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Tertiary Treatment of Wastewater Using Oxidation Ponds

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TERTIARY TREATMENT OF WASTEWATER USING OXIDATION PONDS

by

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A B S T R A C T

The purpose of the project was to determine the value of using lagoons as a supplemental process for treating the effluent from an activated sludge wastewater treatment plant.

Only tentative conclusions can be suggested since the project was not carried to completion. It appears that lagoons will have only minimal effect on the amounts of total nitrogen and phosphate in the plant effluent, although conversion of a portion of the ammonia to nitrate can be expected. However, the concentration of ammonia was never lower than that required by EPA guidelines. Some reduction of soluble BOD appears to occur, perhaps through conversion to new cell material. Suspended solids concentrations can be expected to increase during periods of algae growth.

The numbers of both fecal and total coliform bacteria decreased substantially during the detention period provided by the lagoon system. Although not confirmed, it was concluded that the most probable cause for the decrease was the intensity and duration of sunlight.

The lagoon served very effectively as a buffer between the treatment plant and the receiving stream, providing a considerable measure of protection to the stream even during those periods during which the plant was by-passing a portion of the inflow.

Descriptors: Tertiary Treatment*, Sewage Lagoons*, Effluents, Sewage Bacteria, Waste Water Treatment

Identifier: Waste Water Effluents.

A C K N O W L E D G M E N T S

The work reported here could not have been performed without the assistance and cooperation of the officials of the Lexington-Fayette Urban County Government. In particular, acknowledgment, with thanks, is given to Mr. Jimmie L. Campbell, Director of Water Pollution Control, and Mr. Paul Danheizer, chief operator and engineer at the plant at which the tests were conducted.

A number of students worked on the project in different capacities but the contributions of Mr. John Moeller and Mr. Ray Hamilton deserve special recognition, as they both devoted many hours of their time to the collection and analysis of the samples and data.

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Introduction

The purpose of this project was to evaluate the effectiveness of short detention time oxidation ponds for the tertiary treatment of effluents from activated sludge waste treatment plants. It was felt that this information would be helpful not only in setting standards for the design of such facilities, but would in addition be of considerable value to engineers and planners who are responsible for facilities planning and waste allocation under federal guidelines. The project was terminated before sufficient data was gathered to justify firm conclusions or to meet the projects objectives. This report presents the data which was collected; and tentative conclusions concerning the performance of oxidation ponds used in this manner.

The report is presented in two parts, the first dealing with the chemical changes effected by the pond system; the second with bacteriological.

Part I

Changes in the Chemical and Physical Characteristics of Secondary Effluent During Flow through Oxidation Ponds

Raymond D. Hamilton, Graduate Assistant

Description of treatment plant and oxidation ponds

The plant used for the study was the West Hickman Creek waste treatment plant at Lexington, Kentucky, which is an activated sludge plant using the Kraus modification. The effluent from the secondary sedimentation basins flows into a system of four lagoons, each has an average depth of four feet and a surface area of five acres.

The lagoons are connected in series and provide a theoretical detention time of 6.5 days at a flow of 5 MGD. The effluent from the fourth lagoon is disinfected before it is discharged into the stream. The flow system for the plant is such that, in addition to the secondary effluent, the lagoons receive all flows in excess of the plant's installed pumping capacity. During periods of heavy rainfall, a considerable volume of what is essentially stormwater by-passes the treatment plant and flows directly to the first lagoon through the secondary effluent channel. Liquid flows into the first lagoon through a single inlet. The overflow from one lagoon to the next is through a series of seven overflow pipes arranged in parallel across each lagoon. A schematic representation of the flow arrangement in the lagoon system is shown in Figure 1.

Sampling and analytical procedures

The sampling period covered in this part of the report began on January 11, 1974 and continued thru May 26, 1974. Samples were collected from each sampling station on Mondays and Fridays at nine o'clock in the morning. Each lagoon effluent sample was a composite of individual grab samples obtained from the seven drop inlet discharge spillways at the downstream end of each lagoon. The

