC	11 am	14.5	1.53	240	<1	
I	11 am	14.5	8.52	150	<1	
I (with Cl_2)	11 am	14.5	10.8	0	2	16800
E	1 pm	14.5	2.34	3900	<1	649
EC	1 pm	14.5	1.52	1200	<1	190
E	3 pm	14.5	2.32	880	<1	
E	5 pm	14.5	2.17	440	<1	590
EC	5 pm	14.5	1.50	22	<1	267
I	5 pm	14.5	7.84	110	<1	13703
I (with Cl_2)	5 pm	14.5	9.20	0	<1	16436
E	7 pm	14.5	2.10	410	<1	567

*
I = influent
E = scraped filter effluent
EC = control filter effluent

DATA SHEET

LOCATION: Waverly

DATE: 6/18/84, 6/20/84, 6/21/84
6/22/84, 6/23/84, 6/25/84

Sample Location*	Sample Time	Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
	6/20					
E	9 pm	14.5	2.13	27	<1	567
EC	9 pm	14.5	1.51	6	<1	252
E	11 pm	14.5	2.09	21	<1	731
I	11 pm	14.5	8.21	81	<1	14820
	6/21					
E	8 am	14.0	2.02	27	<1	885
EC	8 am	14.0	1.55	1	<1	428
I	8 am	14.0	8.10	63	<1	15046
I (with Cl_2)	8 am	14.0	8.35	5	<1	15459
E	Noon	14.5	2.02	1	<1	543
EC	Noon	14.5	1.56	1	<1	502
I	Noon	14.5	8.65		<1	
E	4 pm	14.5	1.87	5	<1	413
EC	4 pm	14.5	1.47	2	<1	297
I	4 pm	14.5	8.10	63	<1	15603
I (with Cl_2)	4 pm	14.5	8.40	10	<1	15078
	6/22					
E	8 am		1.82	850	<1	1342
EC	8 am		1.49	2	<1	1181
I	8 am		6.30	190	1	15078
	6/23					
E	7 am		1.82	1000	<1	962
EC	7 am		1.47	2	<1	1078
I	7 am		6.97	170	1	14743

*

I = influent

E = scraped filter effluent

EC = control filter effluent

DATA SHEET

LOCATION: Waverly

DATE: 6/18/84, 6/20/84, 6/21/84, 6/22/84, 6/23/84, 6/24/84, 6/25/84

Sample		Water Temp. (°C)	Turbidity (NTU)	Std. Plate Count (colonies/mL)	Coliform Bacteria (#/100mL)	HIAC Particle Count (#/mL)
Location*	Time					
	6/23					
E	5 pm		1.87	77	1	565
EC	5 pm		1.47	2	<1	426
I	5 pm		7.35	140	<1	15912
	6/24					
E	8 am		1.92	340	<1	570
EC	8 am		1.48	2	<1	500
I	8 am		6.90	220	3	14811
E	7 pm		1.93	660	1	750
EC	7 pm		1.47	6	<1	488
I	7 pm		2.25	100	2	16345
	6/25					
E	8 am		2.08	65	<1	534
EC	8 am		1.62	5	<1	514
I	8 am		7.15		<1	16647
E	4 pm		2.08	300	<1	571
EC	4 pm		1.56	5	<1	458
I	4 pm		7.40		1	16557

*

I = influent

E = scraped filter effluent

EC = control filter effluent

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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16. ABSTRACT
A study was conducted to determine how slow sand filter effluent quality is affected by scraping 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 six full-size slow sand filtration plants in Central New York. The time required for filtrate quality to improve after filter scraping varied from 6 hr to 2 weeks at the slow sand filtration plants visited. In four of ten maintenance operations some quality deterioration occurred. The nature of the particulate matter in 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 needed to determine if filter maintenance operations 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. 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 per 1000 ft^2 of filter plan area. The resanding operation in which 6 to 12 in. of sand is applied to a bed that has been depleted of sand by repeated scraping operations, requires approximately 50 man-hours per 1000 ft^2. No clear relationship was observed between the frequency of scraping and the raw water quality or maintenance procedures.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 123
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