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Environmental Protection Technology Series

HANOVER PARK TERTIARY STUDIES

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The development of practical tertiary treatment methods which allow municipal wastewater treatment facilities to produce low levels of contaminant concentration compatible with receiving stream quality maintenance is an integral part of the above efforts.

Francis T. Mayo
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ABSTRACT

During a 1-year study, four tertiary treatment units were tested and evaluated. Three of the units were deep-bed filters which were used to treat secondary plant effluent. The types of filters used were: (1) an upflow filter with a sand media, (2) a downflow gravity filter with mixed-media consisting of anthracite, sand, and garnet, and (3) a downflow pressure filter utilizing dual-media of anthracite and sand. The fourth unit was a continuous flow ion exchanger that employed activated alumina to remove phosphate from microscreened secondary effluent.

The filtration studies indicate that comparable effluents were produced by all three filters with filtration rates from 2 to 6 gpm/ft^2. Filter effluents generally contained about 4 to 7 mg/l suspended solids in the above flow range.

The results of the ion exchange study indicated that sodium hydroxide successfully regenerated an exhausted activated alumina bed. In a 9-hour test, the ion exchange column removed 73% of the influent phosphorus, using 0.4N sodium hydroxide as the regenerant.

This report is submitted in fulfillment of FWPCA Project Number 11010EZJ under the partial sponsorship of the Environmental Protection Agency, Office of Research and Development.

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SECTION I
INTRODUCTION

The Metropolitan Sanitary District of Greater Chicago (MSDGC) has long realized that secondary treatment of domestic sewage, industrial wastewater and storm water was insufficient to satisfy rising aesthetic values and increasingly stringent water quality standards. In 1965, work began on the design of the Hanover Water Reclamation Plant, and by 1969 the 2 mgd * plant was in operation as the MSDGC's first tertiary treatment plant.

Originally, the Hanover Plant was a series of oxidation ponds that are still used during periods of excessive sewage flow. The sewage to the plant is primarily domestic sewage from a separate sewer system. However, during storms, the flow does increase significantly, possibly because of increased sewer infiltration and rain water connections from sump pumps and gutters. A schematic diagram of the plant facilities is shown in Figure 1. The plant has conventional primary settling and activated sludge facilities. The tertiary portion of the Hanover Plant consists of two coagulation-sedimentation tanks, two rapid sand filters, a microstrainer, a chlorination tank, and a post-aeration tank. These facilities have enabled the MSDGC to gain experience and knowledge of many tertiary treatment methods on a plant scale. The Hanover Plant also provides the capability to study advanced wastewater treatment on a pilot scale, with a study of ozonation of tertiary effluent having been completed. The experimental work of this project was performed entirely at the Hanover Plant.

At the time this work was performed the water pollution regulations of Illinois would have required the effluents from the three major MSDGC treatment plants to contain no more than 5 mg/l suspended solids and 4 mg/l five-day biochemical oxygen demand (BOD) by 1977. In 1974, however, it was determined that the MSDGC could be classified as an exemption to the 5 mg/l suspended solids and 4 mg/l BOD effluent criteria if an in-stream aeration system were provided to maintain adequate dissolved oxygen levels in the waterways receiving effluents from the major MSDGC treatment plants. If this plan were adopted the effluent criteria for the major MSDGC treatment plants would be 12 mg/l suspended solids and 10 mg/l BOD.

* Metric conversions are given in Appendix

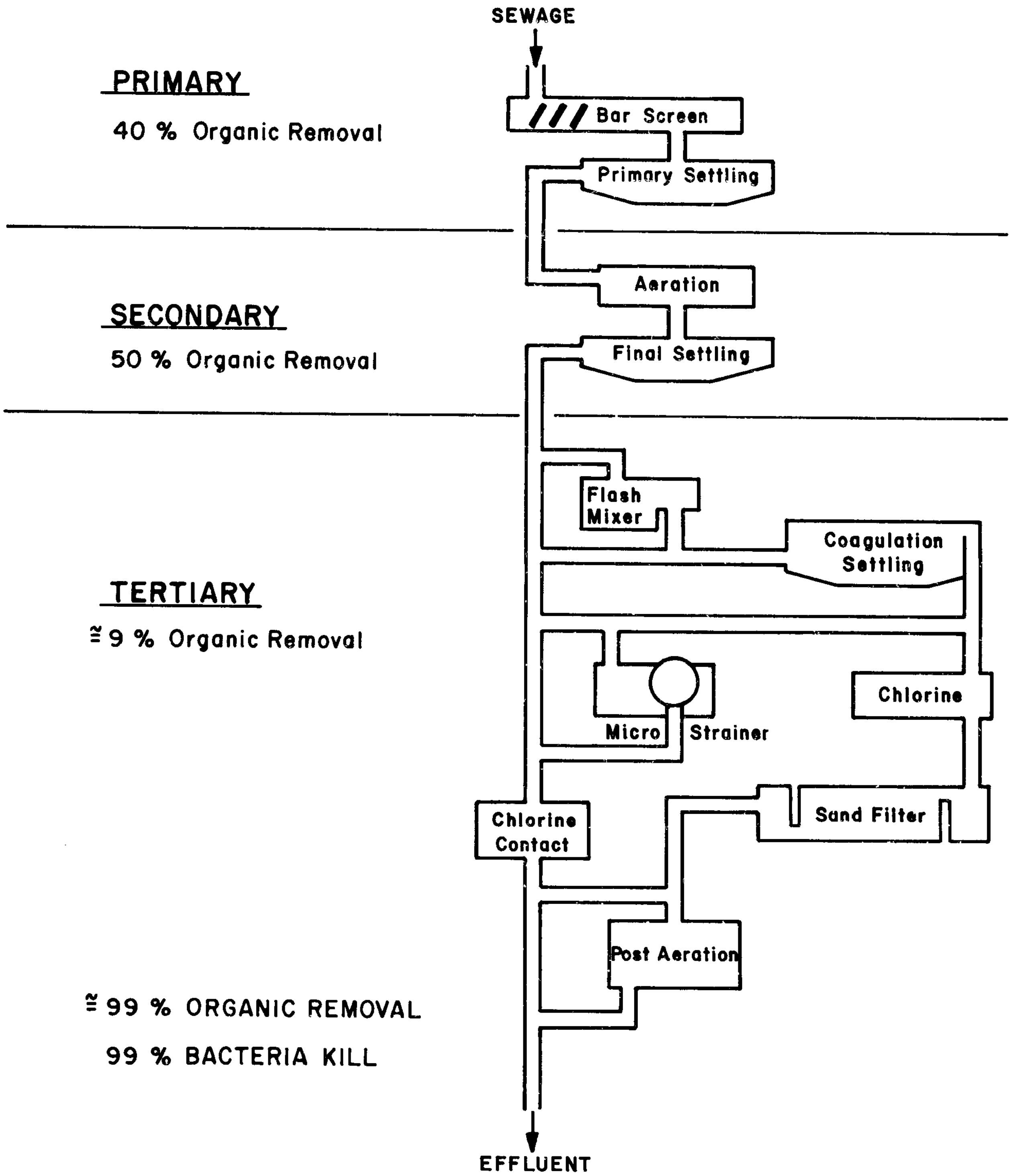

Figure 1. Schematic diagram of the treatment processes at the Hanover Water Reclamation Plant.

Since the MSDGC plants currently treat approximately 1,400 mgd, adequate treatment at these flows is a formidable undertaking that requires careful design considerations. Therefore, many forms of advanced waste treatment have been tested and evaluated in order to determine the most feasible and economical method.

The Hanover Park Experimental Bay Project was designed to test three types of deep-bed, high-rate filters and a continuous ion exchange unit. The three filtration units were a DeLaval upflow filter, a Neptune Microfloc mixed-media filter, and a Graver dual-media pressure filter. The continuous ion exchange unit was manufactured by Chemical Separations Corporation. All four units were placed in operation under direct supervision of the manufacturers, and no unauthorized modifications were made during the 1-year testing period.

The objective of this project was to investigate and optimize the performance of each unit. The filtration devices treated secondary effluent to remove suspended solids and associated biochemical oxygen demand. In addition, chemical coagulation and sedimentation before filtration was investigated with the Neptune Microfloc unit. The ion exchange unit was utilized to remove phosphorus from microscreened secondary effluent.

SECTION II
CONCLUSIONS

1. All the filtration units tested were able to consistently reduce the suspended solids and BOD of a secondary effluent to less than 10 mg/l at a flow rate of 4 gpm/ft^2.

2. At a flow rate of 4 gpm/ft^2, the DeLaval filter improved a secondary effluent of 15 mg/l suspended solids and 24 mg/l BOD to 5 mg/l suspended solids and 6 mg/l BOD (Test 2). Removals of suspended solids and BOD were 67% and 73%, respectively. Filter runs averaged 25.5 hours, and backwash usage was 1.4% of filter throughput.