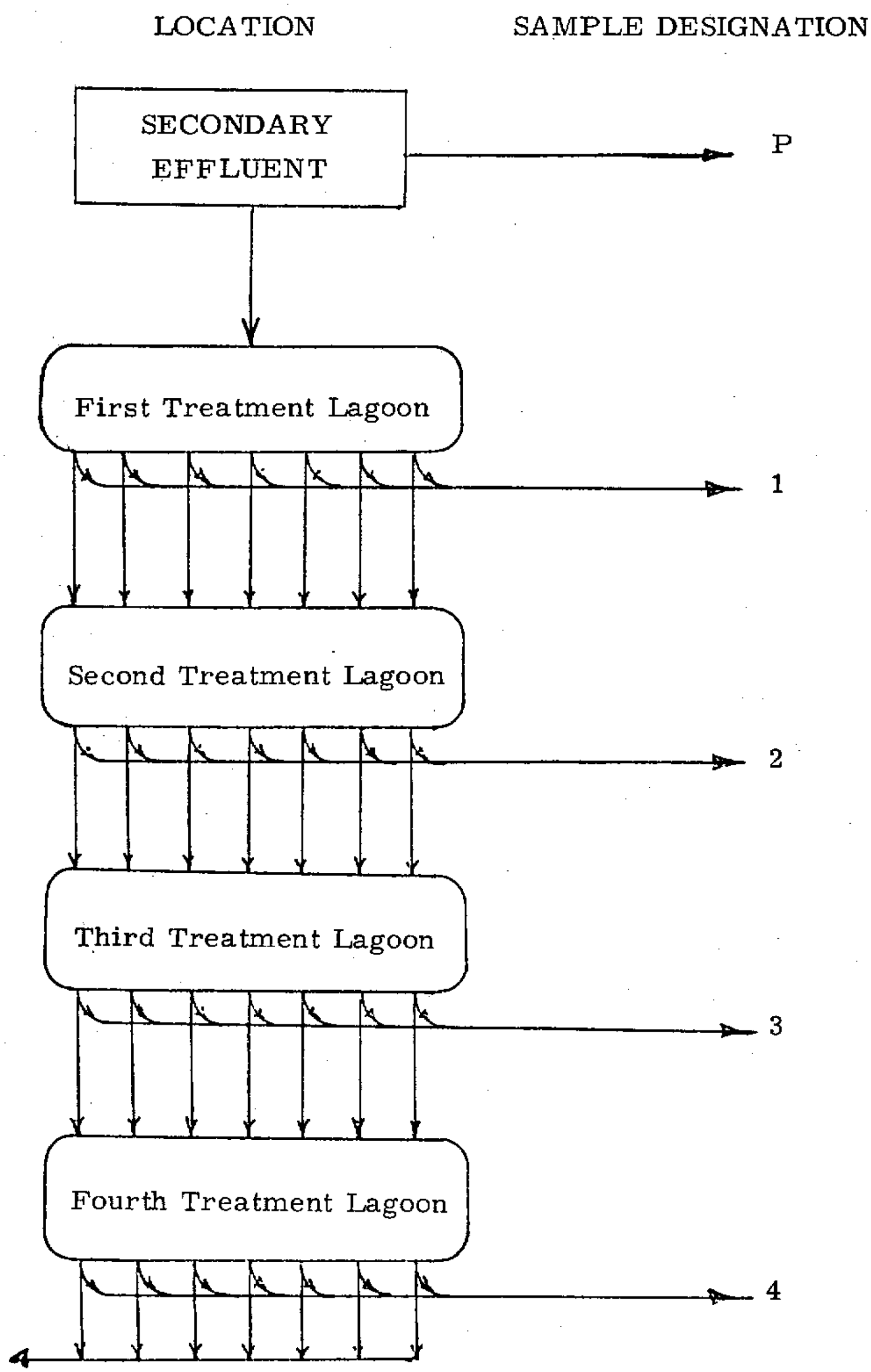


FIGURE 1

SCHEMATIC LAYOUT
TERTIARY TREATMENT LAGOONS
WEST HICKMAN CREEK SEWAGE TREATMENT PLANT
LEXINGTON, KENTUCKY

secondary effluent sample was a single grab sample obtained from the effluent channel following the secondary clarifiers.

The samples were immediately taken to the laboratory for analysis. The samples were first filtered to obtain soluble fractions and for suspended solids analysis. Chemical Oxygen Demand, Organic Carbon, Total and Volatile Solids, and pH analysis were performed on the same day as sample collection along with preparation of biochemical oxygen demand samples. Samples taken for determination of total Kjeldahl, ammonia, and nitrate nitrogen were analyzed on the same day as collected, or were acidified and stored at 4°C. for analysis the day following collection. An additional sample was frozen for later determination of ortho and total phosphorus. The phosphorus samples from two days sampling were analyzed once each week. Samples were analyzed by the procedures given in Standard Methods (7), with the exception of ammonia and nitrate nitrogen. These were measured with specific ion electrodes (8), (9).

Results

In this section, each of the parameters which was measured has been presented has a figure which shows on a day by day basis the changes which were observed in the lagoon system. The points in the figures were joined only to assist in following the trend in each parameter in each basin, and the lines should not be interpreted as indicating continuous functions.

A. Biochemical Oxygen Demand

The results of the BOD tests are presented in Figures 2 and 3. The decrease in the total BOD for the period of the study averaged about 45 percent, and for the soluble BOD about 70 percent. This

