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OBSERVATIONS OF AN INTERMITTENT SAND FILTER FOR PROCESSING LAGOON INFLUENT AT FARMINGTON, ILLINOIS

by Ralph L. Evans and Donald H. Schnepper

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INTRODUCTION

In 1945 there were about 45 sewage lagoons in the United States; currently there are more than 4000 (Lewis, 1979). About 20 percent of them are located in Illinois (C. Fellman, Illinois Environmental Protection Agency, 1980, personal communication). Nine out of ten handle sewage flows of fewer than 500,000 gallons per day. The installations have provided and continue to provide low cost treatment for many small communities.

Their proliferation has been based principally on their capability to reduce coliform bacteria and BOD_5. It has been shown that the BOD_5 of algal laden lagoon effluents represents only about 20 percent of the ultimate BOD (Bain et al., 1970; King et al., 1970). This is because algae do not lyse and create the ultimate oxygen demand within the 5-day incubation period for BOD_5 measurements. Nevertheless the results of a BOD_5 test are considered an acceptable measurement of effluent quality for lagoons.

Studies by Evans et al. (1978) of 12 installations in Illinois showed that the mean BOD_5 in the effluents of non-aerated and aerated lagoons were 37 mg/l and 17 mg/l, respectively. The BOD_5 in the effluents of non-aerated lagoons equalled or exceeded 30 mg/l about 60 percent of the time, while the BOD_5 in the effluents from aerated lagoons equalled or exceeded 30 mg/l about 15 percent of the time.

It was not until suspended solids concentrations began to be used as a measure of lagoon effluent quality that most lagoons in Illinois were judged not to meet effluent standards. In the case of lagoon effluents, suspended solids concentrations are synonymous with algal density.

Generally, the effluent from lagoon systems in Illinois must not exceed 30 mg/l BOD_5 and 30 mg/l suspended solids. However, if the dilution ratio of receiving stream flow to effluent flow is less than 5 to 1, the BOD_5 must not exceed 10 mg/l and the suspended solids must not exceed 12 mg/l. Excepted from this requirement are lagoons with a 3-cell arrangement serving population equivalents of less than 2500 (Illinois Environmental Protection Agency, 1972). In all cases the water quality standards of the receiving stream shall not be exceeded.

Evans et al. (1978) indicate that the suspended solids concentrations of lagoons will on the average range from 40 to 50 mg/l, and concentrations of 30 mg/l will be equalled or exceeded from 60 to 75 percent of the time.

The distribution and probability of occurrence of suspended solids in effluents of non-aerated and aerated sewage lagoons are shown in figures 1 and 2.

There are two choices for minimizing the concentration of suspended solids in lagoon effluents. The suspended solids (algae) can be prevented from reaching the effluent or they can be removed from the effluent. Either case requires the imposition of an energy-dependent methodology resulting in some loss of the economic advantage of lagoon treatment. To minimize that loss, the most cost effective method for suspended solids reduction should be considered. In Illinois the most popular choice has been to remove the algae from the effluent rather than to use treatment within the lagoons. Whether or not this is the most cost effective procedure has not been determined.

The use of filters is the most prevalent technique employed to reduce suspended solids in lagoon effluents. The results reported here are from a study of the effectiveness of an intermittent sand filter in reducing suspended solids (algae) in the effluent of a lagoon system.

Objectives

The overall objectives of the study, as originally conceived, were to measure the efficiency of an intermittent sand filter in removal of suspended solids, BOD_5 , ammonia-nitrogen, and total phosphorus at varying rates of dosage and at differing intervals of dosage application. Unforeseen circumstances coupled with time constraints did not permit much planned variation in dosage rates and intervals of applications. Nevertheless the study did permit detailed observations leading toward a more rational understanding of:

- Suspended solids and BOD_5 removal
- Mechanisms limiting filter runs
- Hydraulic rates
- Operational considerations

Scope of Report

This report contains all the data useful for evaluating the efficiency of an intermittent sand filter as a "remover" of suspended solids originating from a lagoon system. A description of the treatment facilities is presented, the methodologies for sampling and analyses are outlined, and findings are offered that may be helpful for developing design criteria and operation modes. Liberal use is made of figures and tables to document the operational characteristics observed.

Acknowledgments

This investigation, sponsored and financially supported by the Illinois Environmental Protection Agency (IEPA), was conducted under the general

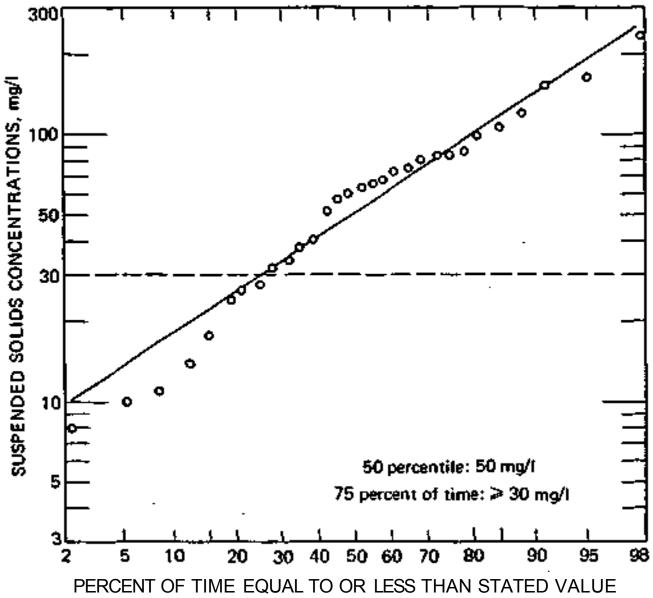


Figure 1. Distribution and probability of occurrence of suspended solids in effluents of non-aerated sewage lagoons

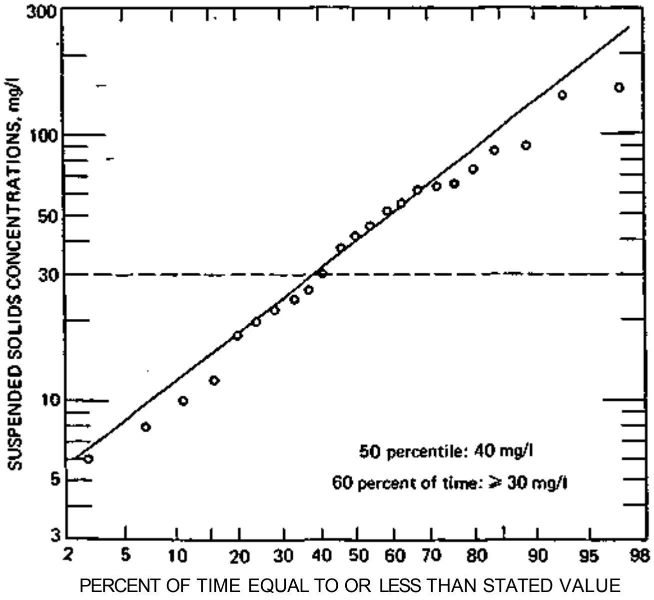


Figure 2. Distribution and probability of occurrence of suspended solids in effluents of aerated sewage lagoons

supervision and guidance of Stanley A, Changnon, Jr., Chief of the Illinois State Water Survey. Illustrations were prepared under the supervision of John Brother, Jr.; Gail Taylor edited the manuscript; and Linda Johnson typed the original manuscript and the camera copy.

Several members of the Water Survey's Water Quality Section participated in various phases of this investigation. David Hullinger and Dana Shackleford performed chemical analyses; Davis Beuscher identified and enumerated algae; and Janet Stowell collected samples and performed field analyses.

Among others to whom the authors are indebted are Ward Akers of IEPA, who offered technical guidance and encouragement; Kenneth Matousek of the Greater Peoria Sanitary District, who performed the BOD_5 analyses; Bud Derry, Superintendent of the Farmington Sewage Treatment Plant, who, with patience and understanding, cooperated extensively during the study; and Charles Ritchie of the firm of Crawford, Murphy, and Tilly, who provided design data and engineering plans.

SEWAGE TREATMENT FACILITIES

The site of the study is the sewage treatment facilities serving the City of Farmington, Illinois. The facilities, which are owned and operated by the Farmington Sanitary District, consist of a two-cell lagoon system followed by intermittent sand filters. The design criteria for the facilities are set forth in table 1, and a layout and flow scheme is included in figure 3. Operation of the plant commenced in the fall of 1979. This study was performed during the warm months of 1980 (May 1 to October 31).

Lagoons

Lagoon #1 is designed for an organic loading of about 25 pounds of BOD_5 per acre per day. At operating depths of 3 to 5 feet the water surface area is 32.2 to 32.9 acres, respectively. Lagoon #2, operating in series with lagoon #1, is also designed for a BOD_5 loading of 25 pounds per acre per day. At operating depths of 3 feet to 5 feet its water surface area is 8.0 to 8.4 acres, respectively. The displacement time within the ponds at the average design flow of 536,000 gallons per day, and the corresponding operation depths, are as follows:

	Depth	*Displacement time*
Lagoon #1	3'	58 days
	5'	98 days
Lagoon #2	3'	14 days
	5'	24 days

Thus the total displacement times for both lagoons at operating lagoon depths of 3 feet and 5 feet are 72 days and 122 days, respectively. The relationships of water depths in the lagoons to lagoon capacities and detention times, at the average design flow, are depicted in figure 4.

Table 1. Design Criteria for Sewage Treatment Facilities at Farmington

Design population	4800 persons
Design average flow	0.536 mgd
Daily peak flow	1.34 mgd
Design storm flow	2.60 mgd
Lagoon type	Two cell - facultative
No. of sand filters	2
Area of sand filters (total)	107,400 sq ft
Anticipated effluent	10 BOD_5/12 susp. solids

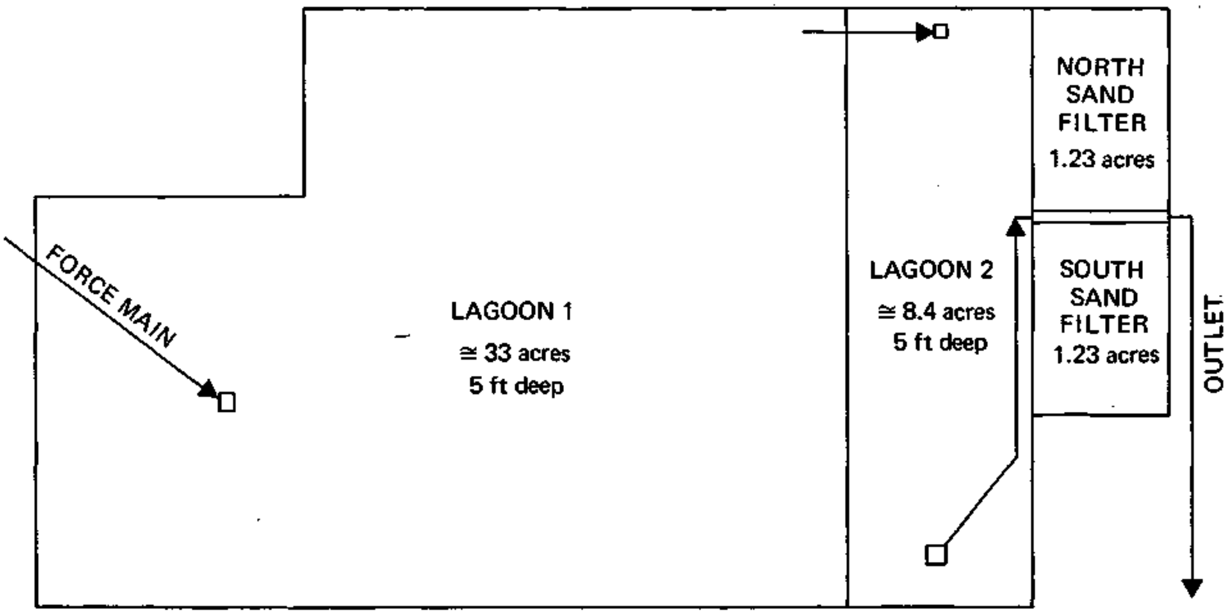


Figure 3. Layout and flow scheme of sewage treatment plant at Farmington

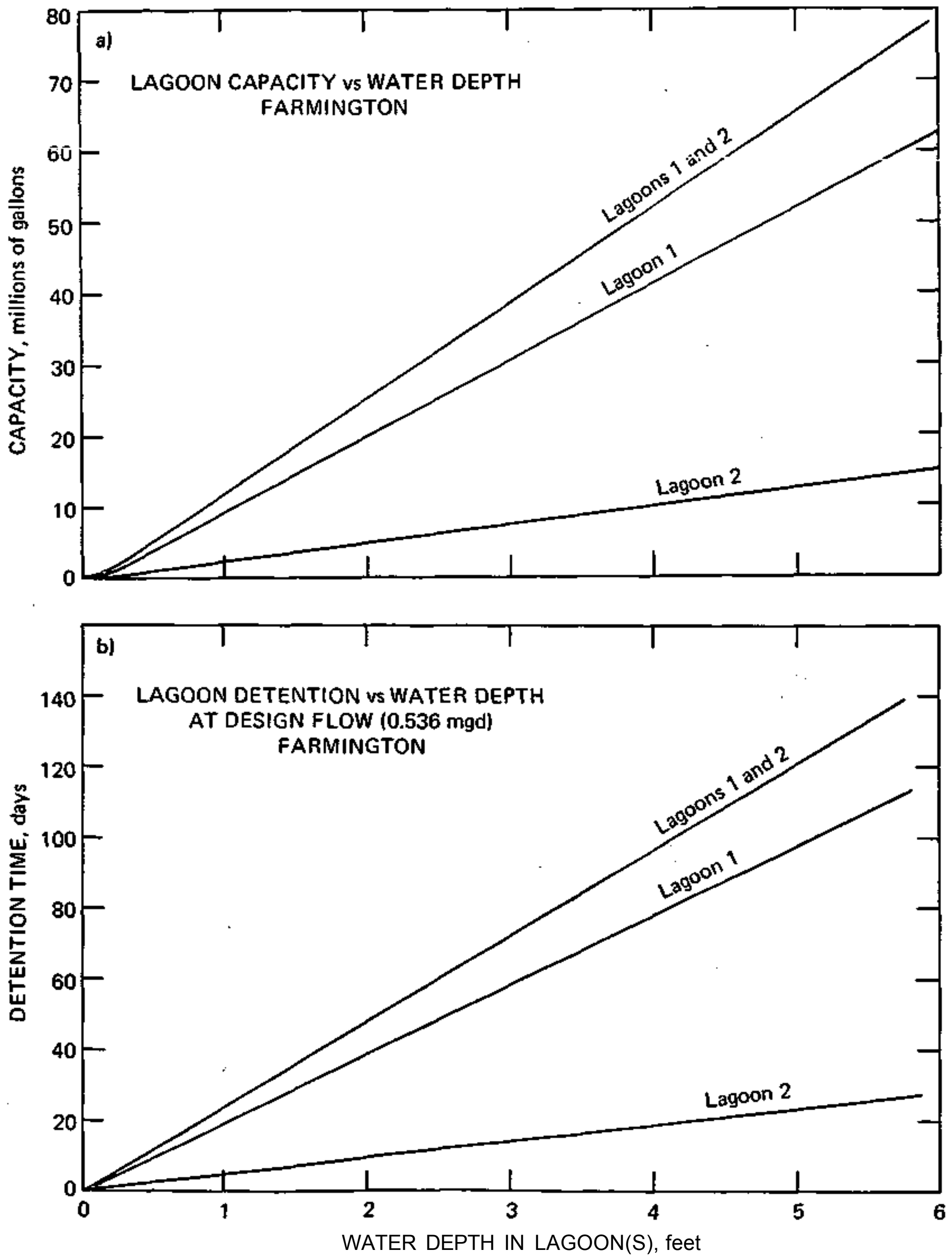


Figure 4. Relationships between water depth and a) lagoon capacity and b) lagoon detention time

Sand filter

The intermittent sand filter consists of two cells, each of which has a sand surface area of 53,700 square feet (1.23 acres). Two feet of sand are supported on a layer of gravel ranging in size from 1/3 inch to 1/4 inch. The pipe underdrain system consists of 4-inch perforated plastic pipe located on 10-foot centers. The two cells are designed to operate in parallel. Their design criteria are shown in table 2.

Effluent from lagoon #2 is delivered through a valved gravity flow 12-inch line to the distribution box of each filter. The box is located at the center of each filter cell. Flow from the distribution box is through 6-inch pipes to four splash plates from which lagoon effluent is applied to the sand surface. A layout and pertinent features of the filters are shown in figure 5. The filters can be operated singularly or in parallel. Flow of the filtered effluent through the underdrain system is governed by a valve that is manually regulated. There is provision to by-pass the filters if required. Anticipated effluent quality is 10 mg/l BOD_5 and 12 mg/l suspended solids.

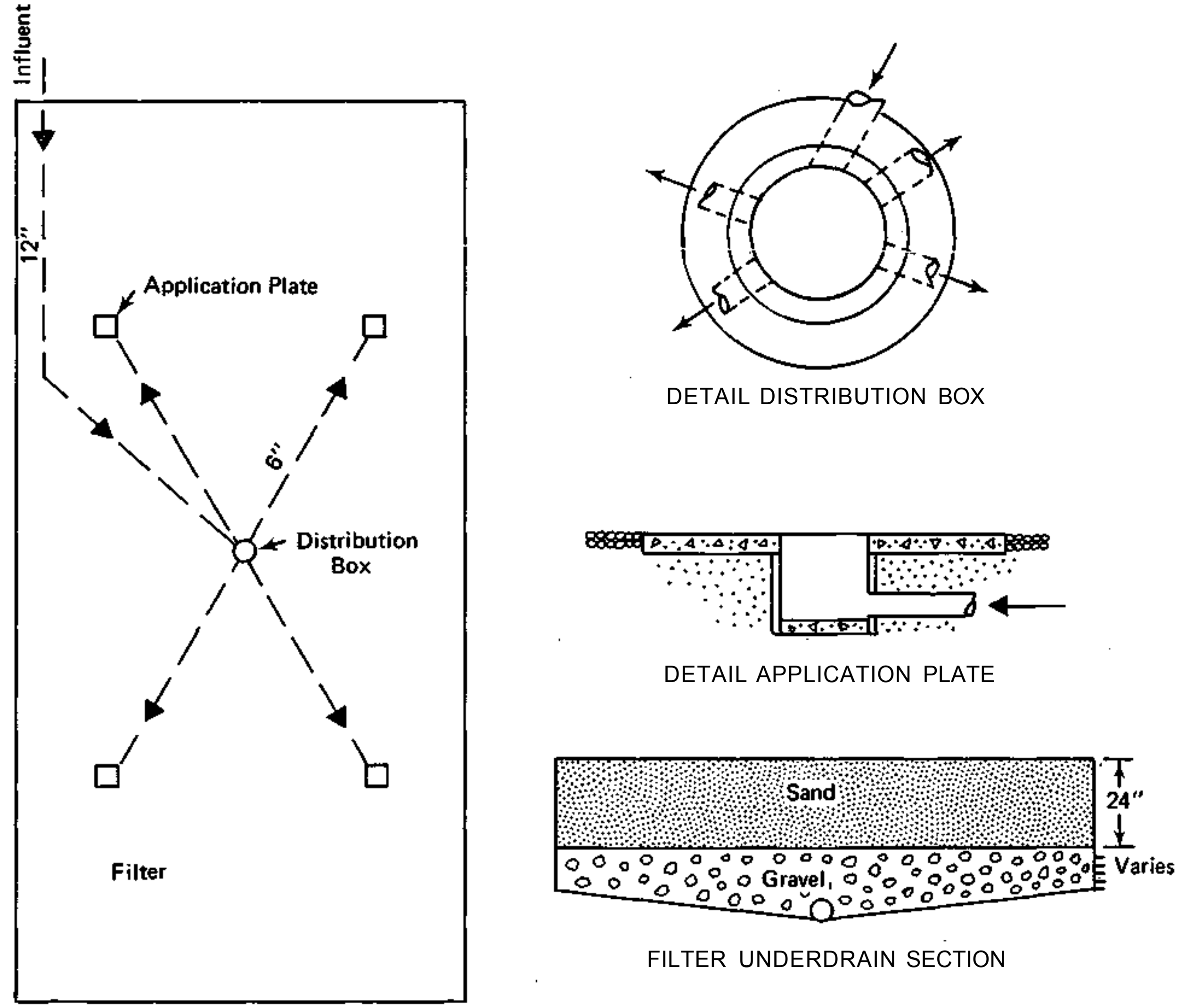
Operation of Filter

As originally conceived, both filter cells were to be equally flooded with about 536,000 gallons while the valves on the underdrain system were closed. The flooding was estimated to take 3 hours. After the selected water depth above the sand level was reached, the valves of the underdrain system were to be opened to permit a discharge rate of about 536,000 gallons for both filters within an 18-hour period. This would provide a filtration rate of 5 gallons per day per square foot, with a rest period of about 3 hours before the next dosage.