3. At a flow rate of 4 gpm/ft^2, the Neptune filter improved a secondary effluent of 16 mg/l suspended solids and 25 mg/l BOD to 4 mg/l suspended solids and 4 mg/l BOD. Removals of suspended solids and BOD were 73% and 85%, respectively. Filter runs averaged 27.2 hours, and backwash usage was 2.5% of filter throughput.

4. At a flow rate of 4 gpm/ft^2, the Graver filter improved a secondary effluent of 15 mg/l suspended solids and 25 mg/l BOD to 5 mg/l suspended solids and 7 mg/l BOD (Test 2). Removals of suspended solids and BOD were 69% and 70%, respectively. Filter runs averaged 51.1 hours and backwash usage was 0.6% of filter throughput.

5. Based on the above results, which demonstrate representative filter performance during identical operating periods, the Neptune filter produced a slightly better effluent than the Graver and DeLaval filters.

6. Also based on the same results, the Graver filter achieved the longest filter runs, approximately twice the length of the filter runs of the DeLaval and Neptune filters.

7. At a flow rate of 10 gpm/ft^2, the Graver filter improved a secondary effluent of 18 mg/l suspended solids and 11 mg/l BOD to 8 mg/l suspended solids and 4 mg/l BOD. Removals of suspended solids and BOD were 56% and 64%, respectively. Filter runs averaged 12 hours and backwash usage was 1.1% of filter throughput.

8. Chemical pretreatment in the Neptune unit to increase suspended solids removal was generally unsuccessful.

9. Activated alumina removed up to 87% of the total phosphorus from a microscreened secondary effluent in a continuous flow ion exchanger. Sodium hydroxide concentrations of 0.4N were necessary for effective regeneration of the alumina.

SECTION III
RECOMMENDATIONS

This program was limited to filtration of Hanover Park secondary effluent. Effluent criteria require filtration of other treatment plant effluents within the jurisdiction of the Metropolitan Sanitary District of Greater Chicago. This work should be expanded to include filtration testing at these other plants in order to design filtration facilities that will meet effluent criteria.

Filters other than those tested should be tested if it is possible that they will produce comparable or better quality effluents. Further investigation of the process of phosphorus removal by activated alumina should be made to determine if this process is a practical method of removing phosphorus from a sewage treatment plant effluent.

SECTION IV
MATERIALS AND METHODS

Experimental Apparatus

The DeLaval Filter--

The filter used was manufactured by the DeLaval Separator Company and was an "Upflow Immedium-filter, Model OT-3." The filter vessel was approximately 3 feet in diameter and 13 feet deep. The filtering media was silica sand and gravel, with the filter bed being approximately 7 feet deep. The bed had an effective surface area of 6.75 square feet and at a maximum flow rate of approximately 6 gpm/ft^2, the unit can filter about 58,000 gallons daily.

As shown in Figure 2 the flow through the filter was upward, with the influent entering the unit through a large number of nozzles located in a distribution plate at the bottom of the filter vessel. The filter media consisted of four layers, with the bottom two layers being gravel and top two layers being sand. The gravel served both to support the sand and to distribute the flow uniformly. The bottom gravel layer was 4 inches deep, consisting of coarse gravel 1-1/4 to 1-1/2 inches in diameter. The second layer was 10 inches thick and contained 3/8- to 5/8- inch gravel. On top of the gravel layer was a 12 inch layer of coarse 2 to 3-millimeter sand and a top layer consisting of 60 inches of finer 1 to 2 millimeter sand. The filter bed was held in place by a grid which was buried near the top of the 60-inch fine sand layer. This filter was designed to utilize the entire media depth for filtration and solids storage.

The backwash cycle was accomplished as follows:
The filtration run was terminated when the head loss through the filter reached a preset level, which was usually 14 psi. With the filtration run terminated, the backwash cycle was then initiated by first draining the filter to a point just above the level of the media. The filter was then fluidized by forcing air through the filter at a pressure of 5 to 10 psi. After three minutes of air flow, the filter was flushed with unfiltered secondary effluent at a rate of 10-13 gpm/ft^2. After approximately ten minutes of flushing, the bed was

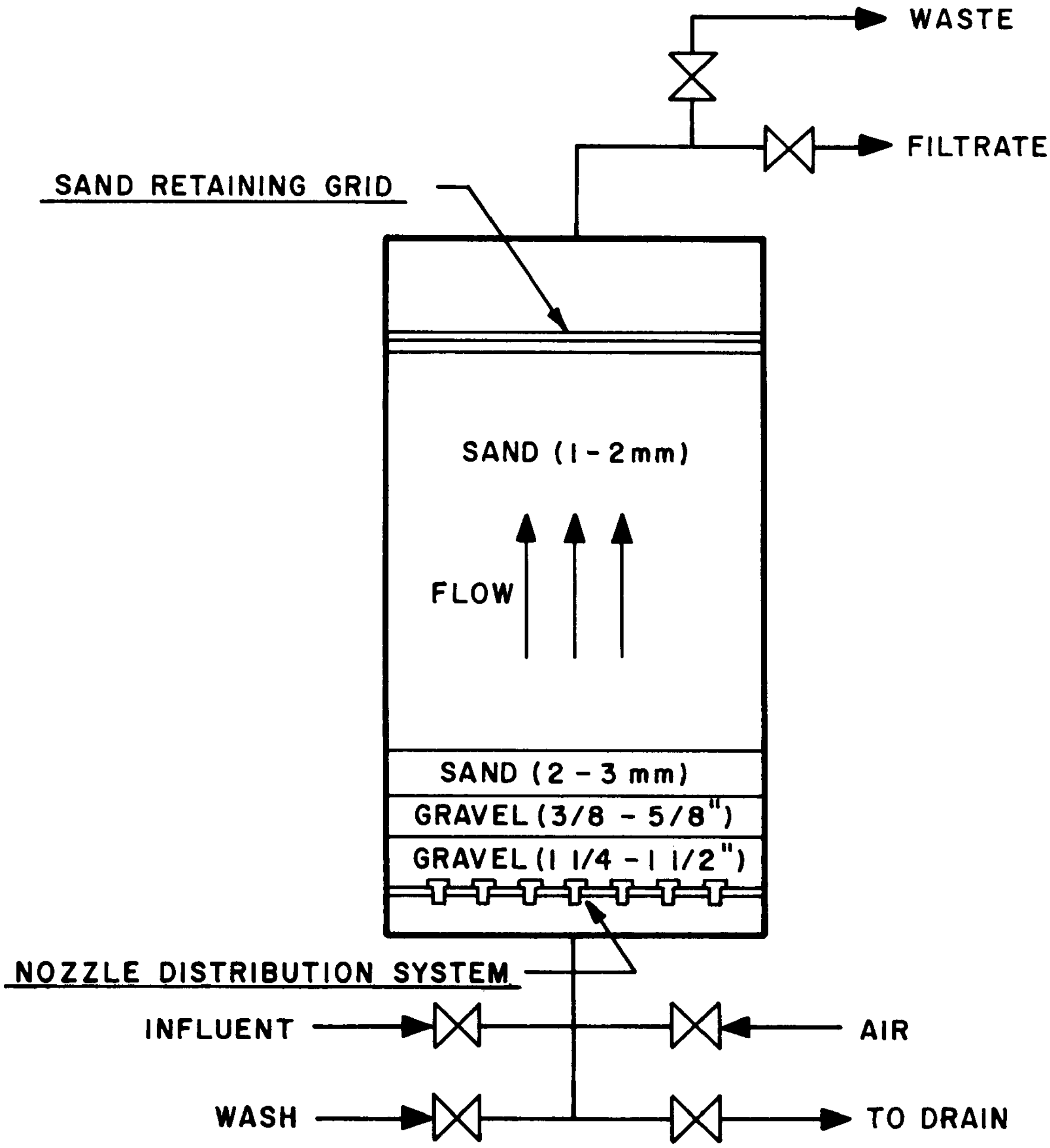

Figure 2. Diagram of the DeLaval Filter.

allowed to settle for five minutes.

The Neptune Microfloc Unit--

The unit used was manufactured by Neptune Microfloc Inc. and was a "Reclamate SWB-27A". The principal tank was 5 feet square and 6 feet deep and was divided into three compartments: a flocculation chamber, a settling chamber, and a filter chamber. The settling chamber contained settling tubes and the filtering media consisted of anthracite coal, silica sand, and garnet supported by gravel. The filter bed was 60 inches deep and had a surface area of 4 square feet, and a maximum flow-through rate of 10 gpm/ft^2 or about 58,000 gpd. The backwash storage tank was approximately 5 feet in diameter and 7 feet deep. Flow through the filter was regulated by an effluent pump and an effluent rate control valve which was operated by a level transmitter positioned above the bed.