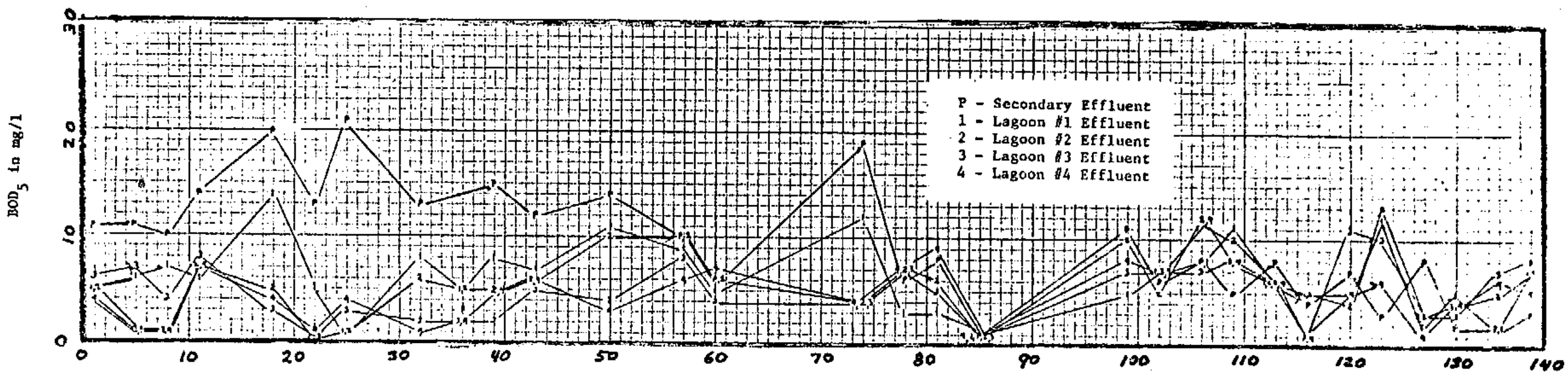


FIGURE 2 TOTAL FIVE DAY BIOCHEMICAL OXYGEN DEMAND

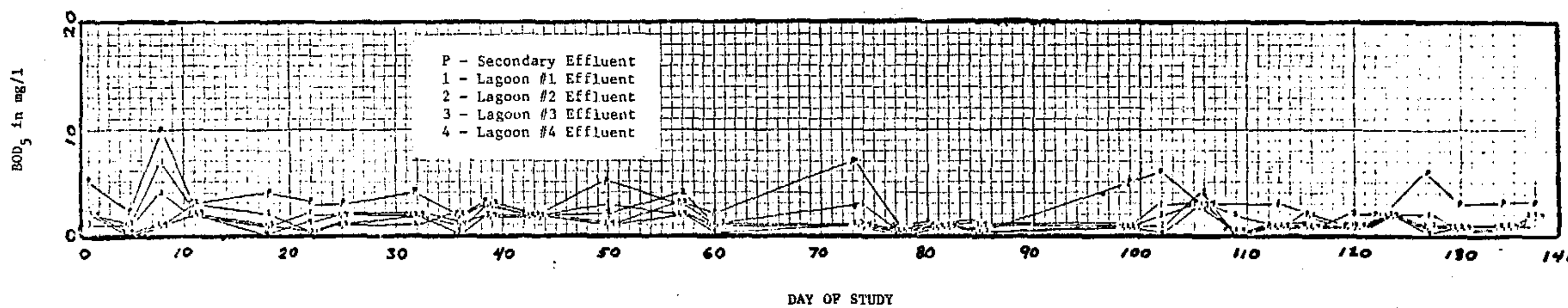


FIGURE 3 SOLUBLE FIVE DAY BIOCHEMICAL OXYGEN DEMAND

would seem to indicate that the organic matter, both soluble and suspended, in the secondary plant effluent is being converted to suspended organics (algae) in the lagoon system. This is further verified by observing that the removal of total BOD_5 by month generally decreases as the study progresses. This corresponds to the increase in volatile suspended solids in the lagoon system observed as the study progresses as shown in Figure 9. The soluble BOD, with very few exceptions, rarely exceeded 4 mg. per liter in the final effluent.

Figure 2 indicates that during cool periods (low algal growth) the BOD_5 removal throughout the system is substantial, but as the volatile suspended solids increased the lagoon effluents often had higher organic strengths. A pattern never developed where any specific lagoon could be guaranteed to have the best effluent. The fact that lagoon effluents could have higher organic strengths than their influents was also observed by Caldwell (10). The total BOD_5's do not appear too high, but King (11) has found that the BOD_5 from samples containing algae is only 20% of the ultimate BOD. If this is indeed the case, it suggests that the conversion of soluble BOD to algal cells, under some conditions, might permit a higher total organic carbon to be discharged without imposing an unacceptable burden on the oxygen resources of the stream. The data also indicate that an effluent of excellent quality could be produced by adding some form of solids separation to the system.

B. Chemical Oxygen Demand

The data for total chemical oxygen demand are shown in Figure 4 and for soluble COD in Figure 5. In general it can be seen that the