During the period of study the southernmost filter was selected for study. That filter was dosed three times a week (Monday, Wednesday, and Friday) to a water depth of about 9 inches, which took about 4 hours. With a sand porosity of about 30 percent the quantity of lagoon effluent applied to the filter was about 542,250 gallons. The valve on the underdrain system was regulated to permit emptying of the filter in about 24 hours. This provided an average filtration rate of 10 gallons per day per square foot. On alternate days the northernmost filter was dosed and operated in a similar manner.

Table 2. Design Criteria for Intermittent
Sand Filters at Farmington

Design average flow	0.536 mgd
Hydraulic loading at design flow	5 gpd/ft^2
Effective size of sand	0.30 mm - 1.0 mm
Uniformity coefficient	<3.5
Depth of sand	24"



DETAIL DISTRIBUTION BOX

DETAIL APPLICATION PLATE

FILTER UNDERDRAIN SECTION

Figure 5. Layout and features of the sand filters at Farmington

METHODS AND PROCEDURES

During the period of study, which extended over a 6-month period from May 1 to October 31, 1980, an effort was made to collect samples from the influent and effluent of the sand filter during each dosing cycle. On occasions the sampling schedule was not possible. Generally, however, samples were collected on Monday, Wednesday, and Friday of each week. In addition to the sampling of the influent and effluent of the sand filter, six samples were collected from the raw sewage and four samples were obtained from the city's potable water. Samples of the sand filter effluent were "grab samples" collected about 2-3 hours after filtration commenced. Previous work by Harris et al. (1978) indicated that the quality of an effluent from a sand filter preceded by lagoons did not vary significantly with time. Thus the collection of grab samples was a justifiable procedure. Samples representative of influent to the filter were "grabs" from lagoon #2. Previous experience (Evans et al., 1978) indicated this to be a satisfactory procedure.

Although most analyses were performed in the laboratory, some measurements were made in the field.

Field Measurements

During most collections of wastewater samples, field measurements were performed for temperature, dissolved oxygen, and pH. The temperature measurements were recorded with a glass thermometer. Dissolved oxygen concentrations were determined by the modified Winkler method as outlined by the American Public Health Association (1975). Determinations for pH were performed with a portable Metrohm-Herisau pH meter (model E588).

Wastewater samples for ammonia determinations received special handling. A 50-ml portion of the samples was filtered through a type HA, 0.45 µm millipore filter 37 mm in diameter. These filters were placed on filter pads held between two-piece circular holders, and positive pressure for filtering the samples was provided by a syringe to force the samples through the filters. The filtrates were collected in small plastic bottles. Micropore filtration is considered superior to acidification or other chemical additives for the preservation of samples to be analyzed for ammonia-nitrogen.

Laboratory Chemical Analyses

Chemical analyses for all wastewater samples collected at the plant site were performed routinely for ammonia-nitrogen, nitrate-nitrogen, total phosphorus, dissolved phosphorus, suspended solids, and volatile suspended solids. Most of the six samples collected from the raw sewage were examined for pH, suspended solids, volatile suspended solids, total phosphorus, ammonia-nitrogen, nitrate-nitrogen, and total dissolved solids. Most of the four samples collected from potable water were analyzed for alkalinity, pH, chloride, sulfate, ammonia-nitrogen, nitrate-nitrogen, potassium, sodium, total dissolved solids, and the metals iron, manganese, copper, mercury, zinc, and lead. Samples for heavy metal analyses were acidified in the field with nitric acid.

Procedures for performing chemical analyses were those recommended by the American Public Health Association (1975). A summary of the procedures is included in table 3.

Biological Determinations

Each wastewater sample at the plant site was also examined for BOD_5 and algae. The determinations for BOD_5 were performed by personnel of the

Table 3. Laboratory Analytical Procedures

Ammonia-N	Phenate method
Nitrate-N	Chromotrophic method
Total phosphorus	Digested with sulfuric-nitric acids mixture and determined by ascorbic acid method
Dissolved phosphorus	Ascorbic acid method after filtration (0.45 µm)
Total dissolved solids	Total filterable residue by evaporation, dried at 103-105°C
Suspended solids	Non-filterable residue through gooch crucible with glass fiber, dried at 103-105°C
Volatile suspended solids	Loss of suspended solids at ignition 550°C ± 50°C
Alkalinity	Titration to pH 4.5 with 0.02 NH_2SO_4
Chloride	Argentometric method
Sulfate	Turbidimetric method
BOD_5	Standard Methods
Iron	Digestion with nitric acid, atomic absorption spectrophotometry
Copper	Digestion with nitric acid, atomic absorption spectrophotometry
Manganese	Digestion with nitric acid, atomic absorption spectrophotometry
Mercury	Digestion with nitric acid, atomic absorption spectrophotometry
Lead	Digestion with nitric acid, atomic absorption spectrophotometry
Zinc	Digestion with nitric acid, atomic absorption spectrophotometry
Sodium	Atomic absorption spectrophotometry
Potassium	Atomic absorption spectrophotometry

Greater Peoria Sanitary District. All samples for BOD_5 analyses were set up within one to two hours of collection and examined according to APHA methods (1975).

Each algal sample was stored in a 380-ml, small-mouth glass bottle and preserved with 10 ml of formalin. Examinations for algae were generally performed within two weeks. At that time the sample was thoroughly mixed and generally a 1-ml aliquot was pipetted into a Sedgwick-Rafter counting cell. If algal counts were found to be low, a 50-ml aliquot was passed through a millipore HA filter (0.45 µm pore diameter), The residue was mixed in 10 ml of filtrate, and a 1-ml aliquot was then examined. A differential interference contrast microscope with 10X eyepieces, 20X or 100X objective, and a Whipple disc was used for identification and enumeration. Appropriate conversion factors were used to estimate algal density in terms of counts per milliliter.

Atmospheric Measurements

Certain measurements were recorded concerning atmospheric conditions during the period of study. A weather station was set up at the plant site which permitted continuous recording of rainfall, air temperature, humidity, wind direction, and wind speed. Rainfall was measured by a weighing-bucket rain gage with an 8-inch diameter top (Belfort Model 550). Air temperature and humidity were recorded with a bourbon-tube thermograph and a hair hydrograph, respectively (Bendix-Friez Model 594). Wind direction and wind speed were recorded by an instrument manufactured by Meteorology Research, Inc.

The weather data gathered as part of the study were not used in the data evaluation process but are included for the record. The station was established and data gathered with the realization that future work at the site, particularly that related to in-lagoon investigations, will be weather-related and several years' lead time of weather data collection will be helpful.

All data pertaining to field measurements, laboratory chemical analyses, biological determinations, and atmospheric measurements are included in the appendices.

CLIMATIC OBSERVATIONS

The climate in the vicinity of Farmington, Illinois, is typical of north-central Illinois. The annual range of temperatures often varies from minus 23 to minus 29 degrees Celsius (-10 to -20°F) in the winter to 38 degrees C (100°F) or higher in the summer. Low pressure areas, or storm centers and/or associated weather fronts, bring frequent short period changes in temperature, humidity, cloudiness, and wind direction.

January is normally the coldest month of the year. Eighty-five to 90 percent of the days from December to March are likely to have minimum temperatures below freezing.. On the average, the daily mean temperature is freezing or below from about the first of December until the last of February,

Summers are warm, but prolonged hot spells are not frequent, July is the warmest month on the average. However the temperature is likely to reach 32°C (90°F) or above on about half the days in July and August,

Light snows are frequent but falls of one inch or more average about 8 to 10 a year. The total annual snowfall averages about 25 inches, but more than 20 inches has fallen in a single month.

Thunderstorms average about 50 each year, with 65 percent of them occurring during the period May through August. A single thunderstorm can produce in excess of an inch of rain along with hail and damaging winds. Nearly 5 inches of rain has been measured in a 24-hour period.

Yearly precipitation averages about 35 inches. Only once has it been less than 27 inches. Nearly 60 percent of the yearly precipitation can normally be expected during the period between mid-April and mid-September.

Data regarding climate conditions at Farmington during the period April 28 to October 31, 1980, are included in appendix B.

Temperature

Daily recorded air temperatures for the study period are depicted in figure 6. The cyclic variation is typical of Illinois climate. The recorded high temperature was 31.5 C on July 15. A low temperature of 0.8°C occurred on October 27. In terms of the historical record, temperatures were moderate during the summer of 1980. Only during the month of July was there a prolonged period of time during which temperatures exceeded 26°C (79°F).

Humidity

Weekly average relative humidity values are shown in figure 7. Generally humidity exceeded 65 percent during the summer months. During all of August and the first half of September values were in excess of 75 percent. The highest value recorded was 95 percent on August 14 and 16.

Rainfall

Daily recorded rainfall is depicted in figure 8. Monthly rainfall, maximum daily intensity, and the number of rainfall events for the months May through October are summarized in table 4. Sixty-two rainfall events occurred during the period with nine of them exceeding a daily total of 1 inch. As shown in figure 8 the maximum rainfall event of 3.2 inches occurred on June 2 and was preceded by an event of 1.98 inches on the previous day. June was the wettest month with a total of 7.62 inches of rainfall. During August, however, 7.41 inches were recorded. The record during this period reflects a very wet period without a prolonged time of dryness.

Wind Speed

Weekly average wind speeds are shown in figure 9. On the average, recorded wind speeds were 4 miles per hour (MPH) or greater. A high of 23.0 MPH occurred on May 1, and only on 7 days did wind speed exceed 10 MPH. Minimum daily values ranged between 2 to 3 MPH.

As mentioned earlier in this report there has not been an effort to relate climate conditions to the operational efficiency of the sand filters. It is uncertain that such relationships exist. It is certain that the bio-

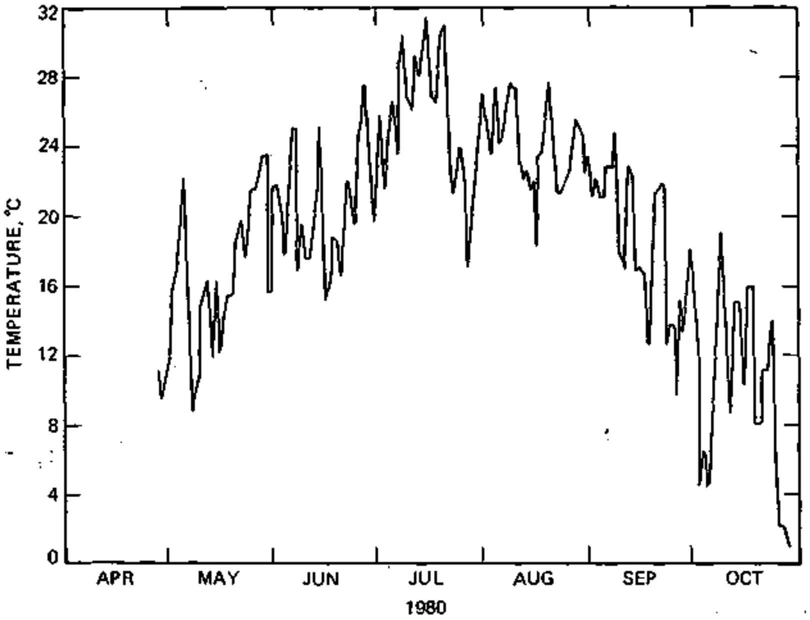


Figure 6. Daily air temperatures at Farmington during the study period

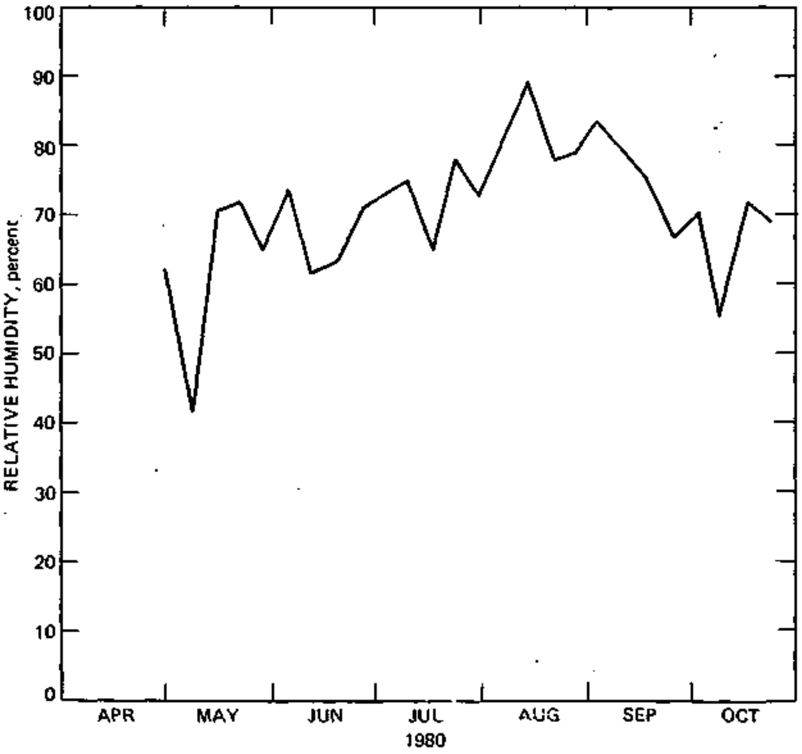


Figure 7. Relative humidity at Farmington (weekly averages) during the study period

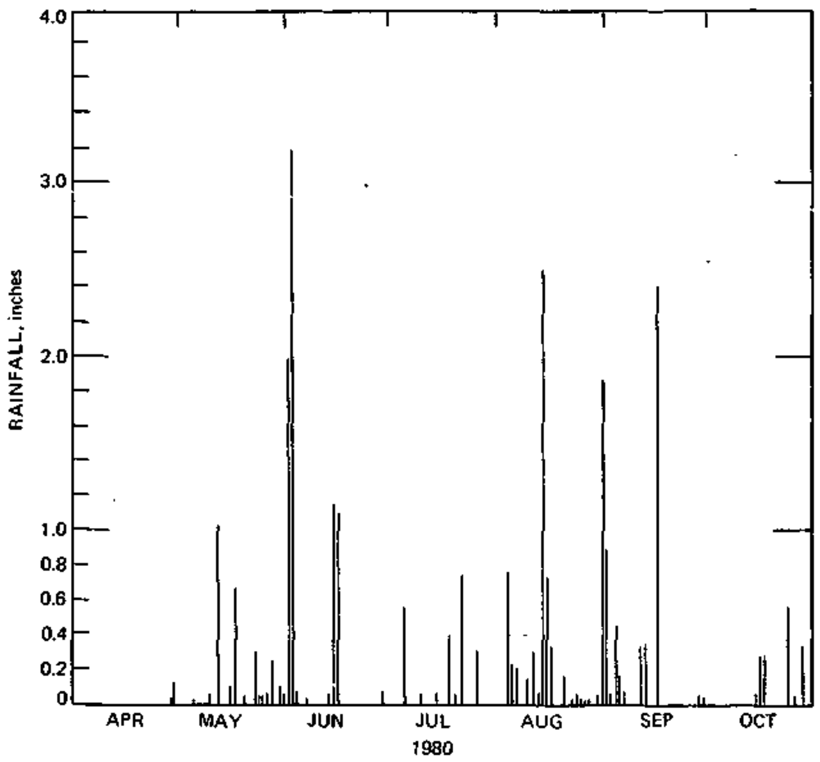


Figure 8. Daily rainfall at Farmington during the study period

Table 4. Monthly Rainfall at Farmington, 1980

	Total (in.)	*Maximum daily amt. (in.)*	*No. of events*
May	2.68	1.02	13
June	7.62	3.20	8
July	2.15	0.75	7
August	7.41	2.50	18
September	4.77	2.41	10
October	1.56	0.55	6
Total	26.19		62

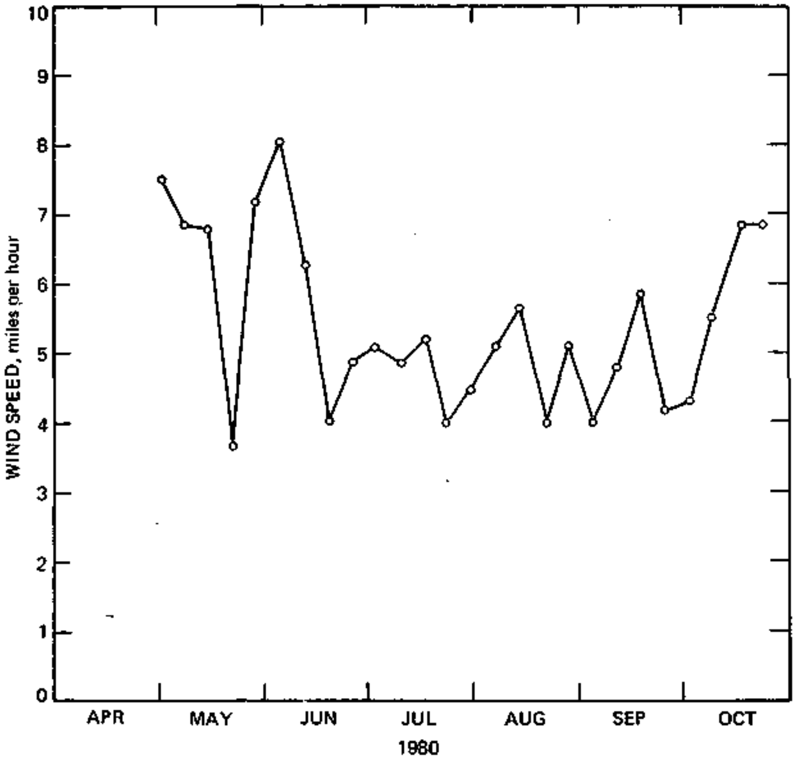


Figure 9. Wind speeds at Farmington (weekly averages) during the study period

logical and chemical reactions occurring in the lagoons are governed substantially by climatic conditions. The climate data base developed as part of this study is viewed as worthy if a continuation of the work at Farmington incorporates an examination of the lagoons and activities therein.

CHARACTERISTICS OF POTABLE WATER AND RAW SEWAGE

The mineral quality of the potable water in a small community, in the absence of significant industrial waste sources, governs the chemical characteristics of the raw sewage to be treated. This is the case at Farmington. Changes of the chemical characteristics do occur within the lagoons, which may in turn affect the efficiency of the filters.