The filter media consisted of from top to bottom: a 30-inch layer of 1.2- to 1.3-millimeter anthracite coal, a 12-inch layer of 0.8- to 0.9-millimeter silica sand, a 6-inch layer of 0.4- to 0.8-millimeter garnet, and a 3-inch layer of 1.5- to 2.0-millimeter support garnet, with the entire bed resting on a 12-inch layer of 3/16- to 2-inch gravel.

As depicted in Figure 3 the "Reclamate SWB-27A" could be operated in several different modes. The complete flow pattern included chemical addition followed by flocculation, settling and filtration. This mode of operation could be utilized for phosphate removal. However, as shown in Figure 3, if chemical addition was not desired, the flocculation and settling chambers could be bypassed. Therefore, the appropriate mode of operation can be selected on the basis of the quality of the influent wastewater, the nature of the suspended solids and the degree of tertiary treatment desired within the performance limits of the unit. When the headloss through the unit increased to the setting on a vacuum switch located between the filter and the effluent pump, the backwash cycle was initiated. As shown in Figure 3, both the filter and the settling chamber were cleaned during the backwash cycle. The backwash flow was 15 gpm/ft^2 and the volume of water required for a backwash was approximately 650 gallons. Settling after backwash restored the anthracite coal, silica sand and garnet media to their proper positions in accordance with their density and size differences.

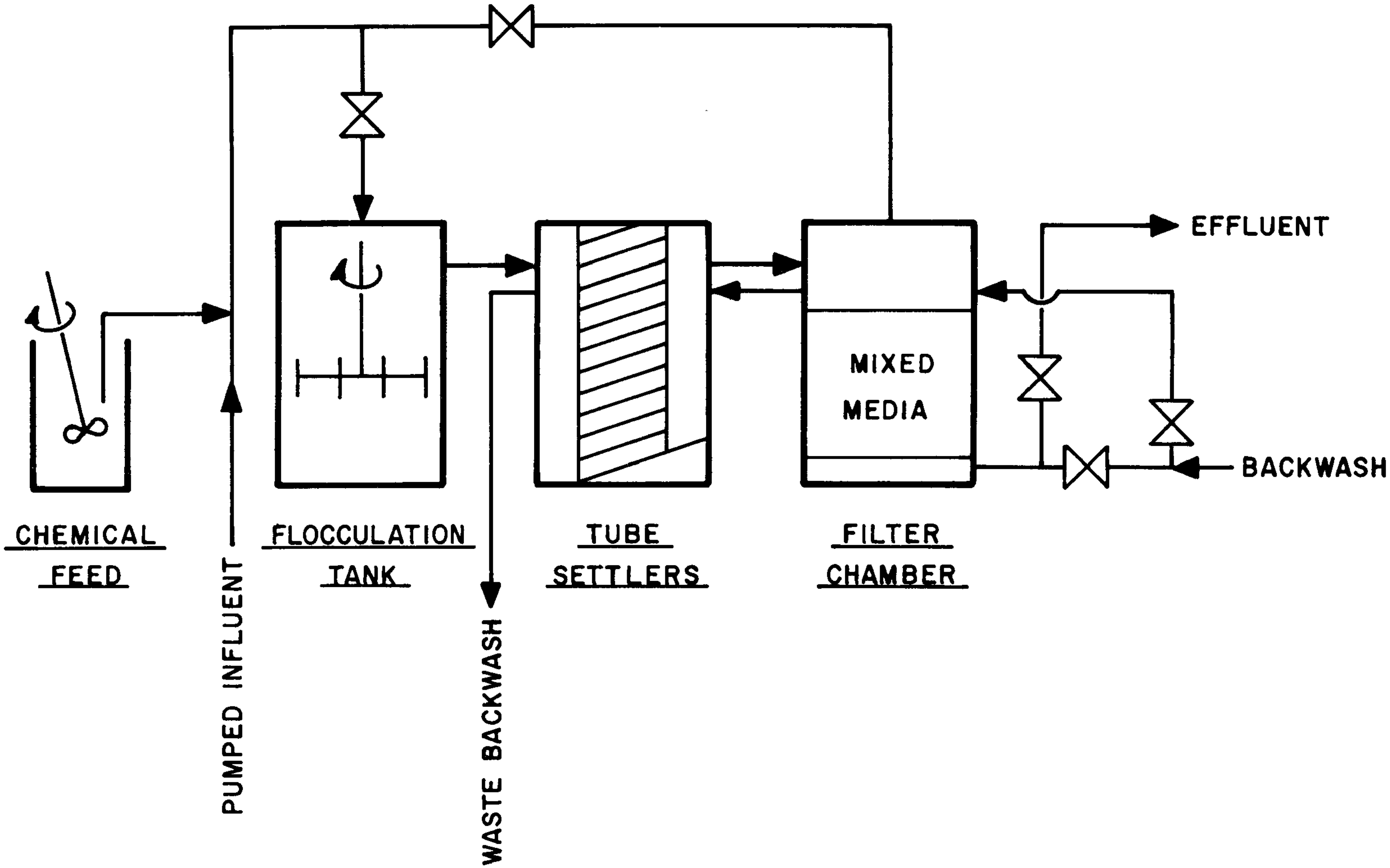

Figure 3. Flow Diagram of the Neptune Microfloc Unit.

The Graver Filter--

The downflow pressure filter manufactured by the Graver Water Conditioning Company was a "Monoscour Filter." A diagram of the Graver filter is shown in Figure 4. The filter vessel was 22 inches in diameter and 7.5 feet in height. The filtering media consisted of anthracite coal and silica sand, with the filter bed being approximately 3 feet deep. The bed has an effective surface area of 2.65 square feet and at a maximum flow rate of 11.5 gpm/ft^2 the unit was capable of filtering about 43,000 gallons daily. As shown in Figure 4, the backwash storage compartment (6 feet in diameter and 5 feet in height) was positioned directly above the filter vessel.

Two different combinations of anthracite coal and silica sand were used during the test period. Initially the aggregate size of the 24-inch layer of anthracite was 1.4 to 1.8 millimeters and the size of the 12-inch layer of silica sand was 0.8 to 1.0 millimeters. Later in the study, the filter media was changed to an anthracite size of 1.0 to 1.4 millimeters and a silica sand size of 0.6 to 0.7 millimeters.

As in the case of the other filters, the filtration run was automatically stopped when the headloss through the filter reached a preset level. The backwash cycle began with the filter being partially drained to a point above the level of the media. The filter bed was then air scoured for 5 minutes at a rate of 15 scfm at 5 psi. Following the air scouring, the filter bed was allowed to settle for 6 minutes, after which it was backwashed for 5 minutes at a rate of about 15 gpm/ft^2. The total volume of water used during backwash was about 200 gallons. After backwashing the filter bed, it was allowed to settle before filtration was begun.

The Continuous-Flow Ion Exchange Unit --

The ion exchange unit used in the study was manufactured by Chemical Separations Corporation and was a "Downflow Single-Loop Continuous Countercurrent Ion Exchange Pilot Plant." The unit was designed for removal of ions which require the regeneration of the exhausted exchange material (exchanger) by one solution. Figure 5 shows a flow diagram of the continuous flow ion exchange unit (CFIEU). As shown in the figure, the unit consists basically of the reactor column, where the ion exchange takes place, and the regeneration loop, where the