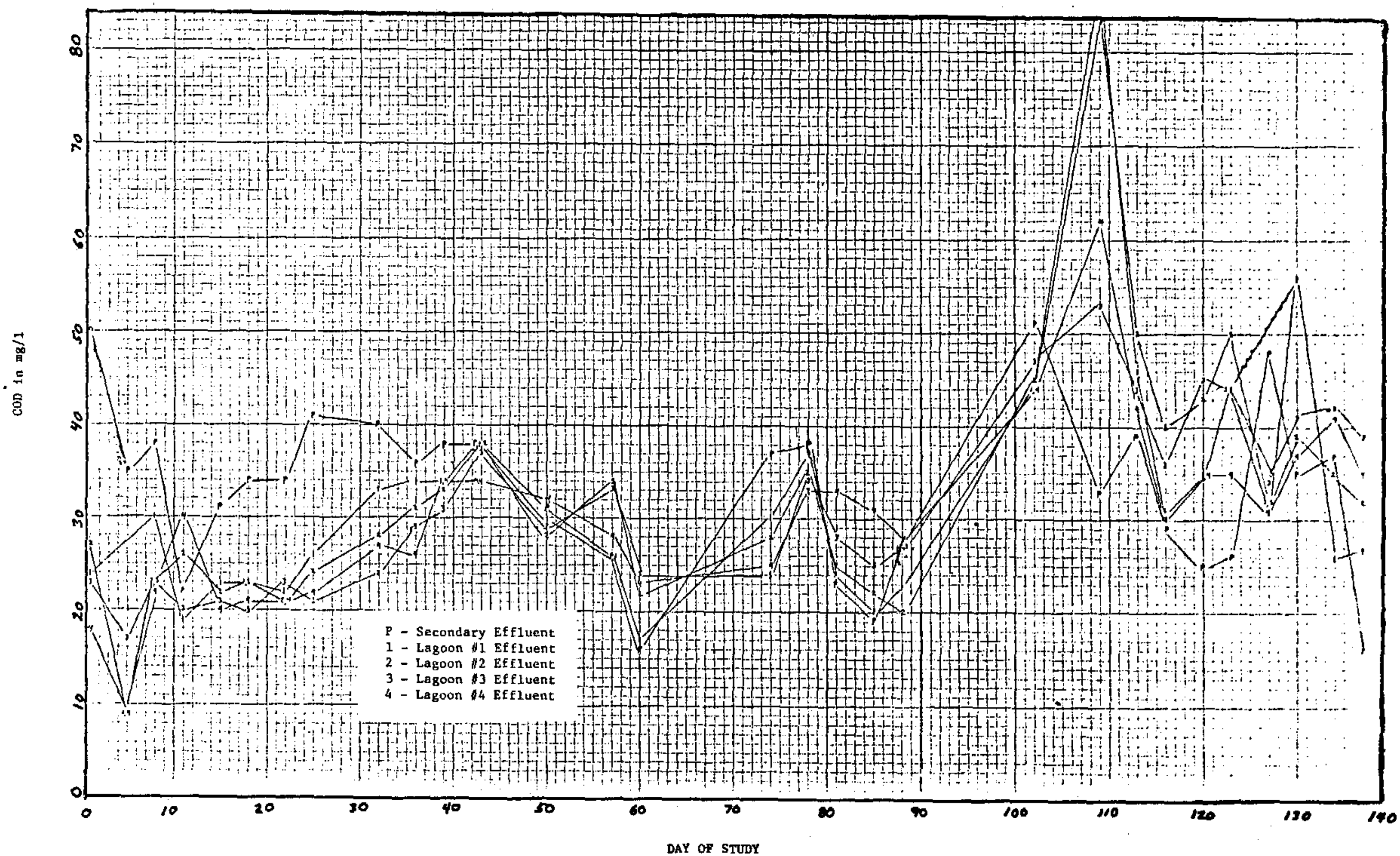


FIGURE 4 TOTAL CHEMICAL OXYGEN DEMAND

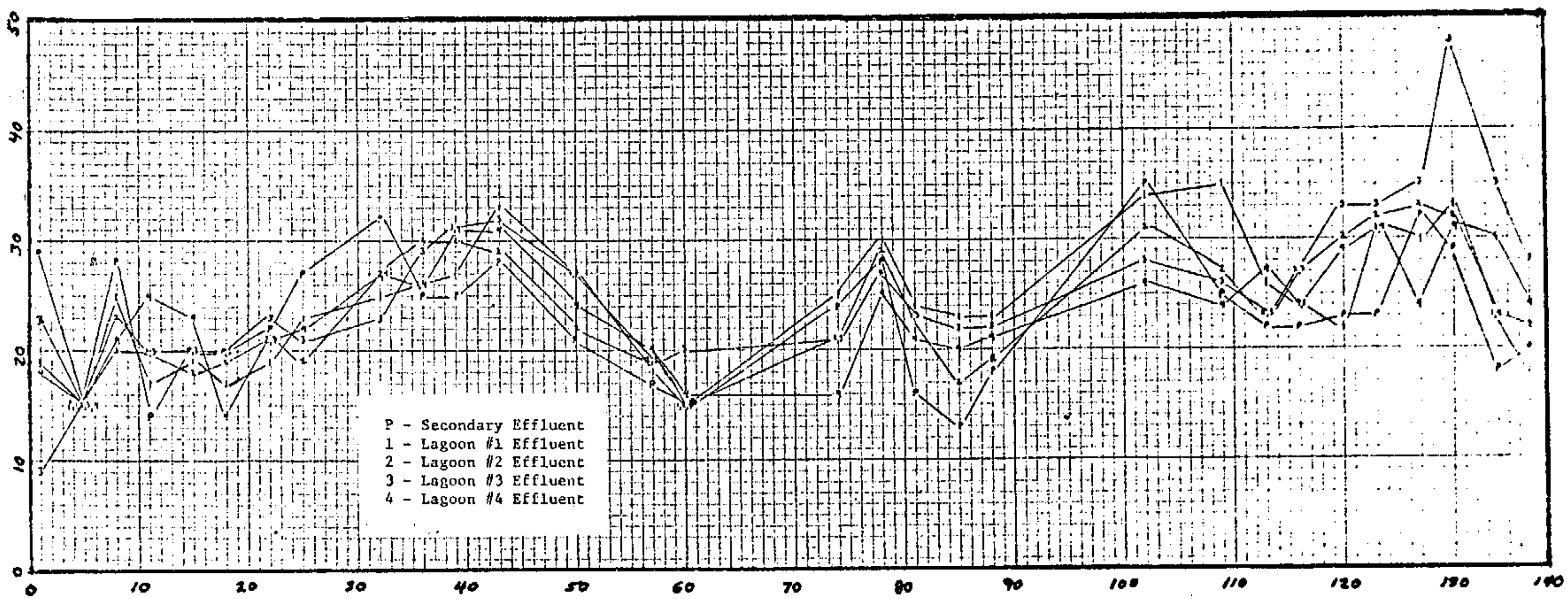


FIGURE 5 SOLUBLE CHEMICAL OXYGEN DEMAND

system was relatively ineffective in achieving a reduction in this parameter.

C. Organic Carbon

These data, shown in Figures 6 and 7, generally follow the trend for COD in that relatively little change was observed as the result of detention in the lagoons. During periods of high suspended solids there may have been some decrease in the soluble organic carbon fraction.

D. Suspended Solids

Total Suspended Solids--The results of total suspended solids analysis with time are shown in Figure 8. From observation of Figure 8 it can be seen that lagoons three and four produce the highest solids concentration during the warmer months, as would be anticipated. During the cooler periods the suspended solids concentration in lagoons one and two generally exceed that of the following lagoons, indicating that they are functioning as sedimentation basins.

Volatile Suspended Solids--Volatile suspended solids analysis are shown in Figure 9, and generally followed the trends observed with the total suspended solids. As was found with the total suspended solids data, the highest values for volatile suspended solids during March, April, and May were found in the third and fourth lagoons, while during January and February the highest values were generally in the first or second lagoons.

E. Hydrogen Ion Concentration

The recorded values for the pH in each lagoon over the period of the study are shown in Figure 10. The pH values were exactly as