Mineral Quality of the Water

The mineral quality of the potable water is summarized in table 5. It is obvious from these data that the water is highly mineralized, with

Table 5. Some Mineral Characteristics of Potable Water at Farmington

Date (1980)	*Temp*	*pH*	*Alk*	*Cl*	SO_4	NH_3-N	NO_3-N	*K*	*Na*	*TDS*
4/11	17.5	8.08	555	692	300	0.13	0.78	10.1	820	2250
7/2		8.10	548	679	324	0.43	0.19	10.0	890	2267
8/15	21.5	7.93	569	691	282		0.01	9.9	896	2306
9/22		8.22	482	626				11.8	725	2294

Note: All values are in mg/l except for temperature (°C) and pH

Table 6. Some Heavy Metal Concentrations of Potable Water at Farmington

Date (1980)	*Fe*	*Mn*	*Cu*	*Eg*	*Zn*	*Pb*
4/11	0.13	0.005	0.019		0.15	0.10
7/2	2.39	0.004	0.030	0.48	0.02	0.05
8/15	1.30	0.038	0.150	0.19	0.11	0.30
9/22	0.21	0.007	0.020	0.23	0.03	0.30

Note: All values are in mg/l except Hg (µg/l)

dissolved solids concentrations ranging from 2250 to 2306 mg/l. It is a well-buffered water with alkalinities varying from 482 to 569 mg/l. The sulfate content, averaging about 300 mg/l, suggests that odor problems in the vicinity of the lagoon site can become substantial in the absence of dissolved oxygen. The heavy metal content of the water, as shown in table 6, is not unlike most groundwater in Illinois. With the exception of iron, the concentrations are well within the maximum allowable concentrations for finished water quality (Illinois Pollution Control Board, 1979).

Characteristics of the Raw Sewage

Some characteristics of the raw sewage pumped to the lagoon system are shown in table 7. Total dissolved solids are high (1100-2700 mg/l) though generally less than those observed in the potable water. Ammonia-nitrogen concentrations range from 6 to 21 mg/l, which is typical of domestic sewage in Illinois. Total phosphorus varies from about 6 to 14 mg/l. Nitrate-nitrogen is generally less than 1 mg/l. Except on two of the six sampling dates, the suspended solids concentration was less than 60 mg/l. This indicates a rather dilute sewage for Illinois conditions. A comparison of rainfall occurrences (figure 8) with the dates of sampling (table 7) suggests that the sewerage system does convey water other than domestic sewage at times. If this is the case, the values noted in table 7 for phosphorus and nitrogen are conservative.

Table 7. Some Characteristics of Raw Sewage at Farmington

Vote (1980)	*Temp*	*pH*	*Susp. sol.*	*Vol. susp. sol.*	*Total P*	NH_3-N	NO_3-N	*TDS*
5/7		8.11	232	152	9.00	16.40	0.38	1962
6/9			51	40	8.40	9.05	2.36	2709
7/2	19.2	7.68	119	90	6.37	11.20	0.14	1912
8/15	21.5	7.62	47	34	5.92	6.40	1.18	1576
9/22			41	37	6.68	8.13	0.09	1676
10/20			57	42	14.21	20.60	0.29	1154

Note: All values are in mg/l except temperature (°C) and pH

MODIFICATION OF LAGOON EFFLUENT BY FILTRATION

Sand filters have been used for water treatment for over 150 years (Daniels, 1945). However, the more recent work of Grantham et al. (1947) in Florida led to the development of the first rational design for the intermittent sand filter as a unit for treating sewage. Later work by Calaway (1957) provided some insight into the role of the intermittent sand filter as an aerobic habitat for bacteria, protozoa, and aquatic worms. Calaway concluded that these organisms were an essential factor in the purification capability of the filter. Since these reports were published there have been many case histories cited regarding the efficiency of intermittent sand filters for the removal of suspended solids, BOD_5, ammonia-nitrogen, and coliform bacteria.

It is very important, however, to realize that: most of the literature cited prior to 1970 regarding the design and operation of intermittent sand filters as sewage treatment units pertains to the application of settled sewage to the filters. In other words the filters functioned as biological secondary treatment units preceded by primary settling tanks. It does not necessarily follow that the dosing rates, characteristics of the residual "Schmutzdecke" (mat of accumulated particulate substances), sand depth, sand size, and other operational or design features of a filter for settled sewage are equally satisfactory for the treatment of sewage lagoon effluent.

The basic difference between these two applications is the characteristics of the sewage applied to the filters. In the case of settled sewage, a large percent of the substances to be removed (BOD_5, nitrogen, phosphorus) are in soluble form. In the case of lagoon effluent, most of the same substances are in particulate form. As would be expected, with a design detention in excess of 100 days, the soluble constituents in lagoon effluent are refractory. Therefore the principal function of an intermittent sand filter following a lagoon system is to remove suspended solids, namely algae. Such installations also function as biological units.

The filtering efficiency of intermittent sand filters, whether they are dosed with settled sewage or lagoon effluent, is not limited by the size of the sand. As particulate substances are strained out of the dosage they accumulate on the surface of the filter in a mat (Schmutzdecke). Ultimately the dosage must pass through the mat before it can reach the filter medium. This is one of the reasons that the major clogging action occurs in the top 1-2 inches of the filter. In the case of lagoon effluent there are other reasons for clogging that will be discussed later.

The major point here is that it is a mistake to rely on the experience of applying settled sewage to sand filters when designing and/or operating filters to which lagoon effluent is applied. The observation by Parker and Uhte (1975) that "the state of the art of algae removal is in its infancy, especially with regard to treatment systems for small communities," continues to be true but to a lesser degree than in 1975.

The most definitive work undertaken to study the effectiveness and associated problems of modifying lagoon effluent by intermittent sand filters commenced in 1972-73 at Utah State University. The work of Middlebrooks et al. (1974, 1977) and Harris et al. (1975, 1978) has established excellent baseline information. But although they are useful, the experiences in Utah are not necessarily of universal application. Differences in the size of the sand (0.17 mm), the suspended solids concentrations in the lagoon effluent (an average of 30 mg/l), and climate conditions there suggest caution if the results are considered for conditions in Illinois.

As mentioned earlier the application rate of lagoon effluent to the filter at Farmington averaged about 10 gpd/sq ft. Observations regarding the removal of suspended solids, BOD_5, nitrogen, and phosphorus were made, and changes in dissolved oxygen, temperature, and pH during filtration were recorded. The following discussion summarizes these observations and notations.

Algae

Sixteen genera of algae were recovered from the influent to the sand filter. Generally, however, about three genera were present in each sample collected, with no more than four genera occurring at any one time. During the month of May the green algae Scenedesmus dimorphus predominated, making up 30-70 percent of the total algae population. At this time counts ranged from about 7000 to 50,000 per milliliter. Thereafter until the end of the study the blue-green algae Aphanizomenon flos-aquae was the dominant species, Until July it represented 40-70 percent of the population, and thereafter it made up about 90 percent of the total algae count. During the month of July and until termination of the study algal counts ranged from 150,000 to 400,000 per milliliter. The algae recovered at Farmington are listed in table 8.

Eleven genera of algae were recovered from the sand filter effluent. Generally three species were present in each sample; frequently, however,

Table 8. Algae Recovered at Farmington

A. Algae Recovered in the Influent of Sand Filter

1. Scenedesmus dimorphus (g)
2. Phacus pleuronectes (f)
3. Euglena viridis (f)
4. Fragilaria intermedia (d)
5. Scenedesmus acuminatus (g)
6. Aphanizomenon flos-aquae (bg)
7. Scenedesmus quadricauda (g)
8. Anacystis flos-aquae (bg)
9. Ourococcus bicaudatus (g)
10. Chlorella ellipsoidea (g)
11. Euglena gracilis (f)
12. Actinastrum hantzschii (g)
13. Chlorella pyrenoidosa (g)
14. Anacystis cyanea (bg)
15. Crucigenia rectangularis (g)
16. Anabaena spiroides (bg)

B. Algae Recovered in the Effluent of Sand Filter

1. Scenedesmus dimorphus (g)
2. Fragilaria intermedia (d)
3. Scenedesmus acuminatus (g)
4. Phacus pleuronectes (f)
5. Aphanizomenon flos-aquae (bg)
6. Anacystis flos-aquae (bg)
7. Euglena viridis (f)
8. Ourococcus bicaudatus (g)
9. Chlorella ellipsoidea (g)
10. Crucigenia rectangularis (g)
11. Anacystis cyanea (bg)

C. Algae Recovered in Influent but Not Effluent

1. Scenedesmus quadricauda (g)
2. Euglena gracilis (f)
3. Actinastrum hantzschii (g)
4. Chlorella pyrenoidosa (g)
5. Anabaena spiroides (bg)

Note: g = green algae; f = flagellates; d = diatoms; bg = blue-green algae

only one or two species were recovered. Except during the period June 20 to 25, when counts in the effluent ranged from 1360 to 2350 per milliliter, the total algal count in the effluent rarely exceeded 500 per milliliter. Although the green algae *Scenedesmus quadricauda* and *Actinastrum hantzschii* were recovered in 13 and 10 percent, respectively, of the 54 influent samples, these species were not recovered in the effluent of the sand filter. Three other species not recovered in the effluent are shown in table 8. However, their recovery in the influent was limited to between 1 and 3 occurrences.

All algal data pertinent to the study are included in appendix C.

Suspended Solids

Fifty samples each from the sand filter influent and effluent were examined for suspended solids concentrations. The values derived were distributed in a geometrically normal pattern; therefore a statistical evaluation of the data was undertaken using probability plots. As shown in figure 10 the geometric mean of suspended solids in the influent to the sand filter (lagoon effluent) was 100 mg/l, with concentrations ranging from 48 to 164 mg/l. The geometric mean of 100 mg/l is substantially higher than anticipated from previous work (see figure 1). Nevertheless, as shown also in figure 10, the effluent contained a geometric mean concentration of only 13 mg/l suspended solids, with a range of 2 to 44 mg/l. Ninety percent of the time the suspended solids concentrations in the filter effluent were equal to or less than 28 mg/l.

During the periodic dosing of the sand filter, on a 3 day per week schedule, there were interruptions due to "clogging." This will be discussed in more detail in a later section of this report. It is mentioned here solely to clarify the use of certain terms considered useful for evaluating the suspended solids data. The term "run" is used here to signify the period between initial dosing and clogging; i.e., the period of time the filter adequately functioned before clogging. The term "episode" is used to designate the number of dosages applied to the filter during the time it was functioning adequately. The term "downtime" is used for that period when the filter was non-operable due to clogging.

The efficiency of the filter as a treatment unit for reducing suspended solids over a 6-month period is shown in figure 11. It is quite obvious that significant variations occur daily in the suspended solids concentration in the influent and effluent of the filter. Even though the variation in the effluent appears less than in the influent, the relative variation or deviation from the mean in the effluent exceeds that in the influent (see figure 10). Attempts to derive a correlation between the concentrations applied versus the concentrations discharged proved fruitless. The development of such a correlation would be helpful in predicting probable effluent quality in terms of influent quality.

An attempt was made to develop an empirical expression that might be of some predictive value. Did a correlation exist between the suspended solids concentration applied and the concentration of suspended solids retained on the filter? For examining this relationship the following terms were used:

x = suspended solids in influent (mg/l)
y = suspended solids in effluent (mg/l)
z = suspended solids retained on filter (mg/l)

where $z = x - y$

The runs considered were #1, #2, #3 and #4 (combined), and #5. The downtime between #3 and #4 was so short that combining the two runs seemed justifiable. The linear relationships between the suspended solids applied and those retained for each run are shown in figure 12. The correlation coefficients suggest that 85 to 95 percent of the variation in the suspended solids retained is a function of the suspended solids applied.

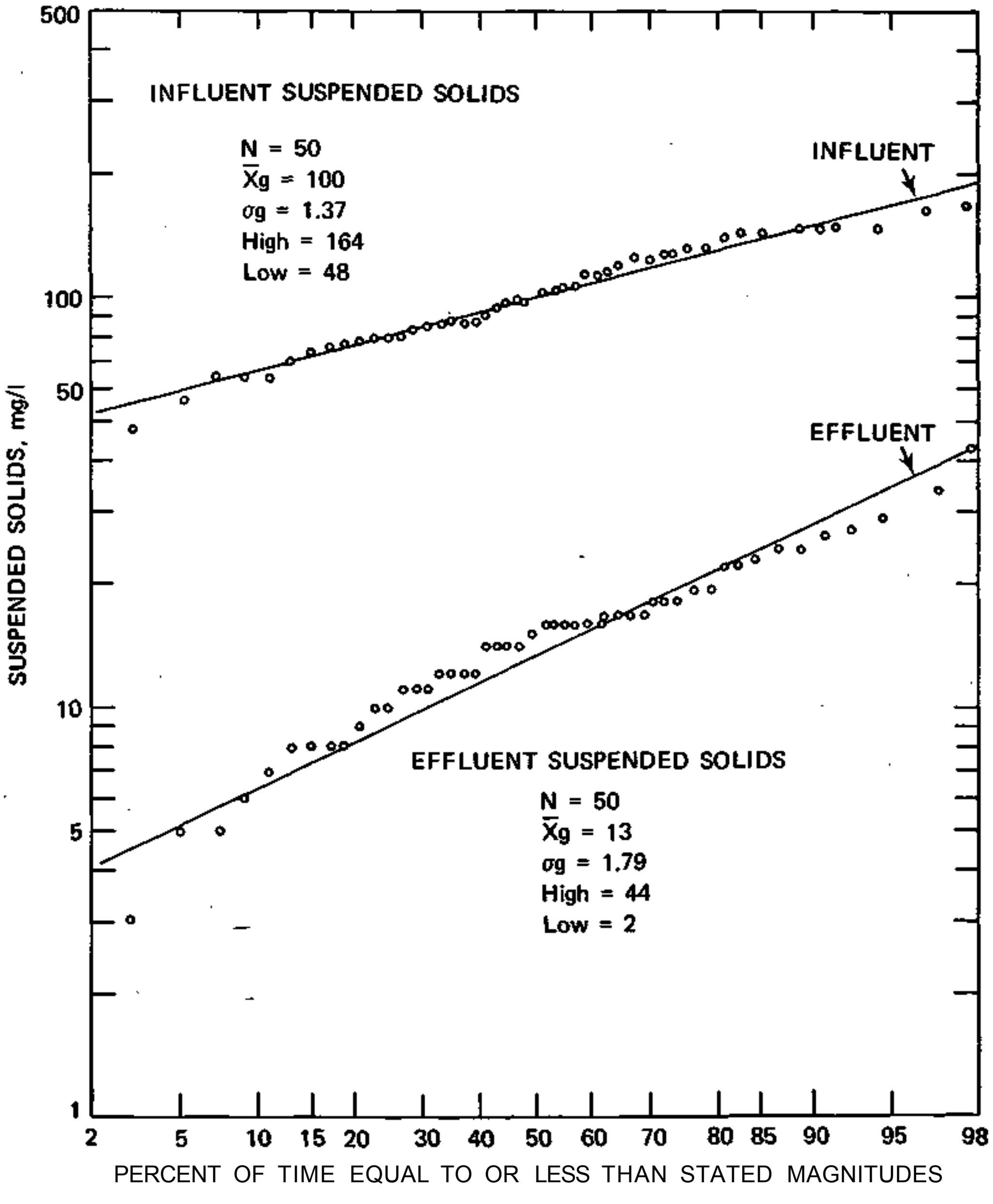


Figure 10. Probability plot for suspended solids in the sand filter influent and effluent

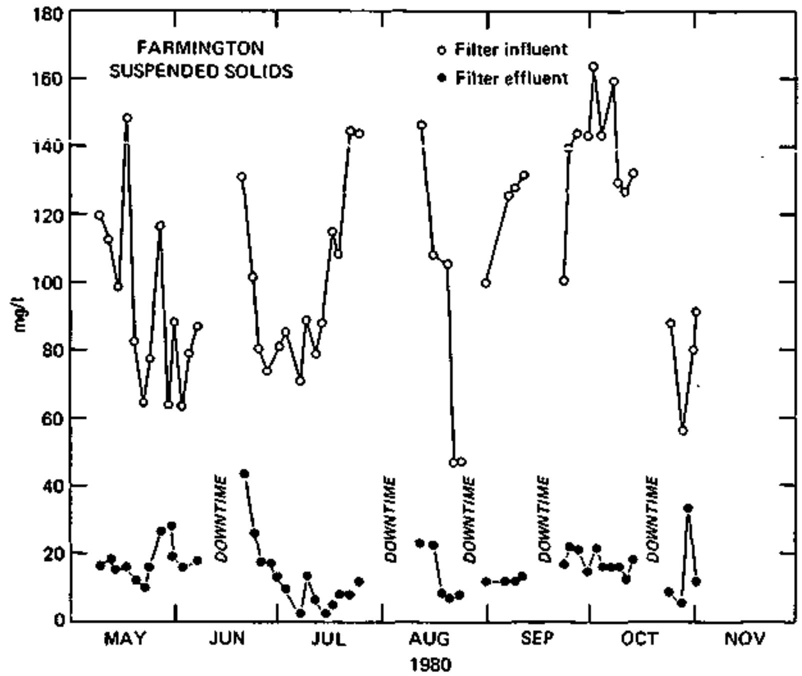


Figure 11. Suspended solids concentrations in the sand filter influent and effluent during the study period

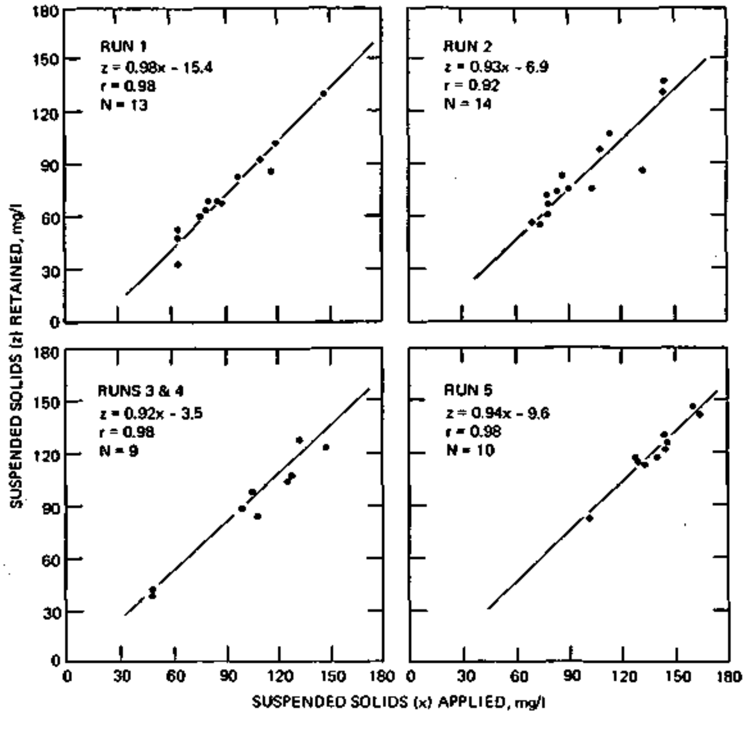


Figure 12. Linear relationships between the suspended solids applied and those retained

The mathematical expressions for these relationships, for each run, are:

Run #1 $z = 0.98x - 15.4$ $r = 0.98$ (1)
#2 $z = 0.93x - 6.9$ $r = 0.92$ (2)
#3 and #4 $z = 0.92x - 3.5$ $r = 0.98$ (3)
#5 $z = 0.94x - 9.6$ $r = 0.98$ (4)

Substituting in the equations the term $(x - y)$ for z, an empirical expression for each run is developed in terms of the influent suspended solids (x) and the effluent suspended solids (y). The predictive expressions for y in terms of x are:

Limits

Run #1 $y = 0.02x + 15.4$ $x = 64 - 168$ (5)
#2 $y = 0.07x + 6.9$ $x = 70 - 145$ (6)
#3 and #4 $y = 0.08x + 3.5$ $x = 48 - 146$ (7)
#5 $y = 0.06x + 9.6$ $x = 128 - 164$ (8)

Plots of predicted effluent quality (suspended solids) and observed effluent quality are shown in figure 13. With the exception of run #2, the differences in general between the predicted and observed values for suspended solids in the effluent are not too great. This is especially true when the range of values for the influent suspended solids concentrations are considered.