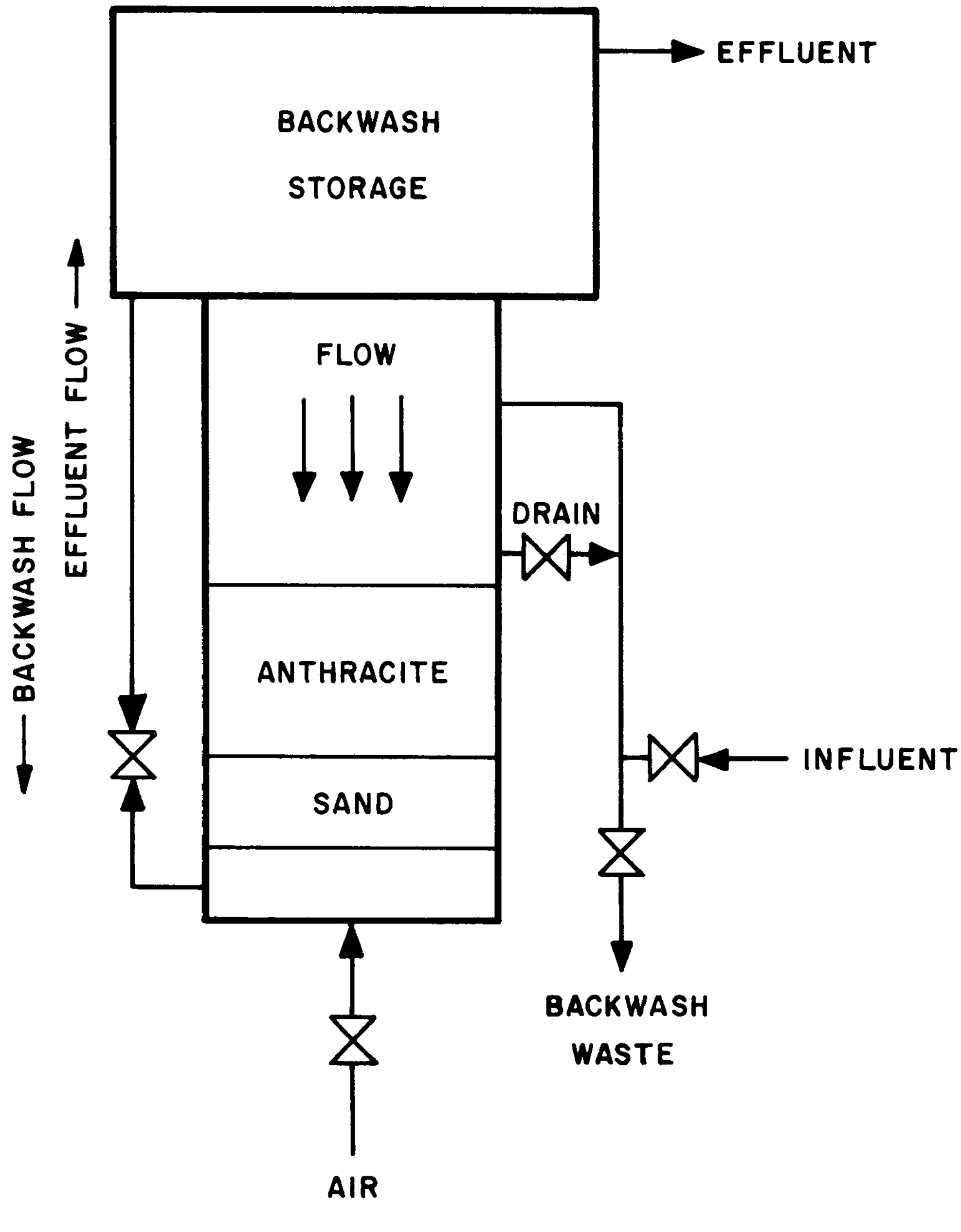

Figure 4. Diagram of the Graver Filter.

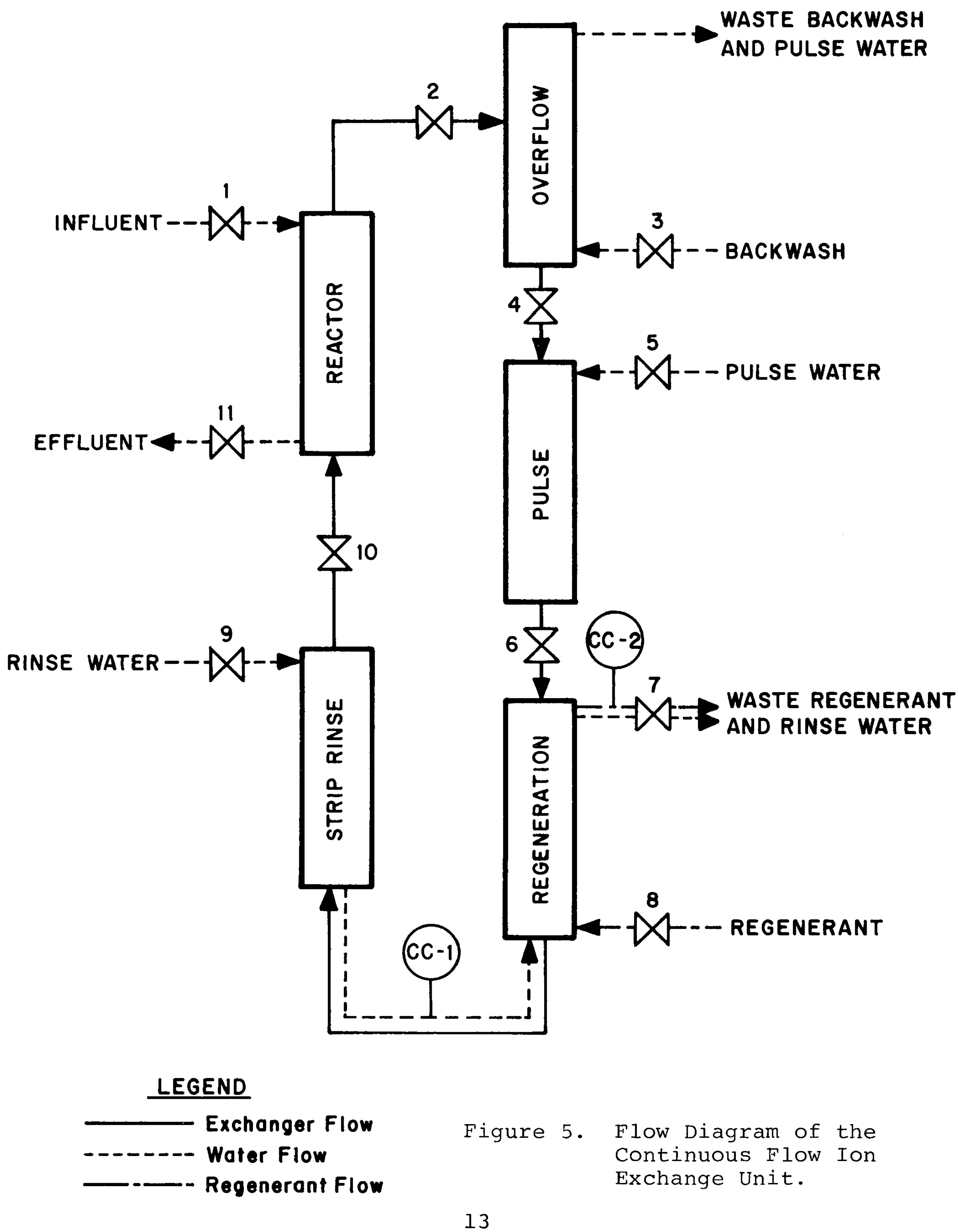

Figure 5. Flow Diagram of the Continuous Flow Ion Exchange Unit.

spent exchanger is regenerated.

The CFIEU had overall dimensions of 6.3 feet in width and 21.5 feet in height. The unit was constructed primarily of 4-inch diameter PVC and pyrex except for the reactor column which was 12-inch diameter 316 stainless steel. The capacity of the CFIEU was 7 cubic feet of exchanger with a flow of 3 to 18 gpm.

The operation of the CFIEU was quite unique in that it was entirely automated. During the normal run period when the influent water was processed, only the influent and effluent valves 1 and 11, as shown in Figure 5, were open. At the start of the pulse cycle the influent and effluent valves (1 and 11) were closed, valves 6, 10 and 2 were opened, and valve 4 remained closed. Pulse water then entered the loop through valve 5 and hydraulically pulsed the exchanger around the loop, pushing regenerated exchanger into the reactor column and forcing the exhausted exchanger out of the reactor column and into the overflow vessel. The pulse period, which usually was set at 10 to 12 seconds, was initiated after the timer controlled process run was completed. After the pulse period, the exhausted resin was backwashed for a preset time in the overflow vessel in order to remove any fines which could have caused excessive pressure drops. Normal run operation commenced when the main valves 2, 6 and 10 were closed and valves 1, 11, 8 and 7 were opened. Regeneration was accomplished by pumping regenerant from valve 8 through valve 7. Regenerant flow was terminated when the regenerant was sensed by the conductivity meter (CC-2). The exchanger in the strip rinse section was rinsed to prevent any regenerant from entering the reactor column. The rinse water entered through valve 9 and was eliminated through valve 7. The amount of rinse was controlled automatically by a conductivity meter (CC-1). The CFIEU was therefore, not truly a continuous flow system. Since the reactor was closed for only a few seconds during pulsing, the shut down time was insignificant when compared to the process time between pulses which usually was about 3 to 5 minutes.

Initially, Chemical Separations Corporation delivered Dow X50 AK resin, which when properly conditioned, the company claimed would remove both nitrate and phosphates, However, preliminary tests demonstrated that the resin was neither suitable for phosphate nor nitrate removal. Thus, the exchanger used in this study was activated alumina from the Davidson Chemical Company, Type SMR-9.