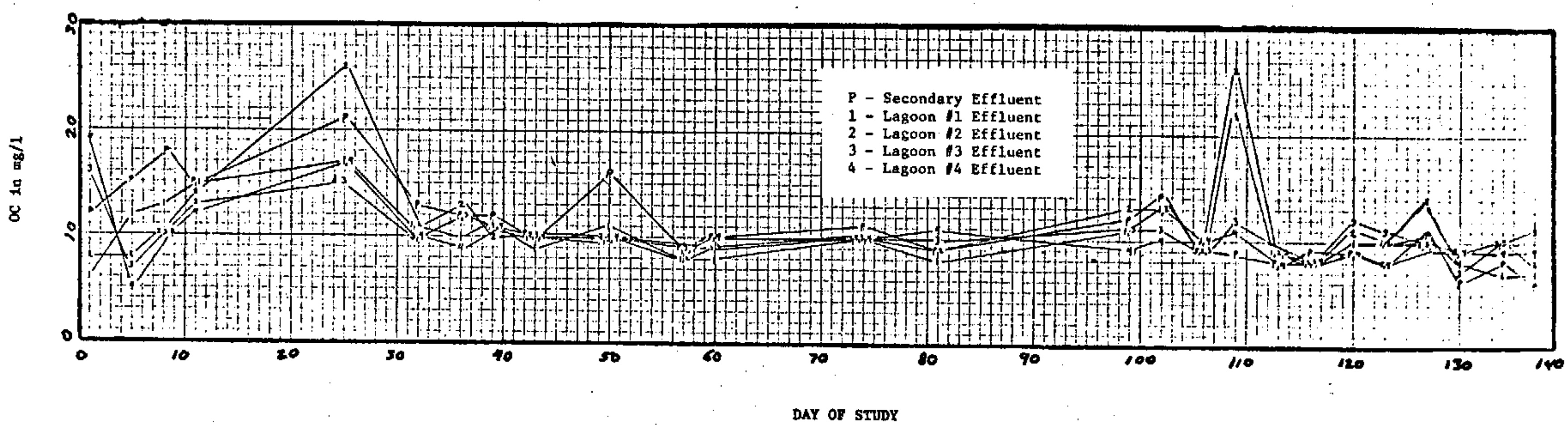
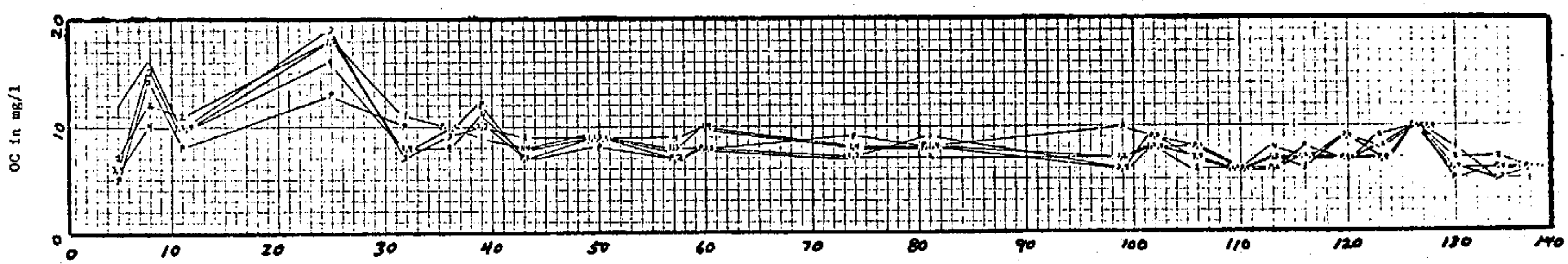


FIGURE 6 TOTAL ORGANIC CARBON



DAY OF STUDY

FIGURE 7 SOLUBLE ORGANIC CARBON

P - Secondary Effluent
1 - Lagoon #1 Effluent
2 - Lagoon #2 Effluent
3 - Lagoon #3 Effluent
4 - Lagoon #4 Effluent