The efficiency of the sand filter as a remover of suspended solids varied from 83 to 89 percent for the 4 runs, assuming an applied concentration of 100 mg/1. The overall mean efficiency of the unit is about 87 percent.

Five-Day Biochemical Oxygen Demand

Forty-eight samples collected from the influent and effluent of the sand filter were examined for BOD_5 A probability plot of the results is shown in figure 14. The mean BOD_5 of the influent was 29 mg/l, and the mean BOD_5 of the effluent was about 7 mg/l. Ninety percent of the time the effluent BOD_5 was equal to or less than 13 mg/l. On the average the BOD_5 removal efficiency achieved by the filter was about 75 percent.

As shown in figure 15 there is not an apparent relationship between the concentration of BOD_5 applied and that discharged in the filter effluent. An examination of the suspended solids concentration in the effluent versus the effluent BOD_5 indicated a significant relationship. The regression equation derived was $BOD_5 = 0.28\ SS + 3.4$ ($r = 0.51$), indicating that about 25 percent of the variation in the effluent BOD_5 is influenced by the suspended solids content.

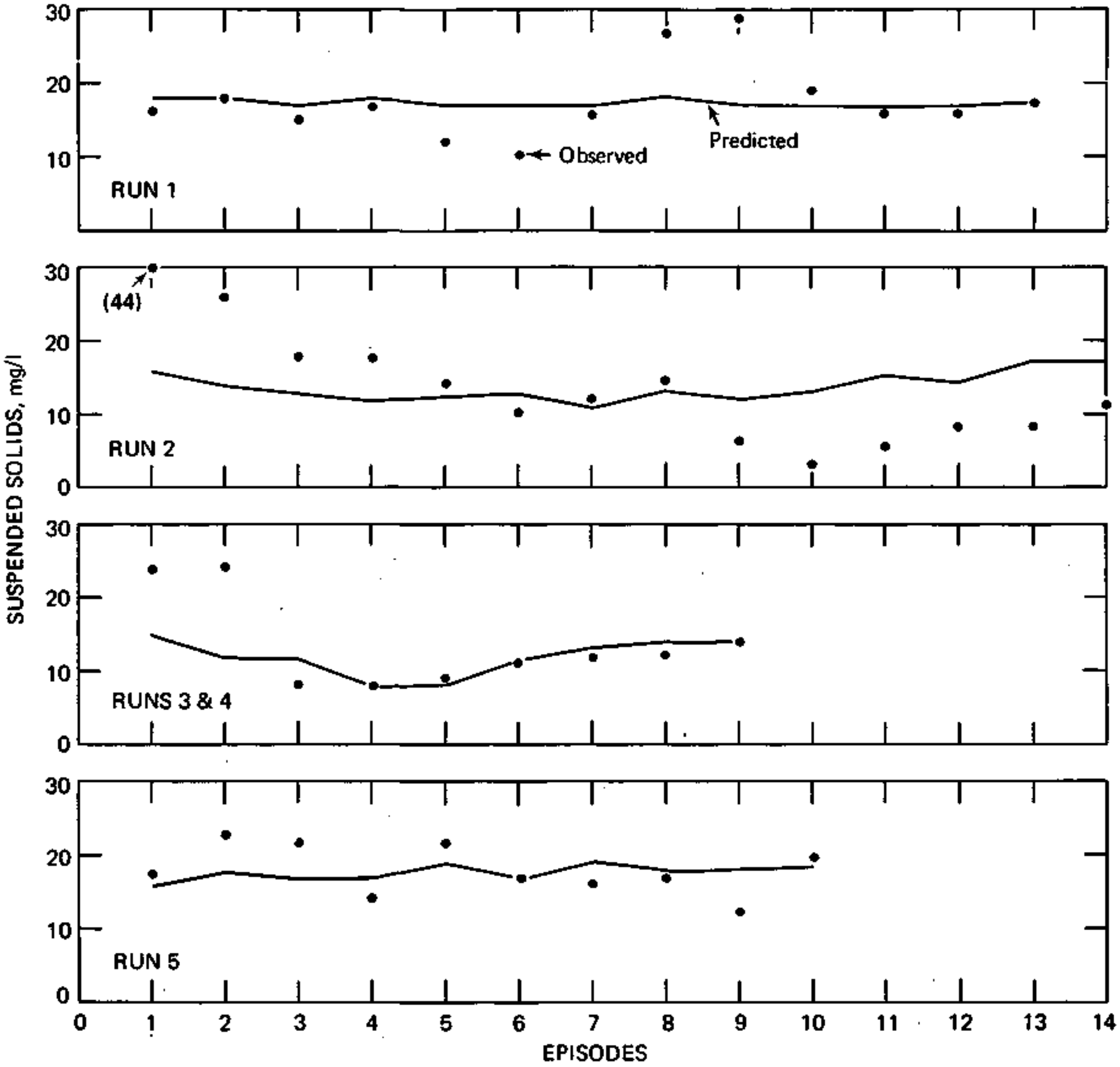


Figure 13. Predicted versus observed suspended solids concentrations in the sand filter effluent

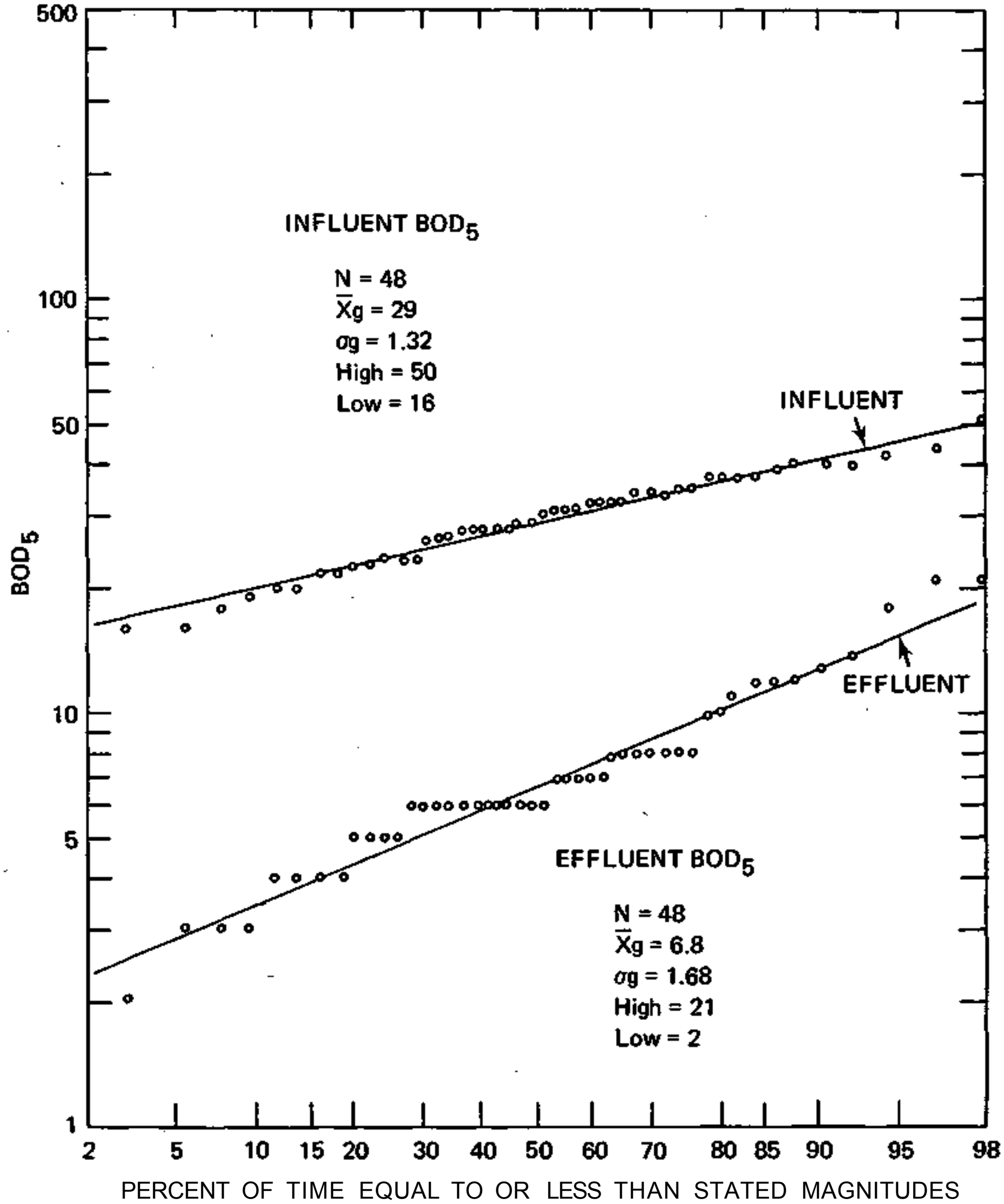


Figure 14. Probability plot for BOD_5 in the sand filter influent and effluent

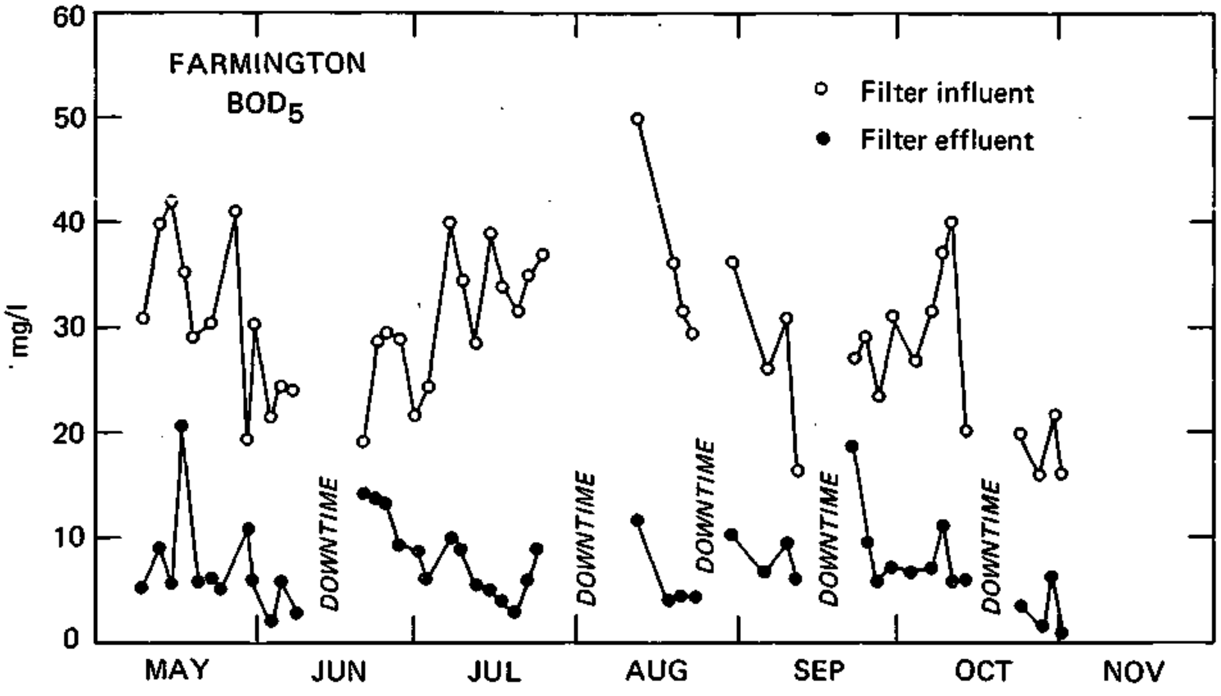


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Figure 15. BOD_5 concentrations in the sand filter influent and effluent during the study period

Dissolved Oxygen

The dissolved oxygen concentrations in the lagoon effluent varied from 5 to 20 mg/l with a mean of about 10 mg/l. The concentrations in the filter effluent varied from 0.3 to 8 mg/l with a mean of about 4 mg/l. The temporal changes are shown in figure 16.

It is obvious that supersaturated conditions occurred in the lagoons. This is not unusual for Illinois conditions, particularly at Farmington where algae densities ranged as high as 400,000 counts per milliliter. Stumm and Morgan (1970) report that 1.2 mg/l of dissolved oxygen is produced for each milligram of algal cells synthesized.

Researchers in Utah (Middlebrooks et al„, 1974, 1977; Harris et al., 1975, 1978) observed very little change in dissolved oxygen concentrations during passage of sewage through sand filters. This was not the case at Farmington. As shown in figure 16 the reduction was often substantial though dissolved oxygen was always maintained in the filter effluent.

This suggests that significant biological reactions occurred within the sand media under aerobic conditions. It is not likely, on the basis of observed BOD_5 reductions, that the demand for carbonaceous oxidation is the

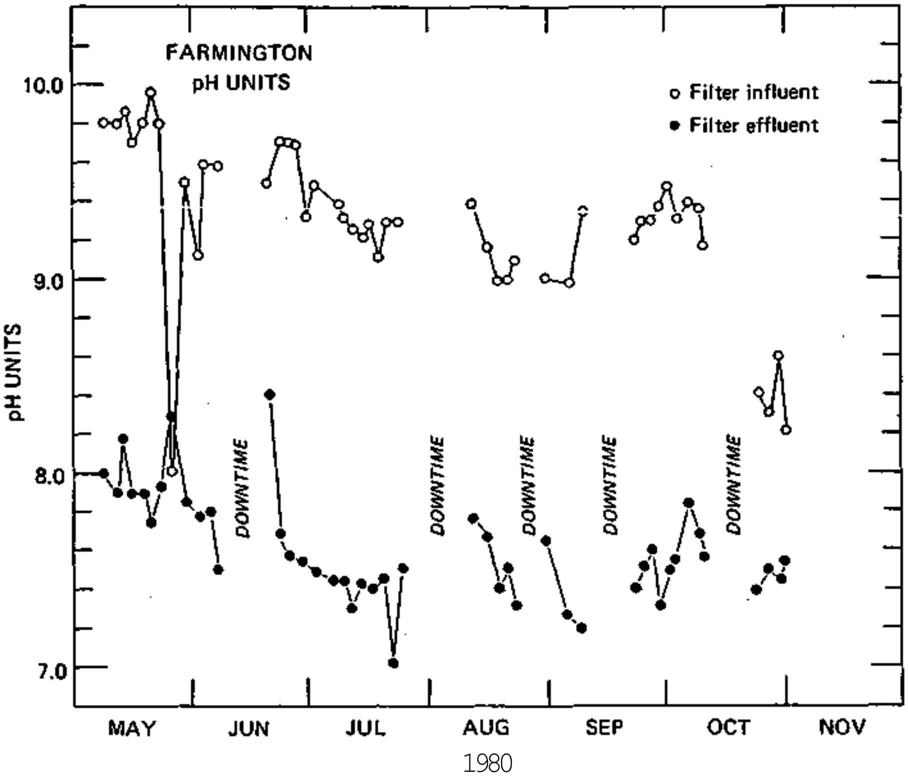

Figure 17. pH levels in the sand filter influent and effluent during the study period

logical activity in the third cell of a lagoon system is generally lessened from that in the second cell. This is fairly well demonstrated by the fact that the observed -mean suspended solids concentrations (algal cells) in the effluent of three-cell systems were about 50 mg/l compared to the effluent of the two-cell system at Farmington of 100 mg/l.

High pH conditions (9 to 10) in lagoons are a direct function of algal activity. Conversely, the lowering of pH in lagoon systems ig principally a function of bacterial activity whereby carbon dioxide (CO) is produced. It is postulated that bacterial activity as evidenced by the demand for dissolved oxygen within the sand filter is the main cause for pH reductions during passage of lagoon effluent through the filter.

Temperature

The temperatures observed for the influent and effluent of the filter are shown in figure 18. As expected, the temperature cycle is similar to that recorded for air temperatures (figure 6). Generally there was less variation in the temperature of the filter effluent than in the lagoon,

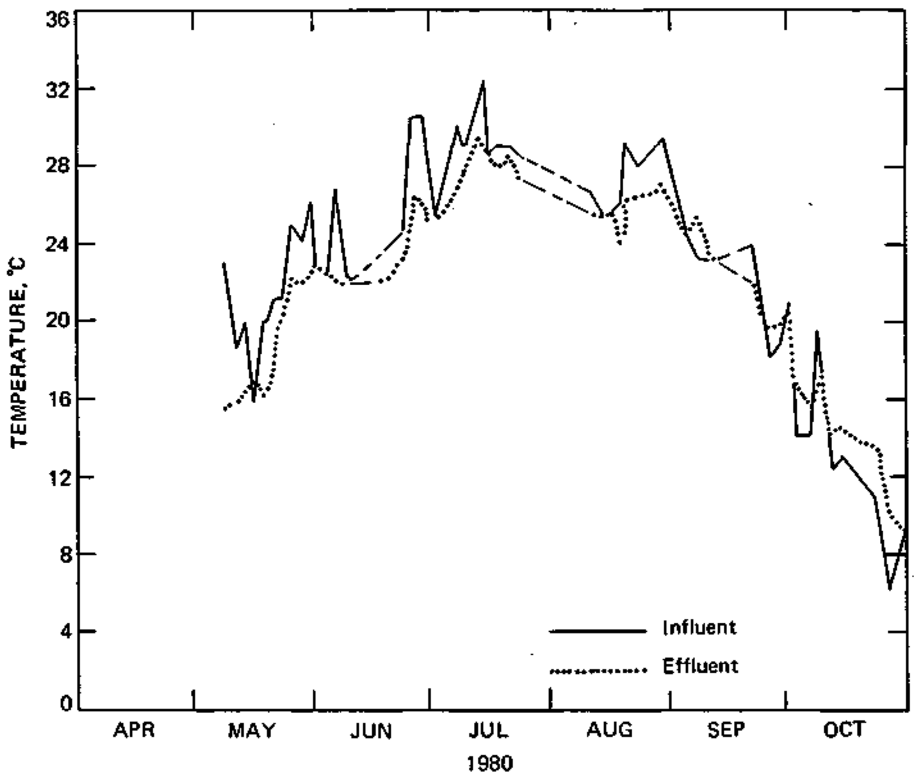

Figure 18. Temperatures of the sand filter influent and effluent during the study period

and until the commencement of the fall months (September) the temperature of the filter effluent was lower than the temperature of the contents of the lagoon. During the period of May through September, temperatures within the sand filter were 16°C or greater, with a maximum of about 29°C occurring during mid-July.

Nitrogen

The nitrogenous substances examined during the course of this study were limited to soluble ammonia-nitrogen (NH -N) and nitrate-nitrogen (NO_3-N). Determinations for organic nitrogen were not performed. In retrospect it would have been desirable to determine organic nitrogen concentrations, which would have permitted an examination of the mass nitrogen balance within the system. Nevertheless the existing data will suffice to permit a reasonable assessment of the response of NH -N and NO_3-N concentrations during passage through the treatment system.