Influent Sources

As illustrated in Figure 6, there were two primary sources of influent to the experimental filters. The first source was the secondary effluent of the activated sludge process, while the second was secondary effluent which had undergone coagulation-sedimentation. Normally the influent to the experimental sand filters was the secondary effluent directly from the final settling tanks of the activated sludge plant. However, late in the study, the secondary effluent from the Hanover Plant deteriorated significantly because plant flow exceeded the design flow of 2 mgd. In addition, construction of a 4 mgd plant expansion caused frequent interruptions in normal plant operations. These conditions resulted in a very poor quality and highly variable secondary effluent. Rather than terminate the project, the last filter runs used secondary effluent which had undergone coagulation-sedimentation. The coagulation dosage was 15 mg/l of alum.

As shown in Figure 6, the source of influent to the ion exchange unit was the tertiary portion of the Hanover Plant. In order to achieve meaningful experimental runs, the suspended solids coming into the ion exchange unit must be low and therefore, the source of the influent to the unit was the microscreened effluent.

Analytical Methods

Chemical Analyses--

All of the analytical work was performed by the Research and Development Control Laboratory of MSDGC at the North Side Treatment Works. Biochemical oxygen demand, suspended solids, volatile suspended solids and pH were analyzed as described in Standard Methods (1). A Beckman Zeromatic pH meter was used for pH determinations.

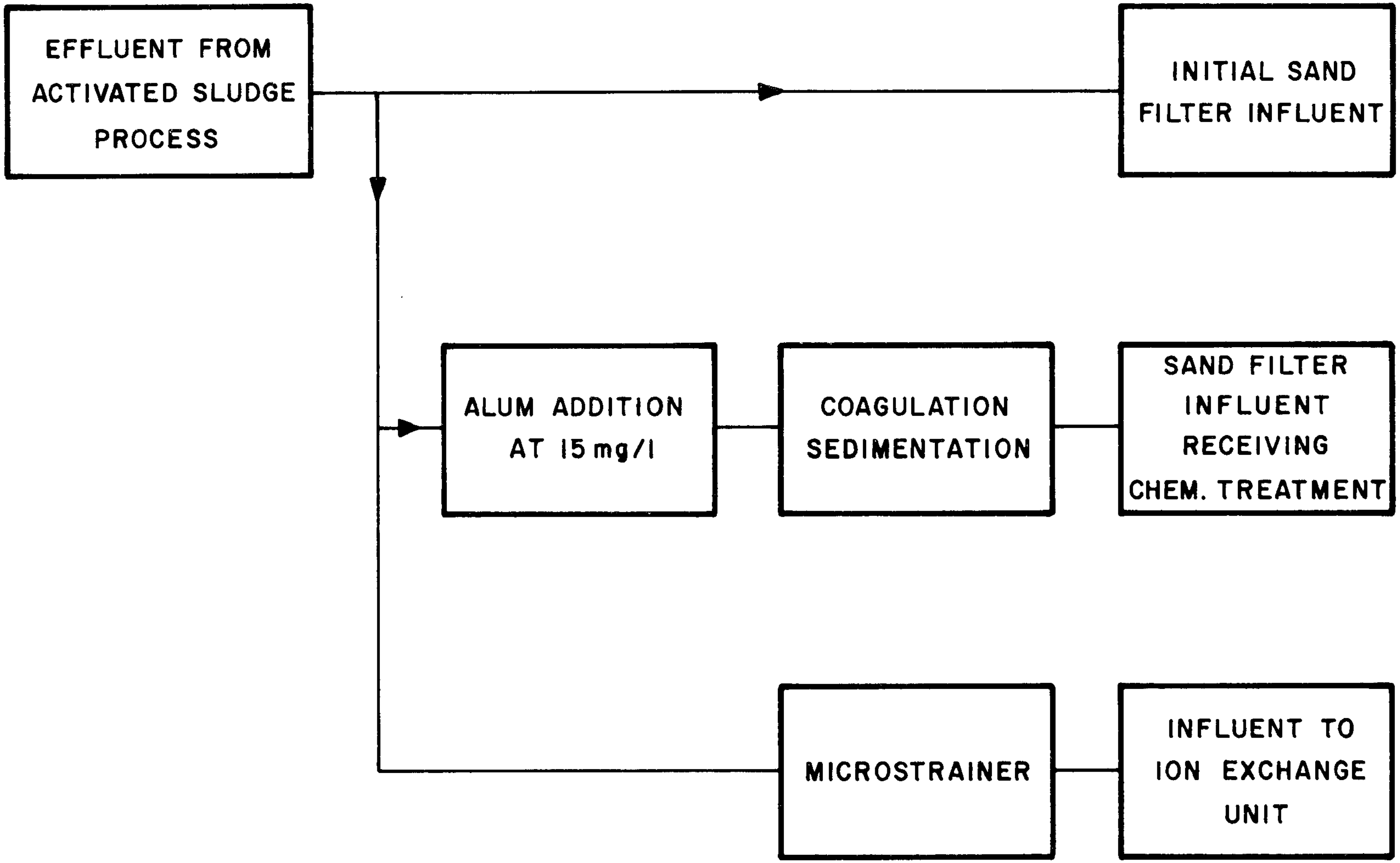

Figure 6. Influent Sources of the Hanover Experimental Bay Project.

Phosphorus was analyzed by the single reagent method using a Technicon Auto-analyzer as described by Stanley and Richardson (2). The single reagent method for total phosphorus included acid hydrolysis of the condensed phosphates, and persulfate digestion of organic phosphates to orthophosphate. Ammonium molybdate and potassium antimony tartrate react with dilute solutions of orthophosphate in an acid medium to form an antimony-phosphate-molybdenum complex. The antimony-phospho-molybdate complex is reduced with ascorbic acid to form an intensely-blue molybdenum complex. The intensity of the color was measured by a colorimeter at a wavelength of 650 milli-microns.

Sampling--

Originally, it was planned to have the samples for the filters and the ion-exchange unit automatically composited and refrigerated. However, due to many problems with the automatic samplers, they were abandoned. Thus, the influent and effluent samples were obtained by compositing nine grab samples daily.

SECTION V
RESULTS

Operation of the DeLaval Filter

Table 1 summarizes the operation of the DeLaval filter using secondary effluent. There were six different test periods with the hydraulic loadings from 2 to 5 gpm/ft^2. As can be seen in the table, the average effluent suspended solids (SS) were fairly consistent (5 to 7 mg/l) despite the differences in influent quality and hydraulic loadings. The influent suspended solids and BOD varied somewhat, with the result being a fluctuation in the percent removals of suspended solids and BOD.

Although the effluent quality from the DeLaval filter was good in terms of BOD and suspended solids the length of the filter runs were drastically reduced as the hydraulic loadings were increased from 2 to 5 gpm/ft^2, with the length of the filter run falling from 150 hours to 7 hours. A slight increase in the length of filtration runs and the suspended solids loading did occur when the hydraulic loading was reduced to 4 gpm/ft^2 in test 4. Prior to test 5 the pressure setting which initiates the backwash cycle was changed from 14 to 17 psi. This change in pressure setting did not significantly lengthen the average filtration runs.

Before the filtration runs of test 6, a visual inspection was made of the filter bed and it could be seen that the bed was not being properly cleaned. In order to improve the backwash efficiency, the backwash time was increased from 10 to 20 minutes. However, as shown in Table 1, this change had little effect upon the backwash efficiency, as the average length of filtration run was only 8.5 hours, even though the influent suspended solids were only 17 mg/l.

In tests 7 through 10, the influent to the DeLaval filter was secondary effluent which had been additionally treated by alum coagulation-sedimentation. The results of these tests are summarized in Table 2. As shown in the table, the effluent quality from the DeLaval filter was similar to that obtained during tests 1 through 6. As in the case of test 6, the DeLaval filter during test 7 was backwashed for 20 minutes instead of 10 minutes. The average length of filtration run did not improve significantly, as was the case in test 6.