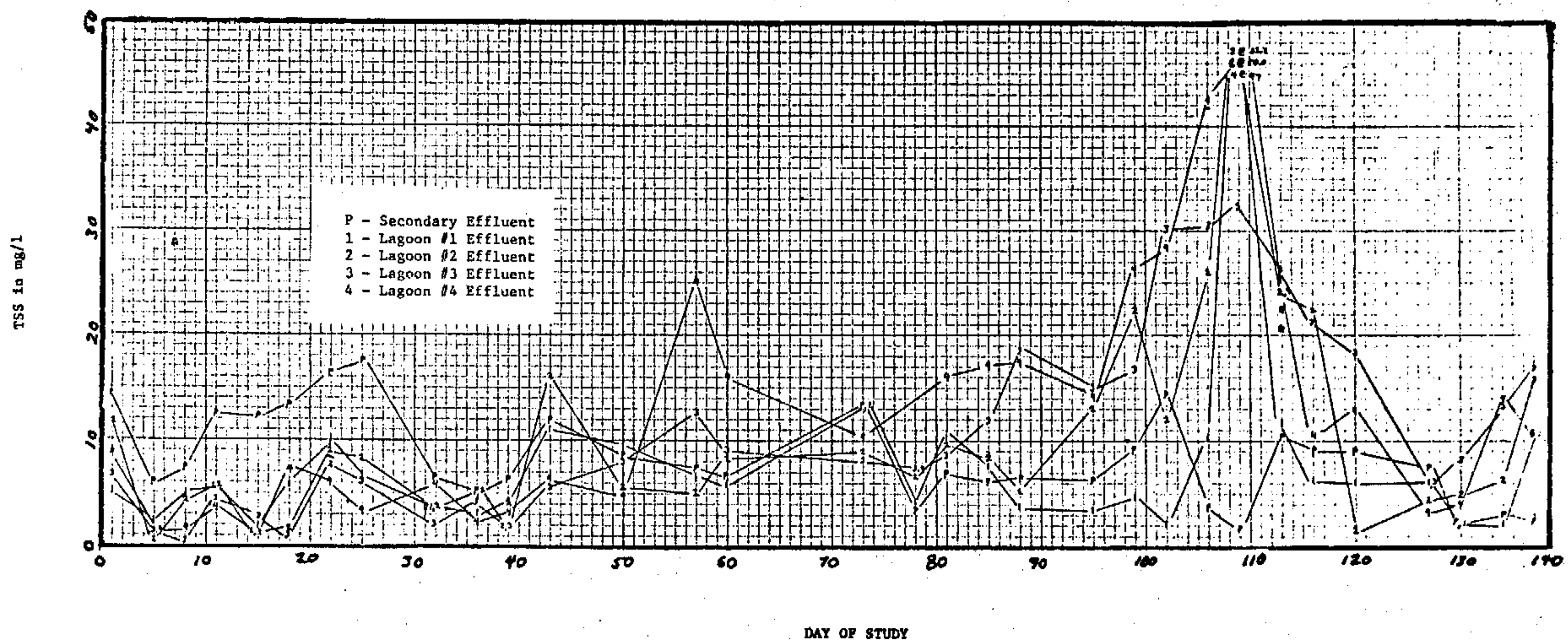


FIGURE 8 TOTAL SUSPENDED SOLIDS

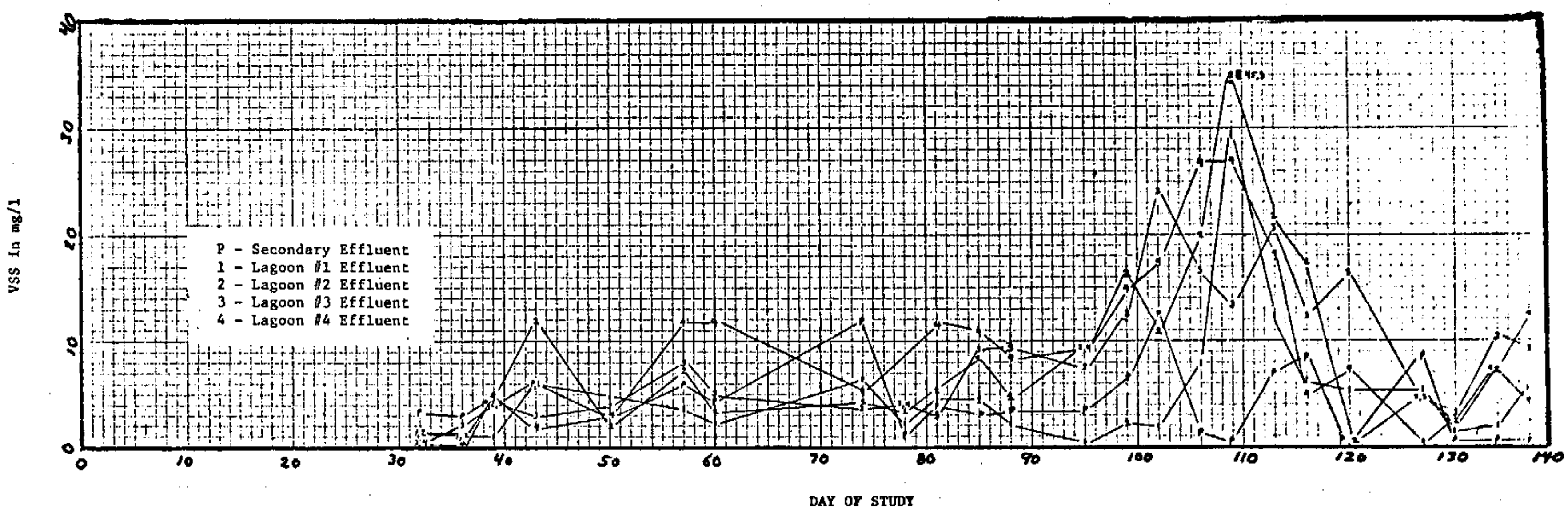
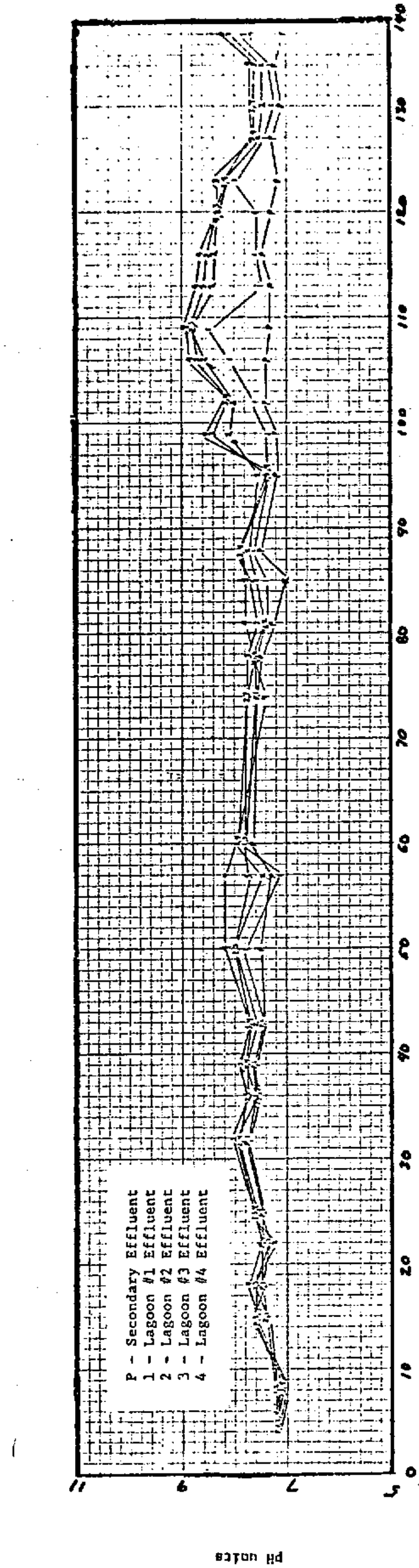


FIGURE 9 VOLATILE SUSPENDED SOLIDS



DAY OF STUDY

FIGURE 10 pH

would be expected. Dates on which a rise in pH in the lagoon system was observed corresponded generally with dates on which increases in volatile suspended solids were measured, and when algal activity was most visible. During periods of minimum algal growth in January and February the pH was relatively constant throughout the lagoon system, and reached a maximum of 8.9 in lagoon 4 in late April.

F. Nitrogen

Nitrate--The results of the nitrate nitrogen analysis are shown in Figure 11. It can be observed that the average nitrate concentration throughout the study decreased through the lagoon system. The average decrease was 17%. This decrease was most apparent in April and May corresponding to the increased algal growth and subsequent uptake of nitrate into new cell mass. During January, February, and March the nitrate concentration was relatively stable throughout the lagoon system. The nitrification of ammonia by bacteria is very temperature dependent, and from observation of Figure 11, it can be seen that the average nitrate concentration increased in all lagoons as the study progressed. This and the peak in the early stage of the study correspond to increasing temperature or unseasonal warm spells.