Ammonia-nitrogen concentrations varied from 6.4 to 21 mg/l in the raw sewage. A substantial reduction of NH3-N occurred within the lagoons as evidenced by the mean concentration of 0.3 mg/l applied to the sand filter.

The NO_3-N concentration applied to the filters also averaged 0.3 mg/l. McCarty (1970) suggests that nitrogen can be removed biologically from wastewater by three different processes: bacterial assimilation, algal harvesting, and nitrification-denitrification. It is not likely that the substantial reduction of NH_3-N that occurred in the lagoons is due to bacterial assimilation. Experience has shown that bacterial assimilation is generally limited to a fixed-film process or, in the case of a mixed reactor, to the activated sludge process. Nor is it likely that nitrification occurred within the lagoons to any significant degree, because of the absence of significant concentrations of NO_3-N in the lagoon effluent. It is conceivable therefore that any NH_3-N reduction occurring in the lagoons from a "biological process" is limited to that NH_3-N incorporated into algal cells.

Aside from a direct biological process, there is the possibility that the NH_3-N may have been lost to the atmosphere. King (1979) reports that under the high pH maintained within a lagoon by continued photosynthetic extraction of carbon dioxide from the carbonic species of alkalinity, the ammonium ion (NH_4^+) is rapidly dissociated to free ammonia gas (NH_3) and is thus lost to the atmosphere. His experience in Michigan suggests that the decrease of nitrogen is a function of detention time according to the equation:

$$N_t = N_o e^{-.03t}$$

where

N = total nitrogen (mg/l) at any time

N_o = initial total nitrogen (mg/l)

t = time in days

According to King, 15 to 20 mg/l of total nitrogen was reduced to about 0.5 mg/l within a detention time of 120 days.

In the absence of bacterial assimilation and nitrification it is reasonable to assume that the reduction of NH_3-N in the lagoons at Farmington is the result of two processes. One is a biological process whereby the NH_3-N is incorporated into algal cells. The other is a physical process wherein the NH_3-N, in gaseous form, is lost to the air.

As shown in figure 19a the NH_3-N concentration applied to the sand filter was minimal until the occurrence of cool weather (water temperature 6-10°C) during late October.

As mentioned previously the mean concentration of NO_3-N applied to the filter was 0.3 mg/l. As shown in figure 19b there was a significant concentration of NO_3-N in the filter effluent. Concentrations ranged from 1.1 to 15.4 mg/l with a mean of 6.8 mg/l. This supports the view that the process of nitrification was occurring within the sand filter.

In the absence of data regarding the quantity of organic nitrogen being applied to the filter, one can only speculate as to the source of

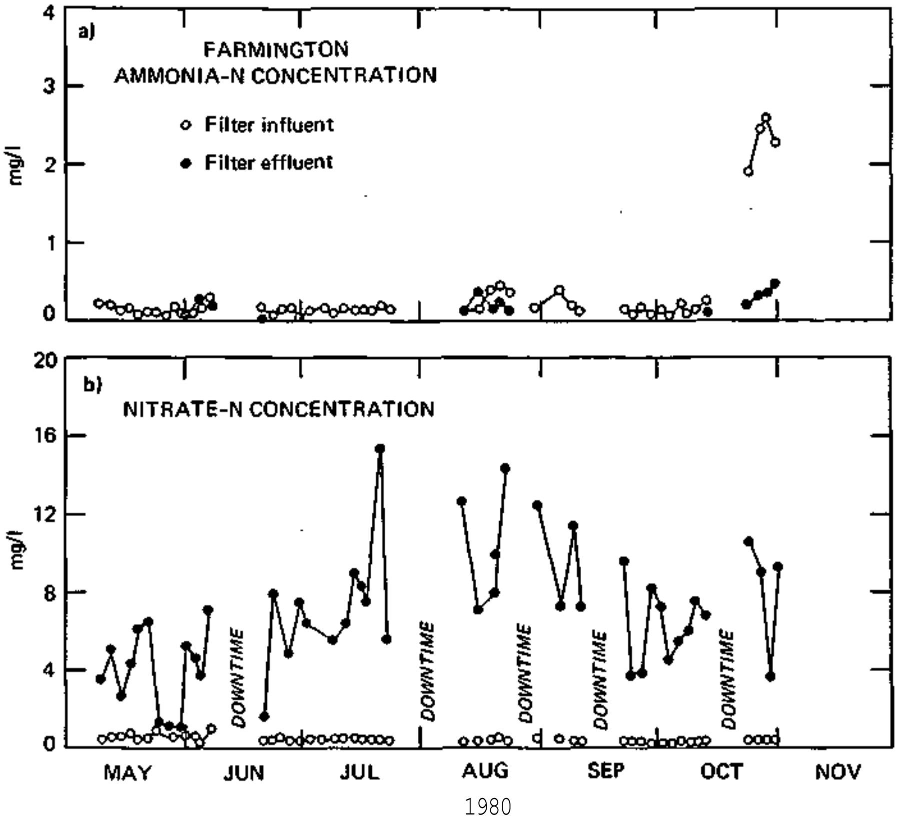

Figure 19. a) Ammonia-nitrogen and b) nitrate-nitrogen concentrations in the sand fitter influent and effluent during the study period

NH_3-N that is being converted to NO_3-N within the filter. However if the hypothesis is accepted that algal cells incorporate NH_3-N while in the lagoon, then it is likely that quantities of organic nitrogen are being applied to the filter in the form of algal cells. According to Sawyer and McCarty (1967) organic nitrogen can be converted to NH_3-N by bacterial activity under aerobic as well as anaerobic conditions. If this occurs in the filters at Farmington, ample quantities of NH_3-N would be available to sustain the nitrification process and produce the NO_3-N concentrations observed in the filter's effluent.

Nitrification of NH_3-N to NO_3-N requires about 4.5 mg/l of dissolved oxygen per milligram/liter of NH_3-N converted. This may explain the reason for depressed dissolved oxygen concentrations in the filter effluent (see figure 16) compared to those applied.

The reduction of BOD_5 coupled with the increases in NO_3-N concentrations support the contention that the sand filter functions as a biological unit as well as a "strainer" for removing particulate matter.

Phosphorus

Measurements were made for total and dissolved phosphorus. The average concentration of total phosphorus applied to the filter was 2.2 mg/l. The average concentration of dissolved phosphorus applied to the filter was 1.1 mg/l. In other words, on the average, the dissolved phosphorus applied represented 50 percent of the total phosphorus applied. Thus 50 percent of the phosphorus applied to the filter was in particulate form.

The temporal reduction of phosphorus during passage through the filter is shown in figure 20. The total phosphorus in the effluent averaged 1.1 mg/l, suggesting a 50 percent reduction. On the average, there was no reduction of dissolved phosphorus. An average of 1.1 mg/l was applied and an average of 1.0 mg/l remained in the filter effluent. Thus it is clear that the phosphorus removed by the filter, on the average, is limited to that incorporated in algal cells. This is consistent with the findings of others.

As shown in figure 20a the total phosphorus concentration in the filter influent reached a maximum of 3.4 mg/l during the month of September. Concentrations in the effluent were quite stable during the course of the study. A review of figure 20b indicates that some reduction of dissolved phosphorus, on the order of 0.5 mg/l, did occur during August and September. It is not inconceivable that this apparent reduction was due to direct sorption of dissolved phosphorus on the residues within the filter. Since the residues may have a finite capacity to sorb phosphorus, the reduction is one that cannot be relied upon for any extended time period.

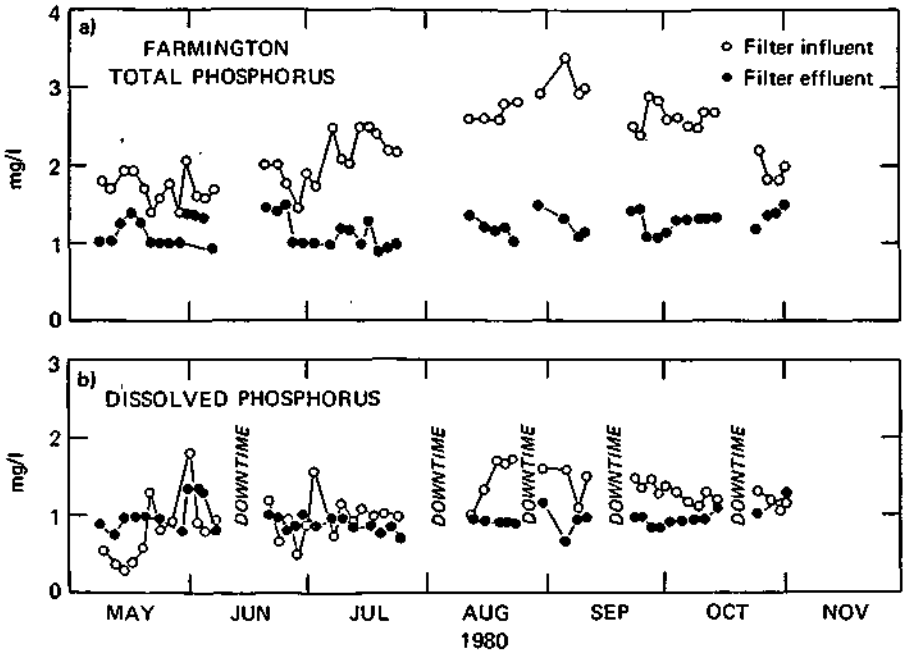

Figure 20. a) Total phosphorus and b) dissolved phosphorus concentrations in the sand filter influent and effluent during the study period

FUNCTIONAL OPERATION OF THE FILTER

A pertinent concern to the operation of granular media filters is clogging and subsequent "downtime." All granular media filters ultimately clog, and intermittent sand filters to which lagoon effluent is applied are no exception. In contrast to other filtering arrangements, the intermittent sand filter treating lagoon effluent is not equipped with 1) flow rate controllers, 2) head loss gages, or 3) backwash facilities. Nor are the dosages applied to it subjected to a pre-treatment process that will permit a predictable influent quality. The operation of intermittent sand filters is consequently an art, not a science. It is therefore incumbent upon the operators, designers, and researchers of intermittent sand filters to exchange views of their respective experiences relative to the operation of these units.

The reports of other researchers reviewed during the course of this study as well as the experience developed from this study point to one indisputable fact. The major clogging site is limited to the top of the filter, within a depth of 1 to 2 inches, and the scraping, raking, or scarifying of the top of the filter at 1 to 2 inches of depth permits the filter to operate once again in a normal mode.

The observations of the filter at Farmington covered a period of 184 calendar days. The times of operation before clogging, and the downtime, are shown in table 9. The total days of filtering operations were 57. The downtime was 20 days. Thus the filter was inoperable 26 percent of the operation days. Experience later showed that the downtime at Farmington could have been reduced to about 10 days, but the availability of the "second" filter did not impose any urgency to get the clogged filter back on line. Generally about 2-3 days were required to scarify the filter with a garden tractor pulling a harrow. This procedure scarified the top 2 inches of the sand and readied the filter for another run.

The lengths of filter runs, as shown in table 9, varied from 10 to 16 days. Assuming that filter renewal operations could be completed within 2 days, the percent of downtime could be limited to 13-20 percent. This is consistent with the observations at Utah (Middlebrooks et al., 1974, 1977; Harris et al., 1975, 1978).

Filter clogging is considered a function of several factors. These include:

1) Characteristics of the media

2) Rates of filtration

3) Retention of solids

4) Chemical and biological activity

Observations at Farmington relative to these factors are summarized in the following discussion.

Table 9. Time of Operation and Time of Interruptions
of Sand Filter at Farmington

Time of operation

Run	*Bates*	*No. of calendar days*	*No. of operation days*
#1	May 1 - Jun 6	37	16
#2	Jun 20 - Jul 23	34	14
#3-4	Aug 11 - Sep 10	31	13
#5	Sep 22 - Oct 13	22	10
#6	Oct 24 - Oct 31*	8	4
	Total	132	57

Time of interrupted operations (downtime)

Bates	*No. of calendar days*	*No. of sched. operation days*
Jun 7 - Jun 19	13	5
Jul 24 - Aug 10	18	7
Sep 11 - Sep 21	11	4
Oct 14 - Oct 23	10	4
Total	52	20

* End of study

Note: Total calendar days (132 + 52) = 184
Total sched. operation days (57 + 20) = 77
Percent downtime (calendar days) =28
Percent downtime (operating days) = 26

Media Characteristics

On several occasions analyses were performed on sand samples collected from the filters at Farmington. Examinations were made for particle size distribution, calcium carbonate, volatile solids content, and clay content. The results except for clay content are shown in table 10. The specifications for the sand required an effective size (D_{10}) within the range of 0.30 mm to 1.0 mm (see table 2). The required uniformity coefficient was to be less than 3.5. The results in table 10 show that the sand generally met the specifications although the effective size provided is at the lower end of the spectrum of the requirements. The clay content was generally less than 0.5 percent.

The results pertaining to calcium carbonate ($CaCO_3$) and volatile solids are interesting. In 1980 after almost a full summer of operation the percentage of $CaCO_3$ was elevated (9.6 percent) in the upper 1 inch of the sand. The percent volatile solids was also elevated. The increase of $CaCO_3$ is

Table 10. Analyses of Sand from Intermittent Sand Filters at Farmington

Date	*Location*	*D60 (mm)*	*D10 (mm)*	*Uniformity coefficient*	*$CaCO_3$ (%)*	*Volatile (%)*
7/28/80	Composite	0.80	0.26	3.08		
8/8/80	Top 1"	0.76	0.38	2.00	9.6	1.0
	1"-6"	0.81	0.28	2.89	5.4	0.6
	6"-12"	0.82	0.31	2.65	4.9	0.5
11/25/80	0"-3"	0.91	0.36	2.53		
	3"-9"	0.92	0.28	3.29		
	9"-15"	0.80	0.39	2.76		
5/12/82*	Top 1"	1.00	0.27		3.8	2.0
	1"-6"	0.72	0.27		3.6	0.6
	6"-12"	0.73	0.27		4.1	0.5
	12"-18"	0.78	0.28		4.2	0.4
8/5/82*	Top 1"	0.84	0.35	2.41	5.7	2.3
	1"-6"	0.68	0.35	2.00	4.6	1.0
	6"-12"	0.74	0.31	2.40	4.5	0.6
	12"-18"	0.79	0.31	2.56	4.7	0.4

* Average of 4 locations on filter

likely due to chemical precipitation, while the increase in volatile solids is due to algal cell retention on the filter. In May 1982 the $CaCO_3$ was not elevated, suggesting a reduction during winter months, but in August 1982 it was once again elevated. The volatile solids content had also increased from about 1 percent to 2.3 percent over the course of two years. These observations indicate that some changes are occurring in the sand filter and that the changes are limited to the upper 1 to 2 inches of the sand. More will be said later about the significance of these changes.

Rate of Filtration

The usual design and operation of intermittent sand filters do not lend themselves to satisfactory monitoring of the filtration rates being applied. At Farmington the underdrain system is provided with a manually operated effluent valve. The valve was closed during the period of dosage until a water level depth of about 9 inches above the top of the sand was achieved. The valve was turned a number of times (from 4 to 7 half turns) with the hope that this would permit the filter to empty in about 24 hours. This provided an average filtration rate of about 10 gallons per day per square foot.

The valve opening on the effluent line is not the sole factor influencing filtration rates. The rate of filtration will also vary with the characteristics of the influent, length of run, interval of dosages, and operating head.

In order to obtain a better estimate of the rate of filtration, a stilling well and float-actuated recorder were installed in the filter. The arrangement consisted of a Stevens type F recorder equipped with a 7-day clock actuated by a 4-inch diameter float housed in a 12-inch diameter tile extending through the 24-inch sand depth to gravel. The arrangement provided a recorded fall in water level with time and thus an estimate of filtration rates. It also provided information that was useful to the operator relative to impending clogging conditions.

The rates of filtration estimated from the float-recorder arrangement are shown in figure 21. The rates ranged from about 4 to 24 gallons per day per square foot (gpd/ft^2) of filter area. The average rate was 9.5 gpd/ft^2, or about 10 gpd/ft^2. Also noted in figure 21 are the operating and non-operating intervals. The variation observed in the filtration rates demonstrates the problem that must be overcome by the operator to achieve performance in accordance with design.

Harris et al. (1978) concluded that the optimum filtration rates for intermittent sand filters ranged from 9 to 13 gpd/ft . They also suggested that plugging increases exponentially with hydraulic loading rate increases.

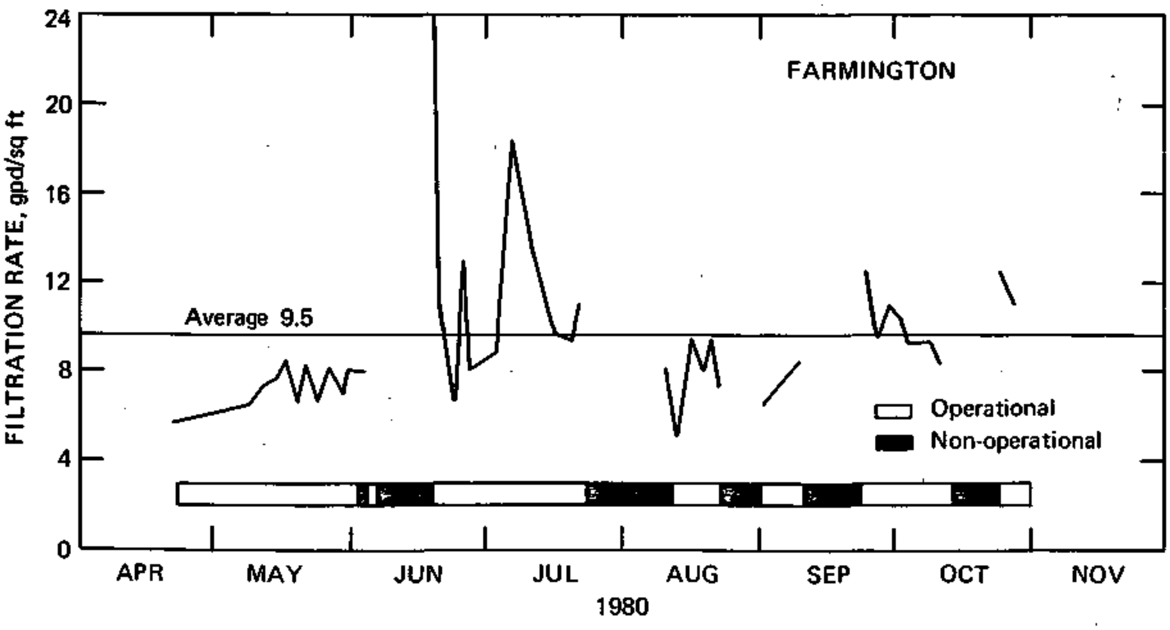

Figure 21. Filtration rates and operational time for the sand filter during the study

It is difficult to rationalize such relationships without considering other factors, particularly the suspended solids concentration of the influent, size of the media, and certain chemical qualities, especially pH and alkalinity. But assuming that all these are equal, it makes sense that limitations should be imposed on permissible filtration rates.

Retention of Solids

The median concentration of suspended solids applied to the filter per dose was 100 mg/l (see figure 10). The average volume of waste applied per dose was 542,250 gallons. Thus an average of about 452 pounds of suspended solids was applied to the filter per dose. As mentioned earlier, measurements for suspended solids in the filter influent and effluent were performed for almost every dose. The total loadings on the filter and the total poundage of suspended solids retained on the filter were computed from these measurements for each run. The following are the results:

Run #	*Applied. (lbs)*	*Retained (lbs)*	*Length of run (days)*
1	6671	5403	16
2	6287	5396	14
3-4	5676	5011	13
5	6265	5460	10

The mass rate of suspended solids removal for four runs, on the average, ranged from 275 to 444 pounds per acre per day (p/A/d). This is comparable to the range observed by Morgan et al. (1981), who found that the removal rate varied from 310 to 412 p/A/d. Harris et al. (1978) developed a predictive relationship between the mass rate of suspended solids removal and the run length. Morgan et al. (1981) could not find a relationship that would permit the estimation of run lengths based on the removal rate of suspended solids. They concluded that currently available mathematical models for estimating the lengths of filter runs are generally inadequate for design purposes. The same conclusion may be drawn from a comparison of the Farmington data with the prediction model proposed by Harris et al. (1978).