TABLE 1. OPERATION OF THE DELAVAL FILTER AT VARIOUS HYDRAULIC LOADINGS: TREATMENT OF SECONDARY EFFLUENT

Item	Test Number					
	1	2	3	4	5	6
Hydraulic loading, gpm/ft^2	2	4	5	4	4.5	4
Test period, days	21	19	6	19	15	7
Influent SS, mg/l	14.1	14.8	13.0	13.8	25.9	16.6
Effluent SS, mg/l	7.0	4.9	5.7	6.7	7.3	6.0
SS removal, %	50	67	56	51	72	74
Influent BOD, mg/l	17	24	20	9	29	10
Effluent BOD, mg/l	6	6	7	4	13	2
BOD removal, %	62	73	65	53	55	80
Number of filter runs	4	16	19	29	23	15
Length of filter runs, hr	150.1	25.5	6.9	14.3	13.3	8.5
SS loading, lb/ft^2/filter run	2.1	0.77	0.22	0.39	0.74	0.25
SS removal, lb/ft^2/filter run	0.96	0.51	0.13	0.20	0.52	0.16
Backwash usage, %	0.5	1.4	4.4	2.5	2.5	9.3
Backwash flow rate gpm/ft^2	9.0	8.7	8.9	8.5	8.5	9.5
Backwash time, min	10	10	10	10	10	20

TABLE 2. OPERATION OF THE DELAVAL FILTER AT VARIOUS HYDRAULIC LOADINGS: TREATMENT OF ALUM-TREATED SECONDARY EFFLUENT

Item	Test number 7	8	9	10
Hydraulic loading, gpm/ft^2	4	4	4.7	5
Test period, days	18	19	26	8
Influent SS, mg/l (alum-treated secondary effluent)	24	12	14	14
Effluent SS, mg/l	7	7	7	5
SS removal, %	71	44	54	62
Influent BOD, mg/l (alum-treated secondary effluent)	18	7	17	18
Effluent BOD, mg/l	6	5	9	5
BOD removal, %	66	26	48	72
Number filter runs	37	11	16	5
Length of filter runs, hr	10.3	43.0	37.0	35.4
SS loading, lb/ft^2/day	0.49	1.04	1.23	1.24
SS removal, lb/ft^2/day	0.35	0.45	0.67	0.70
Backwash usage, %	8.6	2.5	2.7	3.7
Backwash flow rate, gpm/ft^2	10.7	12.9	14.1	14.0
Backwash time, min	20	20	20	20

Moreover, because of the longer backwashing period, the backwash usage increased to 9.5% for test 6 and 8.6% for test 7.

Finally, it was decided to increase the backwash flow rate from less than 10 gpm/ft^2 to approximately 13 gpm/ft^2 in order to improve the backwashing efficiency. As shown in the table, the average length of the filtration run did significantly improve in tests 8, 9 and 10 as a result of the increased backwash flow rate.

Also, the percent backwash usage was considerably reduced. Possibly, further reductions of backwash usage could have been achieved if the backwashing period had been reduced from 20 minutes. No studies were made to determine the necessary period of backwash at the 13 gpm/ft^2 rate, however it was obvious that the backwash flow rate of 10 gpm/ft^2 was inadequate and that a higher backwash flow rate was needed in order to properly clean the filter.

Since the backwash flow rate was only 10 gpm/ft^2 in tests 1 through 7, inclusive, it is difficult to evaluate the DeLaval filter. However, as adjudged by its performance in tests 8, 9 and 10 the DeLaval filter can adequately handle loadings at aroung 4-5 gpm/ft^2, with the effluent suspended solids being about 5 to 7 mg/l and the length of the filtration run being about 40 hours.

Operation of the Neptune Microfloc Unit

Since the Neptune Microfloc unit had the capability for coagulation-sedimentation before filtration, some of the tests employed chemical addition. Table 3 summarizes the treatment of secondary effluent using the Neptune Microfloc filter. Tests 4 and 5 involved the use of ferric chloride, while tests 1, 2 and 3 used no chemicals prior to filtration. In tests 1 and 2 the unit's coagulation-sedimentation tank was bypassed, while in test 3 the flow passed through the unit's coagulation-sedimentation tank with no chemical addition.

As shown in the table, the average effluent suspended solids in tests 1 through 3 were exceptionally low, with the average being about 4 mg/l. Also, the increase in hydraulic loading from 2 to 4 gpm/ft^2 in these tests did not affect the quality of the effluent. However, the length of the filter run was

TABLE 3. OPERATION OF THE NEPTUNE MICROFLOC UNIT: TREATMENT OF SECONDARY EFFLUENT WITH AND WITHOUT CHEMICAL ADDITION

Item	Test number				
	1	2	3	4	5
Chemical dosage	None	None	None	$FeCl_3$ 10mg/l	$FeCl_3$ 20 mg/l
Hydraulic loading, gpm/ft^2	2	4	4	4	4
Test period, days	9	22	18	14	17
Influent SS, mg/l	14.0	16.1	16.6	11.6	16.3
Effluent SS, mg/l	3.8	4.3	3.8	8.6	8.4
SS removal, %	73	73	N.A.*	N.A.	N.A.
Influent BOD, mg/l	22.8	25.3	15.7	8.5	16.5
Effluent BOD, mg/l	6.0	3.9	2.6	3.8	4.0
BOD removal, %	74	85	N.A.	N.A.	N.A.
Number of filter runs	2	19	14	7	21
Length of filter runs, hr	106.3	27.2	26.6	48.0	14.8
SS loading, lb/ft^2/ filter run	1.53	0.86	N.A.	N.A.	N.A.
SS removal, lb/ft^2/ filter run	1.12	0.64	N.A.	N.A.	N.A.
Backwash usage, %	1.3	2.5	2.6	1.4	4.4
Backwash flow rate, gpm/ft^2	15	15	15	15	15
Backwash time, min	10	10	10	10	10

* Not applicable

reduced from 100 hours to 25 hours, with the percent backwash usage increasing from 1.3% to 2.5%.

The addition of ferric chloride to the unit's coagulation-sedimentation tank prior to filtration in tests 4 and 5 did not improve the quality of the effluent when compared to test 3. In fact, it appears that the effluent was significantly poorer in quality, since the average suspended solids in the effluent in tests 4 and 5 were about 8 to 9 mg/l as compared to 4 mg/l in test 3. Note that the influent suspended solids and BOD concentrations are those of the secondary effluent and not those introduced directly to the filter for runs 3, 4 and 5. Since the units coagulation and sedimentation compartments had been introduced into the flow pattern, the backwash usage in test 4 was comparatively low. The backwash usage in test 5 was high in comparison to test 4 because of the shorter filtration runs due perhaps to a higher solids loading to the filter. In general, the addition of ferric chloride did not improve the quality of the effluent from the filtration unit, particularly with respect to suspended solids.

In tests 6 through 10, shown in Table 4, the Neptune Microfloc unit used secondary effluent additionally treated by alum coagulation-sedimentation. As explained previously this chemical pretreatment was necessary to maintain overall plant efficiency during a period of inadequate treatment capacity. As noted previously, the chemical treatment of the secondary effluent was 15 mg/l of alum. In tests 6, 7 and 9, chemicals were also added to the coagulation-sedimentation tank of the Neptune Microfloc unit before filtration. Polymers were added in test 6 and 7, while ferric chloride was added in test 9 to remove phosphorus.

In test 6, Nalco N17 polymer was used at a dosage of 0.5 mg/l. The filter effluent averaged 7 mg/l suspended solids and 9 mg/l BOD. In test 7, Dow A23 polymer was used at a dosage of 0.5 mg/l. The filter effluent averaged 8 mg/l suspended solids and 9 mg/l BOD. Thus, both polymers produced effluents of comparable quality.

In an attempt to remove phosphorus, the Neptune Microfloc unit was dosed with 70 mg/l of ferric chloride as $FeCl_3$. An average of only 55 percent of the incoming 11.6 mg/l phosphorus as P was removed, with the average effluent suspended solids being higher than the influent suspended solids. These results

TABLE 4. OPERATION OF THE NEPTUNE MICROFLOC UNIT: TREATMENT OF ALUM-TREATED SECONDARY EFFLUENT WITH AND WITHOUT CHEMICAL ADDITION

Item	Test number 6	7	8	9	10
Chemical dosage	N 17 polymer 0.5 mg/l	A 23 polymer 0.5 mg/l	None	$FeCl_3$ 70 mg/l	None
Test period, days	14	3	10	26	5
Hydraulic loading, gpm/ft^2	4	4	4	4	6
Influent SS, mg/l (alum treated secondary effluent)	24	33	10	13	15
Effluent SS, mg/l	7	8	6	24	6
Influent BOD, mg/l (alum treated secondary effluent)	18	18	6	16	18
Effluent BOD, mg/l	9	9	6	16	4
Number of filter runs	25	13	9	41	6
Length of filter runs, hr	12.9	6.0	24.4	14.1	21.0
Backwash usage, %	5.2	11.3	2.8	4.8	2.2
Backwash flow, rate gpm/ft^2	15	15	15	15	15
Backwash time, min	10	10	10	10	10

indicate that the chemical treatment was improper for phosphorus removal, and resulted in poor system performance.

In general, the Neptune Microfloc unit operated well at 4 gpm/ft^2, with the average filtration run being approximately 25 to 30 hours and the effluent suspended solids averaging about 4 mg/l. Addition of ferric chloride and polymers prior to filtration produced in most cases an effluent which was inferior in quality when compared to the tests where no chemicals were added.