Ammonia--The results of analysis of the ammonia samples are shown in Figure 12. It can be seen that throughout the study the average ammonia concentration remained essentially constant through the lagoon system. However, the results on a day by day basis were highly variable. This may be due in part to variations in the extent to which the ammonia was oxidized, but more likely to variation in the amount of flow available for dilution. During the early part of the program, the watershed in which the plant is located experienced

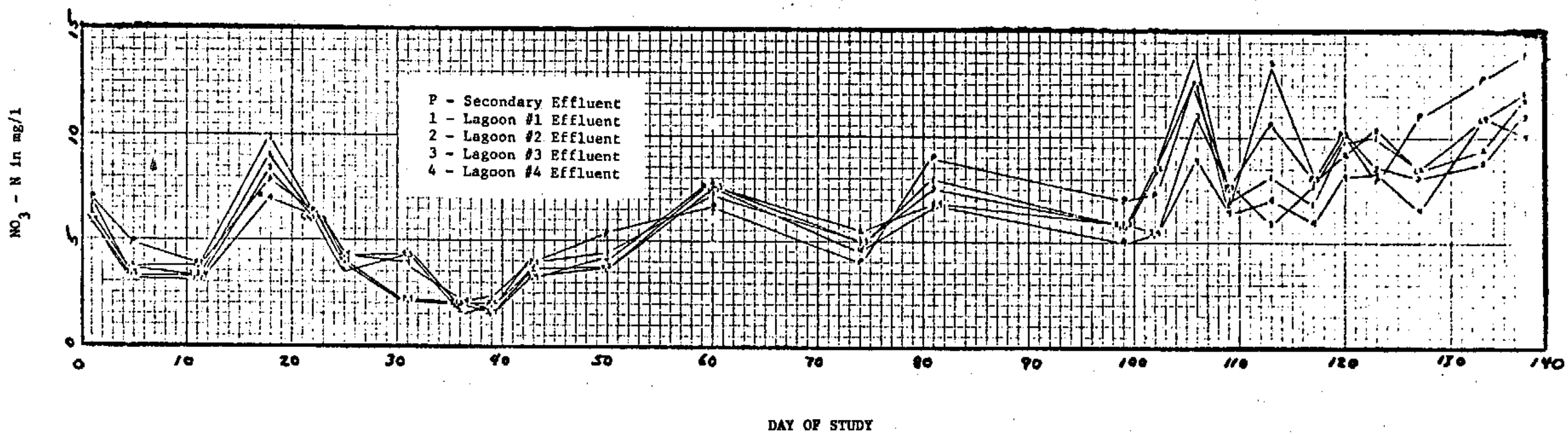


FIGURE 11 NITRATE NITROGEN

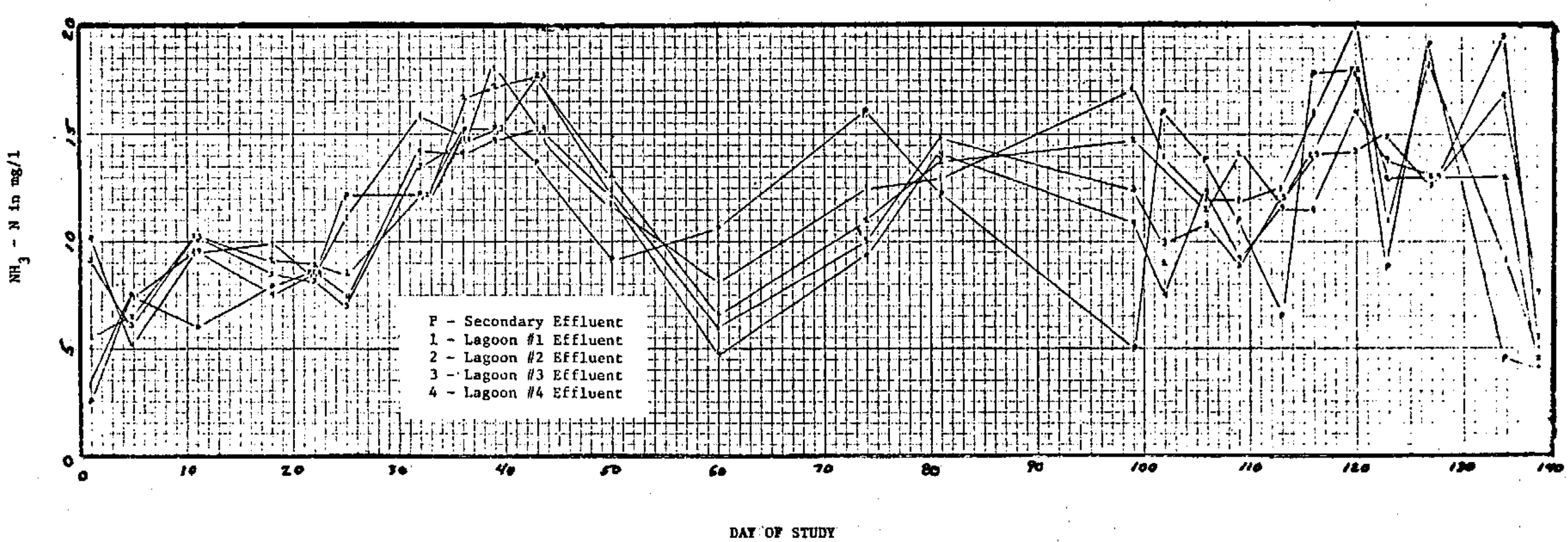


FIGURE 12 AMMONIA NITROGEN

several periods of prolonged rainfall, and the amount of infiltration into the system is substantial.

Total Nitrogen--The results of the total nitrogen analysis are shown in Figure 13. In calculating total nitrogen it was assumed that there was negligible nitrite in the system. This gives the total nitrogen as the sum of total kjeldahl nitrogen and nitrate nitrogen. Similiarly to ammonia, it can be seen that there is almost no nitrogen removed as the liquid flows through the lagoon system. As with the nitrate, the total nitrogen concentration appears to increase throughout the study but this is probably the result of variations in flow. A nitrogen balance was not attempted because of the difficulty in correlating the concentration to the flow and detention time in the system.

G. Phosphorus

Ortho Phosphorus--The results of all the samples with time are shown in Figure 14. The data from the phosphorus tests are spotty and, due to analytical problems of questionable accuracy, they are presented merely as indicators of the magnitude of the phosphorus concentration. However, it can be seen that there was little or no removal of phosphorus from the waste. This is, of course, what would be expected unless some form of solids removal were practiced.

Total Phosphorus--The results of these analyses as a function of time are shown in Figure 15. The comments previously expressed for orthos phosphorus also apply to total phosphorus.