However, more recent work by Cowan and Middlebrooks (1979) may offer more promise for prediction purposes. The Farmington data, when incorporated in their prediction model for 0.40 mm sand, produce a predictive filter run length of 20 days.

It seems however that filter runs at Farmington may be limited by a finite capacity of the sand media. As shown by the data, each filter run terminated (that is, clogging occurred) when the quantity of suspended solids retained on the filter ranged between 5000 to 5500 pounds. Because of the variation in filtration rates (see figure 21) it appears that the lengths of filter runs are more likely to be controlled by the solids retained rather than by the hydraulic loading applied. If removal efficiencies are constant, a suspended solids loading might be useful for prediction purposes, but the removal efficiencies observed during the course of this study varied from 81 to 88 percent. During this time the suspended solids loading to the filter varied, on the average, from 339 to 510 p/A/d. With variations in rates of loading, rates of removal, and removal efficiencies the only constant that is consistent with filter run lengths is the total pounds of suspended solids retained. The concept of finite capacity as applied to intermittent sand filters has not been cited in previous studies reviewed as part of this study. The concept appears applicable to the Farmington instruction. In other words, the filters will clog when the capacity of the filters to retain solids is exceeded. In this case that capacity ranges from 5000 to 5500 pounds or 4100 to 4500 pounds per acre of sand media surface.

Chemical and Biological Activity

Two mechanisms, both mediated by the growth of algae on the filters, have caused wide variance in filter runs according to Harris et al. (1978). It takes about 4 hours to complete a dose of lagoon effluent on the filters at Farmington and about 24 hours to achieve filtration. During this time a maximum depth of about 9 inches of algae-laden wastewater lies atop the filter, and this depth is lessened as filtration proceeds. With these shallow depths the activity of algae already under way in the lagoons is probably enhanced atop the filter. It is the influence of this activity that will be examined here.

The principal chemical activity that will limit filter runs is that related to pH and alkalinity. As algae grow, a rise in pH occurs because of their utilization of carbon dioxide (CO_2). In the absence of free CO_2 the carbonate-bicarbonate alkalinity system serves as a source of CO_2 during the photosynthetic production of oxygen. There is an equilibrium between pH and the components of alkalinity, and any change in the equilibrium will result in changes in the carbonic species. In this case, before the pH rises above 10 the solubility of the carbonate ion will be exceeded and calcium carbonate will precipitate. This precipitate bonds the sand particles of the media into a rigid crust that is practically impermeable. The result is clogging of the filter.

Rigid crusts were observed atop the filter at Farmington, and white particles characteristic of calcium carbonate were noted inter-mixed with sand grains and algal residue. Examination of these crusts revealed calcium carbonate making up as high as 9.6 percent by weight of a sand sample lifted off the top of the filter.

Cowan and Middlebrooks (1979) recognized this problem in developing prediction models for filter run lengths. They concluded that at suspended solids loading rates of about 89 p/A/d or less, intermittent sand filters receiving lagoon wastes having calcium carbonate problems will operate for about one-half the period of time of those installations without such problems. This loading rate is about 25 percent of the average loading rate at Farmington. They further concluded that at loading rates in excess of 89 p/A/d, the filter run length would not be governed by calcium carbonate binding. At these rates the solids retained would govern. In practice it is most difficult to determine which will govern. In the absence of a clear-cut answer it seems prudent to operate the filter in a manner that will minimize the influence of calcium carbonate precipitation.

The other mechanism that may enhance the clogging of filters is related to algal growth atop the filters. Filters that are dosed early in the day and have standing influent on them during daylight hours will probably sustain an algal growth in the liquid above them. An experiment conducted by Harris et al. (1978) compared columns of lagoon wastes exposed to light with columns of lagoon wastes that were in the dark. The results are shown in table 11. The suspended solids in the light column increased from 77 mg/l after one hour to 222 mg/l after 12 hours, whereas in the darkened column the spread was from 75 mg/l to 79 mg/l during a like period. This suggests that in the light column the algae concentration that was filtered was about 3 times that estimated for the filter influent.

The two mechanisms described here may shorten filter runs. They may be negated by the operator who loads the filter late in the day and accomplishes the filtration cycle during the nighttime.

SUMMARY

The observed means and ranges of concentrations in the influent and effluent of the intermittent sand filter for certain constituents are shown in table 12.

> The sand filter is an effective unit for reducing suspended solids.. Concentrations in the effluent averaged 13 mg/l and were equal to or less than 28 mg/l about 90 percent of the time. Removal efficiency' varied from 83 to 89 percent.

Table 11. Changes in Algal Density atop a Filter*

	Light cylinder	*Dark cylinder*
Time (hours)	*Susp. sol. (mg/l)*	*Susp. sol. (mg/l)*
1.0	77	75
2.3	81	81
3.6	93	77
5.0	90	74
6.0	93	73
8.0	102	69
10.0	164	69
12.0	222	79

* From Harris et al. (1978)

Table 12. Means and Ranges of Concentrations in the Influent and Effluent of Intermittent Sand Filter

	Influent		*Effluent*	
	Mean	*Range*	*Mean*	*Range*
Dissolved oxygen	9.7	5.1-20.2	3.5	0.3-8.1
pH		8.0-9.9		7.0-8.4
BOD_5	29*	16-50	7*	2-21
Suspended solids	100*	48-164	13*	2-44
Vol. suspended solids	91	45-140	12	2-32
Total phosphorus	2.2	1.4-3.4	1.2	0.8-1.5
Dissolved phosphorus	1.1	0.3-1.8	1.0	0.7-1.4
Ammonia-nitrogen	0.3	0.0-2.6	0.2	0.0-0.5
Nitrate-nitrogen	0.3	0.1-1.0	6.8	1.1-15.4

* Geometric mean

Note: All values are in mg/l except for pH

The sand filter will reduce BOD_5. Concentrations in the effluent averaged 7 mg/l and were equal to or less than 13 mg/l about 90 percent of the time. Removal efficiency averaged 75 percent.

The dissolved oxygen concentrations in a lagoon effluent are often at supersaturation levels. Substantial reductions occurred during passage through the filter. Nevertheless the filter effluent was never devoid of dissolved oxygen. The suppression of dissolved oxygen during filtration through the filter is likely caused by bacterial activity within the media.

The sand filter reduces the pH of the lagoon effluent applied. This is probably caused by the production of CO_2 within the media during biological reaction.

The sand filter will support the nitrification process whereby either the ammonia-nitrogen or organic nitrogen applied is converted to nitrate-nitrogen. This in turn imposes an oxygen demand likely to result in lowered dissolved oxygen concentrations in the filter effluent. Nitrate-nitrogen concentrations averaged 6.8 mg/l in the filter effluent with a range of 1.1 to 15.4 mg/l.

Phosphorus removal in the filter is limited to that fraction in particulate form. There was not a significant reduction in dissolved phosphorus.

Intermittent sand filters will clog. From the results of this study clogging appears to be principally a function of the finite capacity of the sand media to retain solids. This capacity at Farmington varied from 5000 to 5500 pounds of suspended solids. For comparative purposes with other installations this capacity is in the order of 4100 to 4500 pounds per acre of sand media surface.

All clogging is limited to the upper 1 to 2 inches of the sand, and the filtration characteristics of the sand media are not impaired after raking, scarifying, or harrowing of the sand surface following a clogging event.

Two other mechanisms may influence clogging: excess growth of algae in the influent while it is lying atop the sand surface, and the precipitation of calcium carbonate on the sand surface.

RECOMMENDATIONS

The following recommendations are offered for design purposes and operation considerations. They are based primarily on the observations recorded at Farmington. However, some reliance has been placed on observations of similar installations at other locales subsequent to this study.

Design

The effective size of the sand media should be limited to a range of 0.30 to 0.60 mm.

Samples of sand media should be collected at the site and examined for particle size distribution. Clay content should be limited to 1 percent by weight. It is not satisfactory to solely specify "washed" sand.

A minimum depth of 12 inches of sand should be provided.

The dosing arrangement should provide for a rate of at least 450 gpm/ 5000 sq ft of lagoon effluent to the sand surface.

An average design filtration rate of 10 gpd/sq ft is adequate.

It is proper to assume 30 percent porosity of the sand media in computing volumes of influent per dose.

The underdrain system should have an effluent flow regulating device, such as a valve, to govern flow through the filter.

Some consideration should be given to providing an appurtenance in the filter that would provide some estimate of the rate of water level fall within the sand filter. This would be useful for setting the effluent flow regulating device.

The sand filter should be enclosed by an impermeable curb or wall that would permit a water depth on it of at least 12 inches.

Operation

A garden tractor with a scarifier device should be available for "raking" the sand surface after clogging events.

- Filters should be dosed at about 9 inches of water depth atop the sand media.
- Effluent flow should be regulated so that the filter empties within 18 to 24 hours.
- A rest period of one day should be allowed the filter after each operating day.

If at all possible filters should be dosed late in the day to permit most, if not all, of the filtration to occur during nighttime hours.

Consideration should be given to drawing down all lagoons to a minimum water depth during late fall in order to provide winter storage.

A water depth gage board in each lagoon along with a depth-capacity chart would be helpful for estimating the amount of storage that can be provided.

Record the suspended solids concentration in the wastewater during each dose to the filter as well as in the filter effluent. Compute the pounds of solids retained in the filter. Determine if there is a relationship between the accumulative pounds retained and the interval of time between clogging events.

REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1975. Standard methods for the examination of water and wastewater. American Public Health Association, New York, NY, 1193 p., 14th edition.

Bain, R.C., P.L. McCarty, J.A. Robertson, and W.H. Pierce. 1970. Effects of an oxidation pond effluent on receiving waters in the San Joaquin river estuary. 2nd International Symposium for Waste Treatment Lagoons, R.E. McKinney, Ed., Lawrence, KS, pp. 168-180.

Calaway, W.T. 1957. Intermittent sand filters and their biology. Sewage Works Journal v. 29:1-5.

Cowan, P.A., and E.J. Middlebrooks. 1979. Modeling the performance of the intermittent sand filter. Water Quality Series UWRL/Q-79/03, Utah State University, Logan, pp. 73-74.

Daniels, Francis E. 1945. Operation of intermittent sand filters. Sewage Works Journal v. 17:1001-1006.

Evans, Ralph, Donald Schnepper, Gene Brooks, and Jack Williams. 1978. Performance evaluation of tertiary wastewater treatment systems. Illinois State Water Survey Contract Report prepared for the Illinois Environmental Protection Agency, Springfield, 56 p.

Grantham, G.R., D.L. Emerson, and A.K. Henry. 1949. Intermittent sand filter studies. Sewage Works Journal v. 31:1002-1015.

Harris, Steven E., James H. Reynolds, David W. Hill, D.S. Filip, and E.J. Middlebrooks. 1975. Intermittent sand filtration for upgrading waste pond effluents. Presented at the 48th Water Pollution Control Federation Conference, Miami Beach, FL, October 5-10, 1975, 49 p.

Harris, Steven E., D.S. Filip, James H. Reynolds, and E. Joe Middlebrooks. 1978. Separation of algal cells from wastewater lagoon effluents. Vol. 1; Intermittent sand filtration to upgrade waste stabilization lagoon effluent. EPA-600/2-78-033, Office of Research and Development, USEPA, Cincinnati, OH.

Illinois Environmental Protection Agency. 1972. Water pollution regulations of Illinois. Adopted by the Illinois Pollution Control Board, March 7, 1972, 36 p.

Illinois Pollution Control Board. 1979. Rules and regulations, Chapter 6; Public water supplies. Springfield, Illinois, 22 p.

King, Darrel L. 1979. Some ecological limits to the use of alternative systems for wastewater management. Aquaculture Systems for Wastewater Treatment: Seminar Proceedings and Engineering Assessment, USEPA 430/9-80-006, Washington DC, pp. 299-307.

King, D.L., A.J. Tomsoff, and M.J. Atherton. 1970. Effect of lagoon effluent on a receiving stream. 2nd International Symposium for Waste Treatment Lagoons, R.E. McKinney, Ed., Lawrence, KS, pp. 159-167.

Lewis, Ronald F. 1979. Historical review of oxidation ponds as they impact secondary treatment and water quality. In Performance and Upgrading of Wastewater Stabilization Ponds, E. Joe Middlebrooks, Donna H. Falkenborg and Ronald F. Lewis, Eds., Proceedings of a conference held August 23-25, 1978, at Utah State University, Logan, EPA-600/9-79-011, Office of Research and Development, USEPA, Cincinnati, OH, 217 p.

McCarty, Perry L. 1970. Biological processes for nitrogen removal - theory and application. Proceedings of Twelfth Sanitary Engineer Conference, Department of Civil Engineering, University of Illinois, pp. 136-152.

Middlebrooks, E.J., Donald B. Parcella, Robert A. Gearheart, Gary R. Marshall, James H. Reynolds, and William J. Grenney. 1974. Techniques for algae removal from wastewater stabilization ponds. Journal Water Pollution Control Federation v. 46:2676-2695.

Middlebrooks, E.J., J.H. Reynolds, and C.H. Middlebrooks. 1977. Performance and upgrading of wastewater stabilization ponds. Prepared for the Environmental Protection Agency, Technology Transfer, Washington DC.

Morgan, Joe M., Gary L. Hoffman, Truman Green, and Joseph F. Judkins, Jr. 1981. Hydraulics of intermittent sand filters loaded with a single-cell oxidation pond effluent. Journal Water Pollution Control v. 53: 587-593.

Parker, D.S., and W.R. Uhte. 1975. Discussion: technique for algal removal from oxidation ponds. Journal Water Pollution Control v. 47:2330-2332.

Sawyer, Clair N., and Perry L. McCarty. 1967. Chemistry for sanitary engineers, 2nd Edition. McGraw-Hill Book Company, New York, NY, 518 p.

Stumm, W., and J.J. Morgan. 1970. Aquatic chemistry. Wiley-Interscience, New York, NY, p. 429.

Appendix A-1. Characteristics of Sand Filter Influent

Date	Temp °C	DO mg/l	pH	BOD$_5$	Sus. Sol.	Vol. Sus. Sol.	Total P	Diss. P	NH$_3$-N	NO$_3$-N
5-9-80	23.0	—	9.80	31	120	84	1.77	0.53	0.20	0.54
5-12	18.5	—	9.80	40	112	108	1.70	0.35	0.18	0.60
5-14	19.8	--	9.85	44	98	94	1.89	0.29	0.12	0.70
5-16	15.8	—	9.70	35	148	106	1.94	0.39	0.17	0.88
5-19	20.0	—	9.80	28	82	76	1.71	0.61	0.08	0.38
5-21	21.0	—	9.94	31	64	56	1.40	1.32	0.11	0.42
5-23	21.0	—	9.78	—	76	72	1.66	0.82	0.10	0.53
5-26	25.0	—	8.00	42	116	109	1.75	0.89	0.04	--
5-28	24.3	—	9.49	19	64	55	1.43	0.91	0.16	0.41
5-30	25.2	8.20	—	30	89	67	2.16	1.80	0.07	0.88
6-2	22.8	5.25	9.12	22	64	64	1.60	0.91	0.06	0.58
6-4	22.7	10.90	9.60	24	79	52	1.61	0.89	0.12	0.33
6-6	25.9	14.55	9.58	24	87	82	1.74	0.91	0.26	0.96
6-20	23.9	6.00	9.50	18	131	107	2.02	1.20	0.17	0.26
6-23	24.8	9.58	9.68	28	102	92	1.98	0.72	0.05	0.29
6-25	30.5	20.25	9.68	29	80	68	1.74	0.98	0,13	0.40
6-27	30.5	11.90	9.70	28	74	64	1.46	0.52	0.19	0.26
6-30	28.8	—	9.34	23	81	74	1.89	0.91	0.03	0.20
7-2	—	5.60	9.50	24	85	69	1.75	1.16	0.07	0.40
7-7	30.0	10.40	9.38	40	70	69	2.53	0.73	0.16	--
7-9	29.0	6.50	9.32	34	90	71	2.13	1.17	0.07	0.16
7-11	30.8	13.15	9.25	28	78	69	2.02	0.93	0.10	0.36
7-14	32.5	11.80	9.20	38	88	78	2.47	1.15	0.10	0.28
7-16	28.4	7.60	9.30	34	115	110	2.47	1.01	0.17	0.16
7-18	29.0	6.90	9.12	32	108	108	2.36	1.17	0.10	0.22
7-21	29.0	9.65	9.30	35	145	128	2.24	0.86	0.20	0.35
7-23	28.7	5.10	9.28	37	144	124	2.24	0.99	0.18	0.29
8-11	26.6	7.40	9.36	50	146	124	2.60	0.97	0.18	0.18
8—13	--	--	--	--	--	--	--	--	--	--
8-15	24.5	--	9.17	—	108	94	2.56	1.30	0.15	0.24
8-18	26.0	8.60	8.92	36	106	98	2.64	1.65	0.38	0.27
8-20	29.1	10.70	9.05	32	48	45	2.82	1.71	0.48	0.34
8-22	28.0	9.70	9.10	29	48	47	2.80	1.76	0.36	0.18
8-29	29.5	12.00	9.07	36	100	94	2.91	1.57	0.16	0.16
9-5	24.5	5.10	8.97	26	126	114	3.39	1.62	0.37	0.26
9-8	23.0	18.10	9.35	31	128	120	2.85	1.21	0.17	0.23
9-10	23.0	6.70	—	16	132	112	3.00	1.51	0.10	0.15
9-22	24.0	7.60	9.20	27	100	100	2.50	1.46	0.14	0.20
9-24	20.5	10.00	9.31	28	140	104	2.42	1.39	0.10	0.12
9-26	18.0	10.50	9.31	23	144	128	2.94	1.47	0.16	0.11
9-29	19.0	13.60	9.28	32	144	125	2.80	1.32	0.08	0.10
10-1	21.0	13.40	9.46	—	164	128	2.55	1.44	0.10	0.19
10-3	14.0	8.90	9.31	27	144	136	2.66	1.34	0.06	0.14
10-6	14.0	11.10	9.43	32	160	140	2.48	1.21	0.21	0.15
10-8	19.6	13.50	9.37	37	130	100	2.47	1.17	0.08	0.10
10-10	16.5	9.10	9.15	40	128	116	2.70	1.33	0.13	0.15
10-13	12.2	7.70	—	20	132	108	2.65	1.21	0.23	0.20
10-24	11.0	6.60	8.43	20	88	80	2.17	1.33	1.89	0.20
10-27	6.0	5.90	8.30	16	56	46	1.81	1.16	2.47	0.23
10-29	8.0	8.90	8.61	22	80	63	1.78	1.13	2.60	0.20
10-31	9.5	9.20	8.20	16	92	80	1.98	1.24	2.25	0.22