Operation of the Graver Filter

Table 5 summarizes the operation of the Graver filter using secondary effluent from the Hanover Plant as the influent feed. The hydraulic loadings tested ranged from 2 to 10 gpm/ft^2. As shown in the table, the effluents in all of these tests were of similar quality even though a wide range of hydraulic loadings were tested. The average effluent suspended solids ranged from 5 mg/l to 9 mg/l. The main effect of increasing the hydraulic loading was a reduction in run lengths with the average filtration time ranging from 90 hours at 2 gpm/ft^2 to 21 hours at 10 gpm/ft^2.

During tests 8 through 12 the Graver filter processed alum treated secondary effluent. Table 6 summarizes the results of these tests. The hydraulic loadings tested ranged from 4 to 6 gpm/ft^2 and the quality of the effluent was comparable to the previous tests 1 through 6. However, there was a noticeable difference in the length of the filter runs of tests, 8, 9 and 11 when compared to test 2. In all four of these tests the hydraulic loading was 4 gpm/ft^2, however,the length of the filter runs averaged about 20 hours in tests 8, 9 and 11, while the average filtration run was about 50 hours during test 2. The difference can be attributed to the difference between the influent qualities. During tests 8, 9 and 11, the average during test 2 was 15 mg/l. Therefore, the solids loading was about 30 to 60 percent higher during tests 8, 9 and 11 than in test 2. Another factor which had some effect on filtration is that tests 8, 9 and 11 used secondary effluent which had undergone alum coagulation-sedimentation. However, the change in filterability of the suspended solids caused by this chemical pretreatment was not determined.

TABLE 5. OPERATION OF THE GRAVER FILTER AT VARIOUS HYDRAULIC LOADINGS: TREATMENT OF SECONDARY EFFLUENT

Item	Test number 1	2	3	4	5	6	7
Hydraulic loading of gpm/ft^2	2	4	8	9	10	6	6
Number of days	35	26	11	25	2	19	16
Influent SS, mg/l	16	15	13	14	18	17	16
Effluent SS, mg/l	7	5	6	9	8	7	6
SS removal, %	55	69	48	33	56	61	63
Influent BOD, mg/l	20	25	18	10	11	20	14
Effluent BOD, mg/l	7	7	7	6	4	8	3
BOD removal, %	64	70	64	45	64	60	76
Number of filter runs	10	12	8	17	3	16	20
Length of filter run, hr	90.0	51.1	31.1	32.2	11.8	25.7	18.4
SS loading, lb/ft^2/ filter run	1.45	1.55	1.48	1.92	1.07	1.28	0.89
SS removal, lb/ft^2/ filter run	0.85	1.05	0.71	0.72	0.48	0.78	0.55
Backwash usage %	0.7	0.6	0.5	0.4	1.1	0.8	1.1
Backwash flow rate gpm/ft^2	15	15	15	15	15	15	15
Backwash time, min	5	5	5	5	5	5	5

TABLE 6. OPERATION OF THE GRAVER FILTER AT VARIOUS HYDRAULIC LOADINGS: TREATMENT OF ALUM-TREATED SECONDARY EFFLUENT

Item	Test number 8	9	10	11	12
Hydraulic loading, gpm/ft^2	4	4	5	4	6
Test period, days	13	10	24	12	13
Influent SS, mg/l (alum treated secondary effluent)	25	24	11	20	13
Effluent SS, mg/l	8	10	6	6	5
SS removal, %	69	58	41	68	63
Influent BOD, mg/l (alum treated secondary effluent)	19	13	9	20	16
Effluent BOD, mg/l	6	8	7	6	5
BOD removal, %	66	43	22	68	70
Number of filter runs	19	10	16	13	20
Length of filter run, hr	15.2	20.2	35.5	22.5	14.4
SS loading, lb/ft^2/filter run	0.72	0.92	0.98	0.93	0.58
SS removal, lb/ft^2/filter run	0.49	0.54	0.49	0.64	0.37
Backwash usage, %	2.1	1.6	0.7	1.4	1.5
Backwash flow rate gpm/ft^2	15	15	15	15	15
Backwash time, min	5	5	5	5	5

Before test 11, the filter medium was changed to a slightly smaller size. The anthracite layer size range was reduced from 1.4 to 1.8 millimeters, to 1.0 to 1.4 millimeters while the sand layer size range was reduced from 0.8 to 1.0 millimeter to 0.6 to 0.7 millimeter. As shown in Table 6, the changes in the filter media sizes did not significantly change performance characteristics of the unit, although effluent suspended solids concentrations were somewhat lower.

Operation of the Continuous Flow Ion Exchange Unit

To demonstrate that the activated alumina could successfully remove phosphorus, and experimental run was made using the ion exchange column in which there was no regeneration of the activated alumina. The results of the test are shown in Figure 7. The linear reduction of phosphorus removal efficiency rather than a typical breakthrough curve is due to the fact that the alumina was intermittently pulsed through the loop. Thus the phosphate was exchanged uniformly with all the alumina instead of the progressive complete exhaustion of an exchanger that normally occurs in a fixed bed. The primary reason the ratio of the effluent concentration of phosphorus to the influent concentration of phosphorus was 0.15 and not zero initially was because the activated alumina only removes the soluble phosphates and therefore, the remaining 15% consisted of insoluble phosphorus forms.

Table 7 shows the results of using sodium hydroxide in regenerating the activated alumina. As shown in the table, the use of sodium hydroxide as a regenerant was fairly successful at normalities of 0.4 to 0.5. At these concentrations about 70% of the total phosphorus was removed and effluent phosphorus averaged less than 1.5 mg/l as total phosphorus. Regenerant use was less than 4% of process flow.

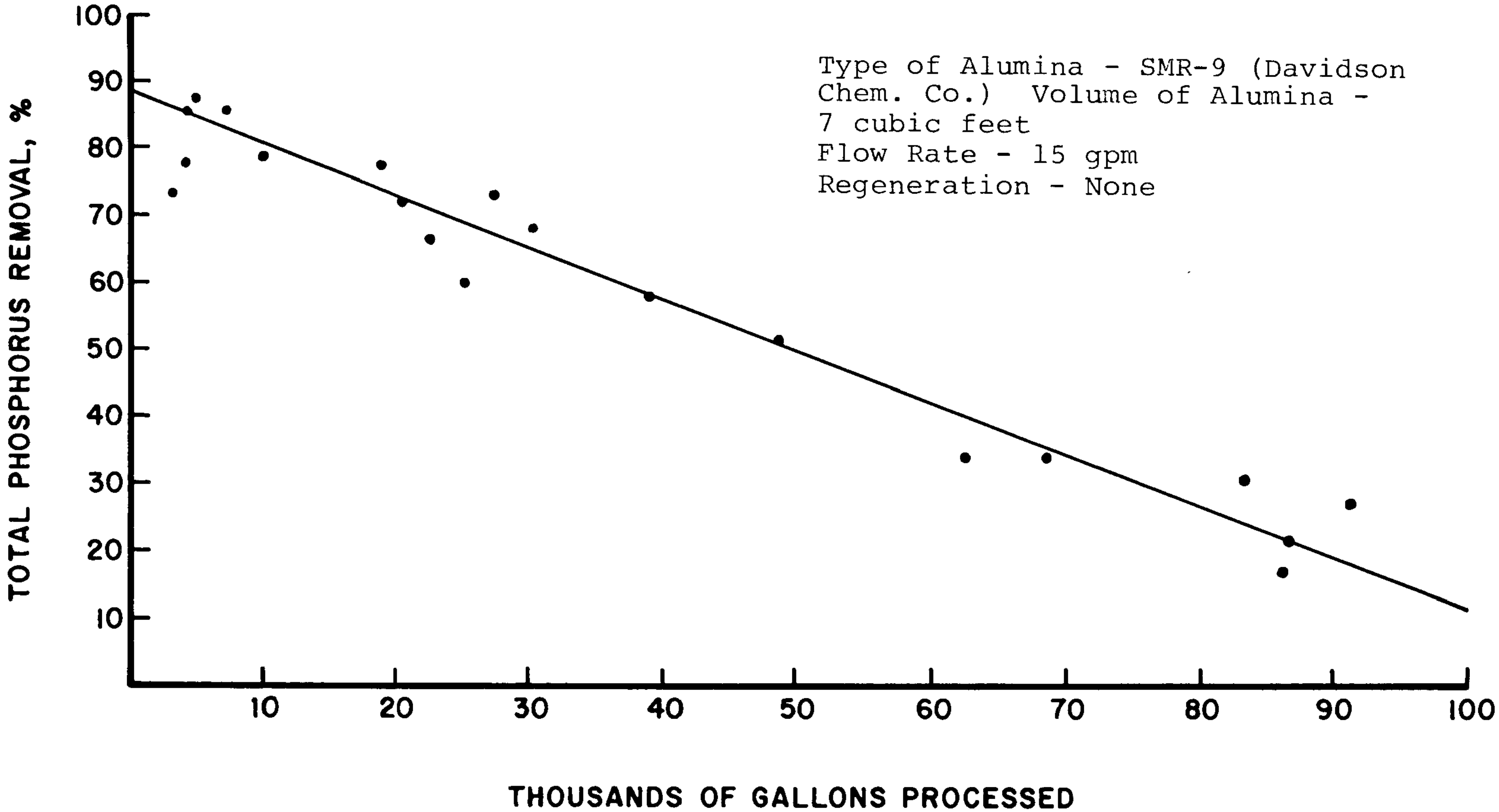

Figure 7. Phosphorus Removal By Activated Alumina

TABLE 7. OPERATION OF THE CONTINUOUS FLOW ION EXCHANGER FOR PHOSPHORUS REMOVAL BY ACTIVATED ALUMINA WITH SODIUM HYDROXIDE REGENERATION

Item	Test number 1	2	3	4	5
Normality NaOH	0.1	0.2	0.3	0.4	0.5
Length of test, hr	7	8	10	9	4
Process flow, gpm	8.5	8.5	8.5	8.5	8.5
Process time, min	4	4	4	4	4
Regenerant flow, gph	14	15	15	16.5	13.5
Regeneration time,min	3.5	3.5	3.5	3.5	3.5
Regenerant usage, %	2.45	2.57	2.57	2.83	3.58
Number of samples	5	3	4	5	2
Influent total P, ppm	9.9	6.3	8.6	5.2	2.8
Effluent total P, ppm	8.1	5.3	4.0	1.4	0.9
Total P reduction, %	18	16	54	73	68

SECTION VI
DISCUSSION

During the first part of the study, the influent to the sand filters was secondary effluent from the Hanover Plant. During the later part of the study, the influent to the filters was coagulated and settled secondary effluent. Since the Hanover Park secondary effluent was of poor quality at that time, it was decided to add alum and utilize the available coagulation-sedimentation basin in order to enhance suspended solids removal. Also, during both periods additional chemical studies were run using the Neptune Microfloc unit since it also had a coagulation-sedimentation basin, as well as the mixed media filtration system. These studies were run to determine phosphorus removal as well as filtrability.

Filtration of Secondary Effluent

In terms of effluent quality, all three units, the DeLaval upflow filter, the Neptune Microfloc mixed media filter, and the Graver dual media pressure filter, consistently produced an effluent of less than 10 mg/l suspended solids when filtering a secondary effluent with influent suspended solids of about 13 to 18 mg/l. Since the Neptune Microfloc filter contained the smallest particle size (0.4 to 0.8 millimeter garnet) of the three filters tested, it was not particularly surprising to observe that the average effluent suspended solids was the lowest (3 to 4 mg/l) at hydraulic loadings of 2 to 4 gpm/ft^2.

Even with the backwashing difficulties encountered with the DeLaval filter during the first part of the study, the effluent quality was good in terms of suspended solids and averaged 5 to 7 mg/l in the hydraulic loading range of 2 to 5 gpm/ft^2. The Graver filter also produced an effluent similar to the DeLaval filter, with the effluent suspended solids of 5 to 7 mg/l in hydraulic loading range of 2 to 4 gpm/ft^2. Furthermore, at higher hydraulic loadings of 8 to 10 gpm/ft^2 to the Graver filter the effluent suspended solids concentrations were still fairly low, averaging 6 to 9 mg/l.

Since the Graver filter was a pressure filter (backwashed at a headloss of 13 ft of water) and contained a relatively coarse media, the time between backwashes was generally the longest among the filters tested at a given hydraulic loading. The time between backwashes ranged from 90 hours at 2 gpm/ft^2 to 11.8 hours at 10 gpm/ft^2. The Neptune filter, with a finer media, a deeper bed, and a terminal headloss (backwashed at 7 ft of water) less than the Graver filter, averaged 27 hours between backwashes at 4 gpm/ft^2. In comparison, at the same hydraulic loading and influent suspended solids of 13 to 16 mg/l, the time between backwashes for the Graver filter averaged 51 hours. As described earlier, there were problems in backwashing the DeLaval filter, therefore the time between backwashes as well as the percentage of effluent water used for backwashing cannot be evaluated.

Because of the relatively long filter runs of the Graver filter, the backwash requirements ranged from 0.4 to 1.1% at hydraulic loadings of 2 to 10 gpm/ft^2. The backwash percentage for the Neptune Microfloc filter varied from 1.3% at 2 gpm/ft^2 to 2.5% at 4 gpm/ft^2.

Filtration of Secondary Effluent Treated with 15 mg/l of Alum

To reiterate, the chemical treatment was undertaken to preserve effluent quality during a period of poor operation caused by construction activities during a 4 mgd plant expansion. The secondary effluent which had undergone this chemical treatment did not show any discernable change in appearance in comparison with the secondary effluent used previously in the study. A comparison of influent suspended solids and BOD for both influent sources shows that they were very similar. However, since it is likely that the chemical treatment caused some changes in particle size and composition, the data for each influent source have been treated separately.

The importance of proper backwashing to the efficient operation of the DeLaval filter was demonstrated. Test 7 of the DeLaval filter shows similar performance for the treatment of alum treated secondary effluent and the normal secondary effluent used in tests 4 and 6 (all at 4 gpm/ft^2). However, when the backwash flow was increased from 10 gpm/ft^2 to 13 gpm/ft^2 in test 8 the length of filter runs increased approximately threefold, abruptly stopping the trend progressively shorter runs at a given hydraulic loading. It is logical to conclude that if the backwash flow had been 13 gpm/ft^2 in tests 1 through 6, increased filter run times would have resulted.

Tests 6 through 10 of the Neptune Microfloc unit were made using alum treated secondary effluent as the influent source to the filter. These tests were performed to determine the effectiveness of chemical treatment utilizing the unit's own coagulation and settling chambers. Since the filter influent was treated twice with chemicals before filtration, these results may not reflect the best performance obtainable with this unit.

Polymer addition in tests 6 and 7 showed no improvement in effluent quality and resulted in shorter filter runs. Ferric chloride addition in test 9 did not effectively remove phosphorus as anticipated.

The performance of the Graver filter in treating alum dosed secondary effluent was very similar to that achieved with normal secondary effluent. The significant difference was a 50% decrease in solids loadings and removals (both expressed as lbs/ft^2/filter run). It is likely that this difference was caused by a change in particle characteristics because of the treatment with alum.

Phosphorus Removal by the Continuous Ion Exchange Unit

Activated alumina is capable of removing phosphorus from a treatment plant effluent as shown in the results presented in Section V. Unfortunately the data obtained are insufficient to make any judgements regarding the applicability of the process on a plant scale. Some unresolved issues are:

1) Can this process achieve the desired effluent quality of 1 mg/l total phosphorus?

2) What are the optimum operating parameters? Parameters such as regenerant strength, flow rates and run times would require much more testing to find the optimum mode of operation of the continuous ion exchange unit.

3) Disposal of waste regenerant may be a problem since the large amounts of waste sodium hydroxide cannot be recycled through the plant without pH adjustment and phosphorus removal.

It is apparant that further investigation of this process is necessary.

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2. Stanley, G. H., and Richardson, G. R., "The Automation of the Single Reagent Method for Total Phosphorus." Presented at the Technicon International Contress (1970).

APPENDIX

Metric Conversions

Length

mm	=	0.03937	in
m	=	3.28	ft

Area

m^2	=	10.76	ft^2

Volume

l	=	0.264	gal

Mass

Kg	=	2.205	lb

Flow

m^3/day	=	2.64×10^4	mgd
	=	2.64×10^2	gpd
l/min	=	0.264	gpm

Hydraulic Loading

m^3/m^2	=	24.51	gal/ft^2

Mass Loading

kg/m^2	=	0.205	lb/ft^2

Pressure

N/m^2	=	0.000145	lb/in^2

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT During a one year study, four tertiary treatment units were tested and evaluated. Three of the units were deep-bed filters which were used to treat secondary plant effluent. The types of filters used were: (1)an upflow filter with a sand media,(2)a downflow gravity filter with mixed-media consisting of anthracite, sand, and garnet, and(3)a downflow pressure filter utilizing dual-media of anthracite and sand. The fourth unit was a continuous flow ion exchanger that employed activated alumina to remove phosphate from microscreened secondary effluent. The filtration studies indicate that comparable effluents were produced by all three filters with filtration rates from 2-6 gpm/ft^2. Filter effluents generally contained about 4-7 mg/l suspended solids in the above flow range. The results of the ion exchange study indicated that sodium hydroxide successfully regenerated an exhausted activated alumina bed. In a 9-hour test, the ion exchange column removed 73% of the influent phosphorus, using 0.4N sodium hydroxide as the regenerant.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sewage Treatment Filtration Phosphorus	Tertiary Treatment BOD Removal SS Removal	13B

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