Appendix A-2. Characteristics of Sand Filter Effluent

Date	Temp ^{o}C	DO mg/l	pH	BOD_5 mg/l	Sus. Sol. mg/l	Vol. Sus. Sol.	Total P mg/l	Diss. P mg/l	NH_3-N mg/l	NO_3-N mg/l
5-9-90	15.5	—	9.00	5	16	16 11	1.04	0.S9	0.06	3.62 .
5-12	16.0	—	7.90	8	18	18	1.11	0.75	0.07	5.24
5-14	16.2	—	8.20	6	15	14	1.28	1.04	0.11	2.80
5-16	17.3	—	7.90	21	17	11	1.39	1.03	0.25	4.25
5-19	16.0	—	7.92	6	12	9	1.25	1.12	0.12	6.10
5-21	17.8	—	7.75	6	10	6	1.00	1.00	0.24	6.67
5-23	20.0	—	7.92	5	16	12	0.99	0.94	0.21	1.14
5-26	22.2	—	8.30	—	27	21	1.01	0.87	0.07	1.13
5-28	22.0	—	7.85	12	29	23	1.01	0.96	0.16	1.10
5-30	23.0	1.35	7.69	7	19	12	1.42	1.37	0.11	5.25
6-2	23.0	4.40	7.78	4	16	16	1-41	1.40	0.14	4.66
6-4	22.5	3.60	7.80	6	16	4	1.28	1.28	0.26	3.80
6-6	22.1	4.32	7.45	5	17	15	0.92	0.82	0.19	7.31
6-20	22.0	4.60	8.42	14	44	32	1.47	1.01	0.12	1.56
6-23	23.2	3.90	7.69	13	26	22	1.38	1.13	0.05	8.01
6-25	24.3	2.55	7.58	12	18	14	1.53	0.82	0.29	--
6-27	26.5	0.80	7.55	8	18	12	1.01	0.84	0.18	5.08
6-30	25.4	2.00	7.55	8	14	12	1.07	1.07	0.13	7.65
7-2	25.7	0.65	7.50	6	10	8	1.09	0.79	0.15	6.34
7-7	26.8	3.10	7.45	10	2	2	1.05	1.05	0.11	--
7-9	27.9	2.60	7.45	8	14	8	1.20	0.95	0.15	5.77
7-11	28.8	1.20	7.30	6	6	6	1.20	0.88	0.15	6.30
7-14	29.5	2.80	7.45	5	3	3	1.04	1.02	0.22	9.28
7-16	28.2	1.60	7.40	4	5	5	1.31	0.88	0.21	8.40
7-18	28.0	4.40	7.45	3	8	5	0.85	0.75	0.19	7.54
7-21	28.5	2.65	7.05	6	8	6	0.95	0.89	0.13	15.38
7-23	27.1	4.50	7.60	8	11	9	1.06	0.70	0.23	5.40
8-11	25.6	3.20	7.78	12	24	20	1.35	1.04	0.13	12.78
8-13	--	--	--	-	-	-	--	--	--	--
8-15	25.5	0.30	7.66	21	24	18	1.20	0.93	0.42	7.09
8-18	24.0	1.30	7.40	3	8	6	0.92	0.89	0.13	7.96
8-20	26.5	0.90	7.50	4	7	5	1.16	0.86	0.21	10.12
8-22	26.5	0.90	7.31	4	8	8	1.04	0.89	0.11	14.40
8-29	27.0	1.80	7.65	10	11	10	1.50	1.19	0.22	12.62
9-5	24.5	5.70	7.29	6	12	10	1.32	0.71	0.41	7.15
9-8	25.5	1.70	7.21	8	12	12	1.13	1.09	0.25	11.75
9-10	24.0	1.50	—	6	14	12	1.24	1.05	0.26	7.11
9-22	22.0	3.60	7.40	18	17	17	1.40	0.97	0.22	9.56
9-24	20.5	4.10	7.49	8	23	20	1.47	1.11	0.19	3.75
9-26	19.5	6.20	7.62	6	22	19	1.10	0.88	0.18	3.92
9-29	20.0	5.00	7.26	7	14	12	1.08	0.86	0.14	8.16
10-1	21.0	3.80	7.51	-	22	17	1.17	0.94	0.15	7.19
10-3	17.0	4.50	7.58	7	17	15	1.35	1.09	0.14	4.41
10-6	15.5	5.60	7.83	7	16	14	1.34	1.16	0.18	5.48
10-8	17.0	4.20	7.68	11	16	11	1.28	1.13	0.14	4.98
10-10	18.5	2.90	7.57	5	12	11	1.27	0.98	0.12	7.55
10-13	14.1	5.70	7.50	6	19	16	1.33	1.19	0.15	6.73
10-24	13.5	4.50	7.41	3	9	9	1.16	1.07	0.20	10.55
10-27	10.0	7.40	7.49	2	5	5	1.35	1.17	0.30	9.00
10-29	9.0	8.10	7.48	7	34	19	1.38	1.20	0.34	3.60
10-31	9.0	7.80	7.55	2	11	11	1.50	1.31	0.49	9.19

Appendix B. Weather Data, April 28, 1980 - October 31, 1980

				Wind							Wind		
Date	Temp (C)	Humi (%)	Rainfall (in)	Dir (deg)	Run (mi)	Vel (mph)	Date	Temp (°C)	Humi (%)	Rainfall (in)	Dir (deg)	Run (mi)	Vel (mph)
4-28	11.1	65	.05	352	158.0	10.5	6-16	15.0	65	0.00	25	130.5	5 4
4-29	19.4	80	.12	333	128.3	5.3	6-17	16.2	63	0.00	145	65.0	2.7
4-30	10.5	80	0.00	342	99.5	4.0	6-18	18.8	64	0.00	176	53.0	2.2
5-1	12.2	69	0.00	3	555.0	23.0	6-19	18.5	64	0.00	241	192.5	8.0
5-2	16.1	53	0.00	50	77.5	3.2	6-20	16.4	64	0.00	164	64.0	2.7
5-3	16.9	44	0.00	350	89.3	3.7	6-21	20.0	57	0.00	162	78.5	3.3
5-3	19.4	38	0.00	283	75.8	3.1	6-22	22.0	61	0.00	152	99.5	4.1
5-5	21.7	33	.03	233	65.0	7.2	6-23	21.3	81	0.00	121	130.0	5.4
5-6	18.0	32	0.00	306	218.5	9.1	6-24	19.3	54	0.00	161	157.5	6.6
5-7	11.1	35	0.00	343	185.8	7.7	6-25	24.4	78	0.00	135	59.0	2.5
5-8	8.6	41	0.00	307	133.0	5.5	6-26	25.7	75	0.00	157	68.0	2.8
5-9	10.8	41	0.00	231	100.0	4.2	6-27	27.4	72	0.00	163	143.0	6.0
5-10	14.8	51	.05	146	215.4	9.0	6-28	26.0	73	.05	241	130.0	5.4
5-11	15.8	51	0.00	330	145.0	6.0	6-29	21.6	62	0.00	314	121.5	6.0
5-12	16.3	61	1.02	96	178.5	7.4	6-30	19.6	66	0.00	227	70.5	2.9
5-13	13.5	74	0.00	258	226.5	9.4	7-1	25.6	71	0.00	252	141.0	5.9
5-14	11.8	57	0.00	159	71.5	3.0	7-2	23.2	79	0.00	220	131.0	5.5
5-15	16.2	52	0.00	100	111.0	4.6	7-3	21.5	61	0.00	105	118.5	4.9
5-16	12.0	73	.10	81	270.0	11.2	7-4	24.6	82	0.00	106	95.0	4.0
5-17	14.3	92	.65	100	157.0	6.5	7-5	26.7	74	.55	237	141.0	5.9
5-18	15.5	84	0.00	244	138.0	5.7	7-6	23.6	75	0.00	121	163.0	6.8
5-19	15.7	79	0.00	335	81.0	3.4	7-7	28.7	73	0.00	194	166.5	6.9
5-20	17.3	69	.04	37	74.0	3.1	7-8	30.3	69	0.00	191	144.0	6.0
5-21	18.2	61	0.00	38	80.0	3.3	7-9	26.7	72	0.00	140	131.0	5.5
5-22	19.3	46	0.00	70	106.0	4.4	7-10	27.4	80	.05	42	80.5	3.4
5-23	17.6	91	.30	51	132.0	5.5	7-11	26.0	83	0.00	258	68.5	2.9
5-24	18.7	85	.04	64	58.0	2.4	7-12	29.3	69	0.00	246	155.0	6.5
5-25	21.5	73	.02	53	91.5	3.8	7-13	28.1	75	0.00	100	88.0	3.7
5-26	21.5	55	.03	84	153.0	6.4	7-14	30.0	69	.05	172	166.0	6.9
5-27	22.8	56	0.00	148	145.0	6.0	7-15	31.5	62	0.00	203	125.0	5.2
5-28	23.3	66	.25	183	152.0	6.3	7-16	28.0	69	0.00	210	128.0	5.3
5-29	23.7	68	0.00	143	157.5	6.6	7-17	26.5	63	0.00	225	68.0	2.8
5-30	15.6	65	.10	202	295.0	12.3	7-18	26.0	72	.40	148	131.5	5.5
5-31	21.8	60	.05	236	113.0	4.7	7-19	29.4	64	0.00	167	90.5	3.8
6-1	21.8	84	1.98	174	201.5	8.4	7-20	31.0	55	.05	194	171.0	7.1
6-2	20.3	84	3.20	147	214.0	8.9	7-21	26.6	75	.75	246	98.5	4.1
6-3	20.7	73	.08	143	114.0	4.8	7-22	22.7	75	0.00	279	124.0	5.2
6-4	17.8	70	0.00	114	214.0	8.9	7-23	21.0	71	0.00	168	62.0	2.6
6-5	23.4	72	0.00	164	241.0	10.0	7-24	22.0	67	0.00	175	77.0	3.2
6-6	25.0	78	0.00	154	165.5	6.9	7-25	24.0	68	0.00	177	93.0	3.9
6-7	25.1	79	.01	237	217.0	9.0	7-26	22.0	91	.30	151	95.5	4.0
6-8	16.9	58	0.00	338	208.5	8.7	7-27	17.0	91	0.00	349	134.5	5.6
6-9	19.5	51	0.00	263	210.5	8.8	7-28	22.2	80	0.00	252	62.0	2.6
6-10	17.6	60	0.00	305	123.0	5.1	7-29	23.7	72	0.00	240	107.0	4.5
6-11	17.5	53	0.00	162	81.0	3.4	7-30	25.4	69	0.00	159	173.0	7.2
5-12	19.3	54	0.00	161	157.5	6.6							
6-13	21.4	59	.01	157	174.0	7.3							
6-14	25.0	67	1.15	117	131.0	5.4							
6-15	18.0	86	1.10	83	194.0	8.1							

Appendix B. Concluded

				Wind		
Date	Temp (C)	Humi (%)	Rainfall (in)	Dir (deg)	Run (mi)	Vel (mph)
7-31	27.0	75	0.00	259	113.5	4.7
8-1	26.0	78	0.00	162	100.0	4.2
8-2	25.0	67	0.00	223	137.5	5.7
8-3	23.5	71	0.00	245	68.0	2.8
8-4	27.6	80	.75	172	159.0	6.6
8-5	24.1	82	.22	193	137.5	5.7
8-6	24.9	92	.20	173	125.0	5.2
8-7	25.9	81	0.00	172	116.0	4.8
8-8	27.9	74	0.00	217	111.0	4.6
8-9	27.5	79	0.00	200	77.0	3.2
8-10	24.7	78	.15	151	139.0	5.8
8-11	23.0	91	.30	229	109.0	4.5
8-12	21.9	77	0.00	285	57.0	2.4
8-13	22.6	81	.05	175	137.0	5.7
8-14	21.2	95	2.50	211	104.5	4.4
8-15	21.5	89	0.00	111	145.0	6.0
8-16	18.1	95	.72	98	267.0	11.1
8-17	23.3	90	.33	163	149.0	6.2
8-18	23.9	89	0.00	166	73.0	3.0
8-19	26.3	83	0.00	168	120.0	5.0
8-20	27.7	75	.15	185	128.0	5.3
8-21	22.8	77	0.00	262	138.0	5.8
8-22	21.8	72	0.00	282	74.0	3.1
8-23	21.2	72	.02	148	63.5	2.6
8-24	21.9	78	.06	148	85.5	3.6
8-25	22.8	77	.03	150	112.0	4.7
8-26	24.5	74	.01	158	91.0	3.8
8-27	25.6	73	.01	168	85.5	3.6
8-28	25.4	76	.01	163	88.0	3.7
8-29	24.4	75	0.00	165	212.1	8.8
8-30	22.6	86	.03	289	133.0	5.5
8-31	23.2	91	1.87	116	147.0	6.1
9-1	21.0	94	.89	191	107.0	4.5
9-2	21.9	76	.05	245	72.5	3.0
9-3	21.5	72	0.00	139	127.0	5.3
9-4	20.9	87	.45	163	112.5	4.7
9-5	21.0	88	.17	209	60.0	2.5
9-6	23.0	81	.07	175	67.5	2.8
9-7	22.8	81	0.00	146	138.5	5.8
9-8	24.9	87	0.00	156	86.5	3.6
9-9	17.9	81	0.00	297	156.0	6.5
9-10	16.3	73	0.00	297	69.0	2.9
9-11	19.8	70	0.00	154	74.5	3.1
9-12	22.9	75	.32	154	166.5	6.9
9-13	22.4	82	.36	228	135.0	5.6
9-14	16.9	87	0.00	315	125.5	5.2
9-15	17.0	87	0.00	98	113.5	4.7
9-16	16.8	92	2.41	236	203.5	8.5
9-17	12.6	73	0.00	53	92 5	3.9
9-18	15.9	71	0.00	178	103.0	4.3
9-19	19.5	65	0.00	154	150 0	6.3
9-20	21.4	61	0.00	176	186.0	7.8
9-21	21.8	70	0.00	198	138.0	5.8
9-22	21.6	70	0.00	260	184.0	7.7
9-23	12.4	44	0.00	297	71.0	3.0
9-24	13.9	75	0.00	164	72.5	3.0
9-25	13.9	69	0.00	262	134.0	5.6
9-26	9.5	71	0.00	261	81.0	3.4
9-27	12.1	69	0.00	176	102.0	4.3
9-28	15.3	71	.03	127	65.0	2.7
9-29	15.2	79	.02	141	74.5	3.1
9-30	18.0	75	0.00	193	83.0	3.5
10-1	17.6	68	0.00	272	163.0	6.8
10-2	11.1	66	0.00	278	150.0	6.3
10-3	4.5	71	0.00	284	124.0	5.2
10-4	6.5	66	0.00	189	81.0	3.4
10-5	4.2	65	0.00	161	52.0	2.2
10-6	11.9	64	0.00	208	145.5	6.1
10-7	14.1	62	0.00	235	71.5	3.0
10-8	18.1	54	0.00	263	103.5	4.3
10-9	15.0	65	0.00	69	1325	5.5
10-10	13.7	51	0.00	230	172.0	7.2
10-11	8.5	57	0.00	293	175.0	9.2
10-12	-0.0	-0	0.00	271	79.0	3.3
10-13	14.7	40	0.00	134	124.0	5.2
10-14	14.7	55	0.00	172	170.2	7.1
10-15	10.4	94	.06	22	131.0	5.5
10-16	16.5	85	.27	142	171.7	7.2
10-17	15.6	73	.28	210	230.9	9.6
10-18	8.6	66	0.00	270	167.5	7.0
10-19	7.8	63	0.00	256	172.5	7.2
10-20	11.0	66	0.00	263	128.0	5.3
10-21	10.7	62	0.00	329	109.5	4.6
10-22	10.1	57	0.00	84	180.0	7.5
10-23	13.9	60	0.00	161	179.5	7.5
10-24	6.4	83	.55	236	227.5	9.5
10-25	2.1	63	0.00	284	217.0	9.0
10-26	1.8	65	.05	243	120.5	5.0
10-27	.8	93	.35	70	243.5	10.1
10-28	—	66	0.00	325	205.5	8.6
10-29	—	72	0.00	265	59.0	2.5
10-30	—	71	0.00	209	152.5	6.4
10-31	—	—	0.00	251	45.0	3.6

Appendix C-1. Principal Types and Densities of Algae Applied to Sand Filter

	5/7/80	Percent	Count per ml
1	Scenedesmus dimorphus (g)	71.5	25,935
2	Phacus pleuronectes (f)	12.0	4,358
3	Euglena viridis (f)	5.2	1,890
			Total: 36,278
	5/9/80		
1	Scenedesmus dimorphus (g)	54.5	21,683
2	Phacus pleuronectes (f)	14.2	5,670
3	Fragilaria intermedia (d)	10.7	4,253
			Total: 39,795
	5/12/80		
1	Scenedesmus dimorphus (g)	30.3	10,815
2	Phacus pleuronectes (f)	20.4	7,298
3	Fragilaria intermedia (d)	18.5	6,615
4	Euglena viridis (f)	9.7	3,465
			Total: 35,648
	5/14/80		
1	Scenedesmus dimorphus (g)	38.5	19,478
2	Scenedesmus acuminatus (g)	19.3	9,765
3	Phacus pleuronectes (f)	13.5	6,825
4	Aphanizomenon flos-aquae (bg)	10.5	5,303
			Total: 50,610
	5/16/80		
1	Scenedesmus dimorphus (g)	43.7	21,053
2	Scenedesmus acuminatus (g)	14.5	6,983
3	Aphanizomenon flos-aquae (bg)	13.8	6,668
4	Phacus pleuronectes (f)	12.1	5,828
			Total: 48,195
	5/19/80		
1	Scenedesmus dimorphus (g)	44.2	22,628
2	Aphanizomenon flos-aquae (bg)	22.5	11,498
3	Phacus pleuronectes (f)	13.6	6,983
	5/21/80		
1	Scenedesmus dimorphus (g)	43.4	21,315
2	Aphanizomenon flos-aquae (bg)	17.4	8,558
3	Scenedesmus quadricauda (g)	14.2	6,983
4	Scenedesmus acuminatus (g)	12.9	6,353
			Total: 49,140
	5/23/80		
1	Scenedesmus dimorphus (g)	41.5	20,108
2	Aphanizomenon flos-aquae (bg)	22.9	11,078
3	Scenedesmus acuminatus (g)	14.7	7,140
4	Scenedesmus quadricauda (g)	11.0	5,355
			Total: 48,458

Appendix C-1. Continued

	5/26/80	Percent	Count per ml
1	Scenedesmus dimorphus (g)	45.1	20,475
2	Aphanizomenon flos—aquae (bg)	18 9	8,558
3	Scenedesmus acuminatus (g)	17.1	7,770
			Total: 45,360
	5/28/80		
1	Scenedesmus dimorphus (g)	46.9	10,973
2	Scenedesmus quadricauda (g)	21.5	5,040
3	Scenedesmus acuminatus (g)	13.9	3,255
			Total: 23,415
	5/30/80		
1	Aphanizomenon flos-aquae (bg)	40.4	9,503
2	Scenedesmus dimorphus (g)	36.4	8,558
3	Scenedesmus quadricauda (g)	18.1	4,253
			Total: 23,520
	6/2/80		
1	Aphanizomenon flos-aquae (bg)	45.5	10,185
2	Scenedesmus dimorphus (g)	35.8	8,033
3	Scenedesmus quadricauda (g)	14.3	3,203
			Total: 22,418
	6/4/80		
1	Aphanizomenon flos-aquae (bg)	42.2	11,603
2	Scenedesmus dimorphus (g)	33.8	9,293
3	Phacus pleuronectes (f)	9.7	2,678
			Total: 27,458
	6/6/80		
1	Aphanizomenon flos-aquae (bg)	45.1	16,853
2	Phacus pleuronectes (f)	11.4	4,253
3	Scenedesmus quadricauda (g)	10.0	3,728
4	Scenedesmus dimorphus (g)	29.0	10,815
			Total: 37,328
	6/9/80		
1	Aphanizomenon flos-aquae (bg)	53.6	21,578
2	Scenedesmus dimorphus (g)	23.6	9,503
3	Phacus pleuronectes (f)	9.1	3,675
			Total: 40,215
	6/20/80		
1	Anacystis flos-aquae (bg)	42.0	21,368
2	Aphanizomenon flos-aquae (bg)	39.2	20,003
			Total: 51,030

Appendix C-1. Continued

	6/23/80	Percent	Count per ml
1	Anacystis flos-aquae (bg)	55.6	48,090
2	Aphanizomenon flos-aquae (bg)	38.8	33,495
			Total: 86,415
	6/25/80		
1	Anacystis flos-aquae (bg)	71.8	127,628
2	Aphanizomenon flos-aquae (bg)	23.9	42,558
			Total: 177,818
	6/27/80		
1	Aphanizomenon flos-aquae (bg)	61.5	189,578
2	Anacystis flos-aquae (bg)	36.9	113,508
			Total: 208,123
	6/30/80		
1	Anacystis flos-aquae (bg)	50.6	160,913
2	Aphanizomenon flos-aquae (bg)	48.9	155,400
			Total: 317,993
	7/2/80		
1	Aphanizomenon flos-aquae (bg)	68.7	110,775
2	Anacystis flos-aquae (bg)	28.7	46,253
			Total: 161,280
	7/7/80		
1	Aphanizomenon flos-aquae (bg)	89.2	163,065
2	Ourococcus bicaudatus (g)	7.5	13,703
3	Scenedesmus dimorphus (g)	1.8	3,255
			Total: 182,858
	7/9/80		
1	Aphanizomenon flos-aquae (bg)	90.7	149,310
2	Ourococcus bicaudatus (g)	6.2	10,290
3	Actinastrum hantzschii (g)	1.3	2,153
			Total: 164,693
	7/11/80		
1	Aphanizomenon flos-aquae (bg)	90.7	137,498
2	Ourococcus bicaudatus (g)	7.0	10,553
3.	Chlorella ellipsoidea (g)	1.1	1,628
			Total: 151,620
	7/14/80		
1	Aphanizomenon flos-aquae (bg)	91.1	229,583
2	Anacystis flos-aquae (bg)	4.2	10,553
3	Ourococcus bicaudatus (g)	2.8	6,983
			Total: 251,895

Appendix C-1. Continued

	7/16/80	Percent	Count per ml
1	Aphanizomenon flos-aquae (bg)	95.9	335,108
2	Ourococcus bicaudatus (g)	2.7	9,765
3	Euglena gracilis (f)	.6	2,048
			Total: 349,283
	7/18/80		
1	Aphanizomenon flos-aquae (bg)	92.0	306,653
2	Ourococcus bicaudatus (g)	4.2	14,123
3	Chlorella ellipsoidea (g)	2.9	9,503
			Total: 333,218
	7/21/80		
1	Aphanizomenon flos-aquae (bg)	94.7	353,693
2	Euglena gracilis (f)	2.6	9,870
3	Ourococcus bicaudatus (g)	1.4	5,408
			Total: 373,590
	7/23/80		
1	Aphanizomenon flos-aquae (bg)	94.8	312,008
2	Euglena gracilis (f)	2.4	7,928
3	Ourococcus bicaudatus (g)	1.4	4,620
			Total: 328,965
	8/11/80		
1	Aphanizomenon flos-aquae (bg)	94.0	332,903
2	Anacystis cyanea (bg)	3.1	11,078
3	Chlorella ellipsoidea (g)	1.3	4,620
			Total: 354,008
	8/15/80		
.1	Aphanizomenon flos-aquae (bg)	88.3	166,373
2	Chlorella ellipsoidea (g)	4.5	8,453
3	Ourococcus bicaudatus (g)	3.0	5,670
4	Actinastrum hantzschii (g)	1.3	2,468
			Total: 188,423
	8/18/80		
1	Aphanizomenon flos-aquae (bg)	95.6	269,745
2	Anacystis cyanea (bg)	2.0	5,565
3	Actinastrum hantzschii (g)	1.1	3,203
			Total: 282,240
	8/20/80		
1	Aphanizomenon flos-aquae (bg)	92.8	374,378
2	Actinastrum hantzschii (g)	2.8	11,235
3	Chlorella pyrenoidosa (g)	2.7	10,868
			Total: 403,358
	8/22/80		
1	Aphanizomenon flos-aquae (bg)	95.5	336,683
2	Chlorella pyrenoidosa (g)	1.1	3,885
3	Anacystis cyanea (bg)	1.0	3,570
			Total: 352,538

Appendix C-1. Continued

	8/29/80	Percent	Count per ml
1	Aphanizomenon flos-aquae (bg)	93.6	278,828
2	Scenedesmus dimorphus (g)	1.5	4,358
3	Chlorella ellipsoidea (g)	1.4	4,253
			Total: 297,990
	9/5/80		
1	Aphanizomenon flos-aquae (bg)	90,2	273,840
2	Chlorella ellipsoidea (g)	3.7	11,078
3	Crucigenia rectangularis (g)	2.4	7,035
			Total: 303,608
	9/8/80		
1	Aphanizomenon flos-aquae (bg)	95.8	331,433
2	Chlorella ellipsoidea (g)	2.9	9,870
3	Ourococcus bicaudatus (g)	.6	2,100
			Total: 345,975
	9/10/80		
1	Aphanizomenon flos-aquae (bg)	93.5	202,703
2	Crucigenia rectangularis (g)	2.6	5,618
3	Ourococcus bicaudatus (g)	1.9	4,148
			Total: 216,773
	9/12/80		
1	Aphanizomenon flos-aquae (bg)	93.4	270,953
2	Crucigenia rectangularis (g)	3.1	8,873
3	Ourococcus bicaudatus (g)	1.8	5,198
			Total: 290,168
	9/15/80		
1	Aphanizomenon flos-aquae	96.4	242,078
2	Chlorella ellipsoidea (g)	2.3	5,670
3	Anabaena spiroides (bg)	1.0	2,520
			Total: 251,213
	9/24/80		
1	Aphanizomenon flos-aquae (bg)	96.1	213,203
2	Ourococcus bicaudatus (g)	1.5	3,308
3	Anacystis cyanea (bg)	1.4	3,203
			Total: 321,813
	9/26/80		
1	Aphanizomenon flos-aquae (bg)	90.9	242,183
2	Chlorella ellipsoidea (g)	4.4	11,498
3	Anacystis cyanea (bg)	2.0	5,565
			Total: 266,438
	9/2 9/80		
1	Aphanizomenon flos-aquae (bg)	89.5	336,683
2	Chlorella ellipsoidea (g)	5.6	21,315
3	Anacystis cyanea (bg)	1.9	7,298
			Total: 377,370

Appendix C-1. Continued

	10/1/80	Percent	Count per ml
1	Aphanizomenon flos-aquae (bg)	90.3	302,978
2	Chlorella ellipsoidea (g)	4.7	15,803
3	Actinastrum hantzschii (g)	2.6	9,293
			Total: 335,528
	10/3/80		
1	Aphanizomenon flos-aquae (bg)	95.6	215,933
2	Actinastrum hantzschii (g)	2.3	5,303
3	Anacystis cyanea (bg)	2.1	4,620
			Total: 225,855
	10/6/80		
1	Aphanizomenon flos-aquae (bg)	96.1	204,278
2	Anacystis cyanea (bg)	1.8	3,728
3	Ourococcus bicaudatus (g)	1.8	3,728
			Total: 212,468
	10/8/80		
1	Aphanizomenon flos-aquae (bg)	96.4	189,578
2	Ourococcus bicaudatus (g)	2.1	4,200
3	Anacystis cyanea (bg)	1.1	2,100
			Total: 196,613
	10/10/80		
1	Aphanizomenon flos-aquae (bg)	95.9	162,802
2	Ourococcus bicaudatus (g)	1.9	3,150
3	Anacystis cyanea (bg)	1.5	2,625
			Total: 169,680
	10/13/80		
1	Aphanizomenon flos-aquae (bg)	96.3	153,090
2	Ourococcus bicaudatus (g)	1.7	2,783
3	Anacystis cyanea (bg)	1.6	2,468
			Total: 159,023
	10/15/80		
1	Aphanizomenon flos-aquae (bg)	97.4	163,065
2	Ourococcus bicaudatus (g)	1.6	2,783
3	Anacystis cyanea (bg)	1.0	1,628
			Total: 167,475
	10/24/80		
1	Aphanizomenon flos-aquae (bg)	97.1	174,248
2	Ourococcus bicaudatus (g)	1.8	3,203
3	Anacystis cyanea (bg)	1.1	1,995
			Total: 179,445
	10/27/80		
1	Aphanizomenon flos-aquae (bg)	97.9	110,565
2	Ourococcus bicaudatus (g)	.9	1,050
3	Anacystis cyanea (bg)	.8	945
			Total: 112,928

Appendix C-1. Concluded

	10/29/80	Percent	Count per ml
1	Aphamzomenon flos-aquae (bg)	98.7	68,822
2	Anacystis cyanea (bg)	1.3	893
		Total:	69,720
	10/31/80		
1	Aphanizomenon flos-aquae (bg)	96.8	36,803
2	Anacystis cyanea (bg)	1.4	525
3	Ourococcus bicaudatus (g)	1.2	473
		Total:	38,010

Note:

(g) is green algae

(bg) is blue-green algae

(f) is flagellate

(d) is diatom

Appendix C-2. Principal Types and Densities of Algae in Sand Filter Effluent

	5/7/80	Percent	Count per ml
	No Sample		
	5/9/80		
1	Scenedesmus dimorphus (g)	32.1	123.9
2	Fragilaria intermedia (d)	31.0	119.7
3	Scenedesmus acuminatus (g)	24.4	94.5
			Total: 386.4
	5/12/80		
1	Scenedesmus dimorphus (g)	32.1	212.1
2	Fragilaria intermedia (d)	32.1	212.1
3	Scenedesmus acuminatus (g)	19.7	130.2
			Total: 661.5
	5/14/80		
1	Scenedesmus dimorphus (g)	66.4	646.8
2	Scenedesmus acuminatus (g)	14.9	144.9
3	Phacus pleuronectes (f)	9.0	88.2
			Total: 974.4
	5/16/80		
1	Scenedesmus dimorphus (g)	60.3	165.9
2	Phacus pleuronectes (f)	19.8	54.6
3	Fragilaria intermedia (d)	9.9	27.3
			Total: 275.1
	5/19/80		
1	Scenedesmus dimorphus (g)	68.0	237.3
2	Phacus pleuronectes (f)	16.3	56.7
3	Fragilaria intermedia (d)	10.8	37.8
			Total: 348.6
	5/21/80		
1	Scenedesmus dimorphus (g)	47.4	136.5
2	Phacus pleuronectes (f)	31.4	90.3
3	Fragilaria intermedia (d)	19.0	54.6
			Total: 287.7
	5/23/80		
1	Scenedesmus dimorphus (g)	44.1	126.0
2	Phacus pleuronectes (f)	21.3	60.9
3	Fragilaria intermedia (d)	16.9	48.3
			Total: 285.6
	5/26/80		
1	Phacus pleuronectes (f)	57.8	111.3
2	Scenedesmus dimorphus (g)	22.5	48.3
3	Fragilaria intermedia (d)	17.6	37.8
			Total: 214.2
	5/28/80		
1	Phacus pleuronectes (f)	42.0	153.3
2	Scenedesmus dimorphus (g)	30.0	109.2
3	Fragilaria intermedia (d)	19.0	69.3
			Total: 365.4

Appendix C-2. Continued

	5/30/80	Percent	Count per ml
1	Aphamzomenon flos-aquae (bg)	35.4	140.7
2	Scenedesmus dimorphus (g)	28.6	113.4
3	Phacus pleuronectes (f)	28.6	113.4
			Total: 396.9
	6/2/80		
1	Phacus pleuronectes (£)	46.2	178.5
2	Scenedesmus dimorphus (g)	26.6	102.9
3	Aphanizomenon flos-aquae (bg)	25.5	98.7
			Total: 386.4
	6/4/80		
1	Scenedesmus dimorphus (g)	30.4	172.2
2	Aphanizomenon flos-aquae (bg)	26.7	151.2
3	Phacus pleuronectes (d)	25.9	147.0
			Total: 567.0
	6/6/80		
1	Scenedesmus dimorphus (g)	36.2	159.6
2	Aphanizomenon flos-aquae (bg)	34.3	151.2
3	Phacus pleuronectes (f)	23.3	102.9
			Total: 441.0
	6/9/80		
1	Phacus pleuronectes (f)	40.5	184.8
2	Aphanizomenon flos-aquae (bg)	34.1	155.4
3	Scenedesmus dimorphus (g)	25.3	115.5
			Total: 455.7
	6/20/80		
1	Anacystis flos-aquae (bg)	70.3	1652.7
2	Aphanizomenon flos-aquae (bg)	24.0	564.9
3	Euglena viridis (f)	3.1	73.5
			Total: 2349.5
	6/23/80		
1	Anacystis flos-aquae (bg)	53.9	1243.2
2	Aphanizomenon flos-aquae (bg)	36.6	844.2
3	Scenedesmus dimorphus (g)	5.6	128.1
			Total: 2307.9
	6/25/80		
1	Anacystis flos-aquae (bg)	60.0	814.8
2	Aphanizomenon flos-aquae (bg)'	30.7	415.8
			Total: 1356.6

Appendix C-2. Continued

	6/27/80	Percent	Count per ml
1	Aphanizomenon flos-aquae (bg)	54.4	117.6
2	Anacystis flos-aquae (bg)	32.0	69.3
			Total: 246.3
	6/30/80		
1	Aphanizomenon flos-aquae (bg)	69.0	71.4
2	Anacystis flos-aquae (bg)	22.4	23.1
			Total: 102.9
	7/2/80		
1	Aphanizomenon flos-aquae (bg)	77.0	119.7
2	Anacystis flos-aquae (bg)	23.0	35.7
			Total: 155.4
	7/7/80		
1	Fragilaria intermedia (d)	56.2	56.7
2	Ourococcus bicaudatus (g)	37.5	37.8
3	Aphanizomenon flos-aquae (bg)	6.2	6.3
			Total: 100.8
	7/9/80		
1	Fragilaria intermedia (d)	41.5	81.9
2	Ourococcus bicaudatus (g)	35.0	69.3
3	Aphanizomenon flos-aquae (bg)	19.0	37.8
			Total: 197.4
	7/11/80		
1	Ourococcus bicaudatus (g)	65.0	27.3
2	Aphanizomenon flos-aquae (bg)	20.0	8.4
3	Scenedesmus dimorphus (g)	15.0	6.3
			Total: 42.0
	7/14/80		
1	Aphanizomenon flos-aquae (bg)	59.6	65.1
2	Ourococcus bicaudatus (g)	32.7	35.7
3	Anacystis flos-aquae (bg)	7.7	8.4
			Total: 109.2
	7/16/80		
1	Chlorella ellipsoidea (g)	59.3	73.5
2	Ourococcus bicaudatus (g)	40.7	50.4
			Total: 123.9
	7/18/80		
1	Chlorella ellipsoidea (g)	52.2	75.6
2	Ourococcus bicaudatus (g)	47.8	69.3
			Total: 144.9

Appendix C-2. Continued

	7/21/80	Percent	Count per ml
1	Ourococcus bicaudatus (g)	65.5	266.7
2	Chlorella ellipsoidea(g)	24.2	98.7
3	Fragilaria intermedia (d)	10.3	42.0
			Total: 407.4
	7/23/80		
1	Ourococcus bicaudatus (g)	47.6	170.1
2	Euglena gracilis (f)	35.3	126.0
3	Fragilaria intermedia (d)	17.1	60.9
			Total: 357.0
	8/11/80		
1	Ourococcus bicaudatus (g)	95.3	86.1
2	Phacus pleuronectes (f)	4.7	4.2
			Total: 90.3
	8/15/80		
1	Aphanizomenon flos-aquae (bg)	71.5	205.8
2	Ourococcus bicaudatus (g)	28.5	81.9
			Total: 287.7
	8/18/80		
1	Aphanizomenon flos-aquae (bg)	43.0	340.2
2	Chlorella pyrenoidosa(g)	39.4	310.8
3	Ourocuccus bicaudatus (g)	17.6	138.6
			Total: 289.6
	8/20/80		
1	Chlorella pyrenoidosa(g)	55.2	218.4
2	Aphanizomenon flos-aquae (bg)	45.8	184.8
			Total: 403.2
	8/22/80		
1	Aphanizomenon flos-aquae (bg)	100	157.5
			Total: 157.5
	8/29/80		
1	Aphanizomenon flos-aquae (bg)	100	126.0
			Total: 126.0
	9/5/80		
1	Aphanizomenon flos-aquae (bg)	73.9	237.3
2	Chlorella ellipsoidea (g)	26.1	84.0
			Total: 321.3
	9/10/80		
1	Aphanizomenon flos-aquae (bg)	100	115.5
			Total: 115.5
	9/12/80		
1	Aphanizomenon flos-aquae (bg)	74.8	24 9.9
2	Crucigenia rectangularis (g)	25.2	84.0
			Total: 333.9

Appendix C-2. Continued

		Percent		Count per ml
	9/15/80			
1	Aphanizomenon flos-aquae (bg)	100		331.8
			Total:	331.8
	9/24/80			
1	Aphanizomenon flos-aquae (bg)	85.9		165.9
2	Anacystis cyanea (bg)	14.1		27.3
			Totai:	193.2
	9/26/80			
1	Aphanizomenon flos-aquae (bg)	83.1		289.8
2	Anacystis cyanea (bg)	16.9		58.8
			Total:	348.6
	9/29/80			
1	Aphanizomenon flos-aquae (bg)	61.3		153.3
2	Ourococcus bicaudatus (g)	38.7		96.6
			Total:	24 9.9
	10/1/80			
1	Aphanizomenon flos-aquae (bg)	66.9		254.1
2	Ourococcus bicaudatus (g)	33.1		126.0
			Total:	380.1
	10/3/80			
1	Aphanizomenon flos-aquae (bg)	74.2		151.2
2	Ourococcus bicaudatus (g)	25.8		52.5
			Total:	203.7
	10/6/80			
1	Aphanizomenon flos-aquae (bg)	78.1		105.0
2	Ourococcus bicaudatus (g)	21,9		29.5
			Total:	134.4
	10/8/80			
1	Aphanizomenon flos-aquae (bg)	75		75.6
2	Ourococcus bicaudatus (g)	25		25.2
			Total:	100.8
	10/10/80			
1	Aphanizomenon flos-aquae (bg)	100		54.6
			Total:	54.6
	10/13/80			
1	Aphanizomenon flos-aquae (bg)	100		96.6
			Total:	96.6
	10/15/80			
1	Aphanizomenon flos-aquae (bg)	64.3		75.6
2	Ourococcus bicaudatus (g)	35.7		42.0
			Total:	117.6

Appendix C-2. Concluded

	10/24/80	Percent	Count per ml
1	Aphanizomenon flos-aquae (bg)	100	23.1
			Total: 23.1
	10/27/80		
1	Aphanizomenon flos-aquae (bg)	100	21.0
			Total: 21.0
	10/29/80		
1	Aphanizomenon flos-aquae (bg)	100	18.9
			Total: 18.9
	10/31/80		
1	Chlorella ellipsoidea (g)	85.7	12.6
2	Aphanizomenon flos-aquae (bg)	14.3	2.1
			Total: 14.7

Note:

(g) is green algae

(bg) is blue-green

(f) is flagellate

(d) is diatom