H. Sewage Flowrate

Figure 16 shows the average daily raw sewage flows plotted at two day intervals during the study period. The flows given in Figure 16

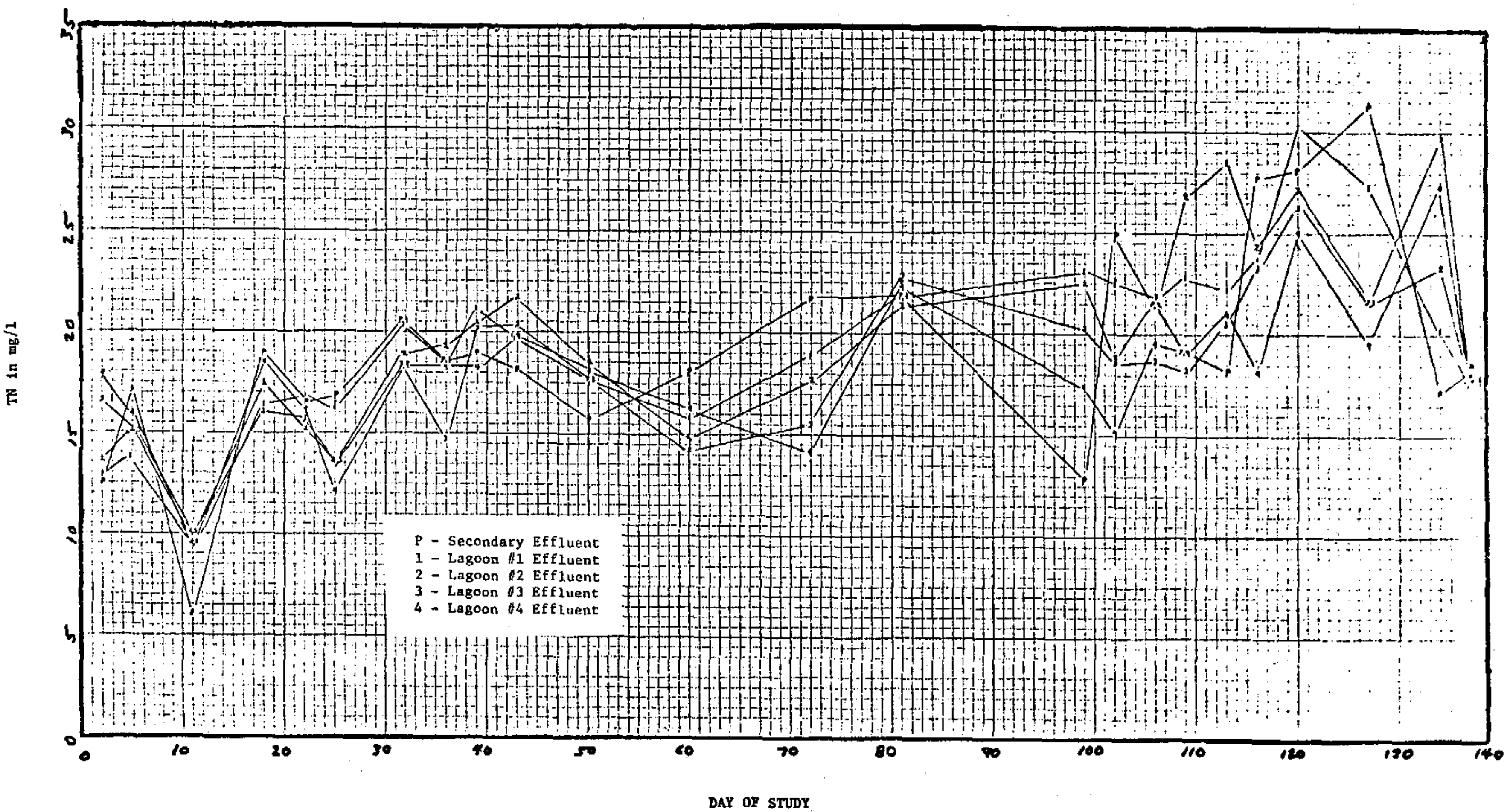


FIGURE 13 TOTAL NITROGEN

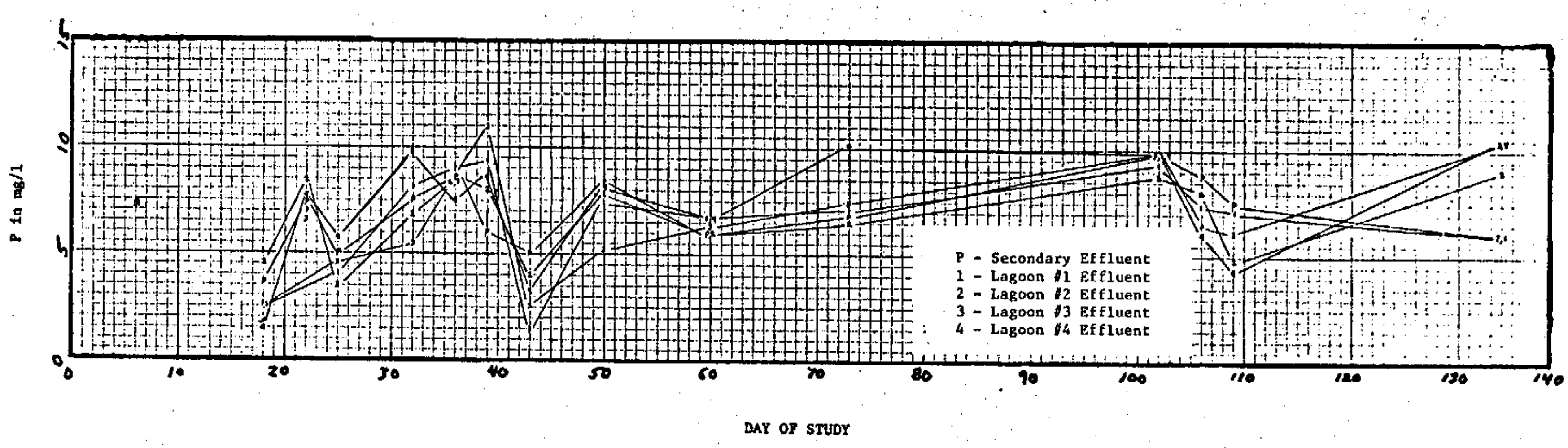


FIGURE 14 ORTHO PHOSPHORUS

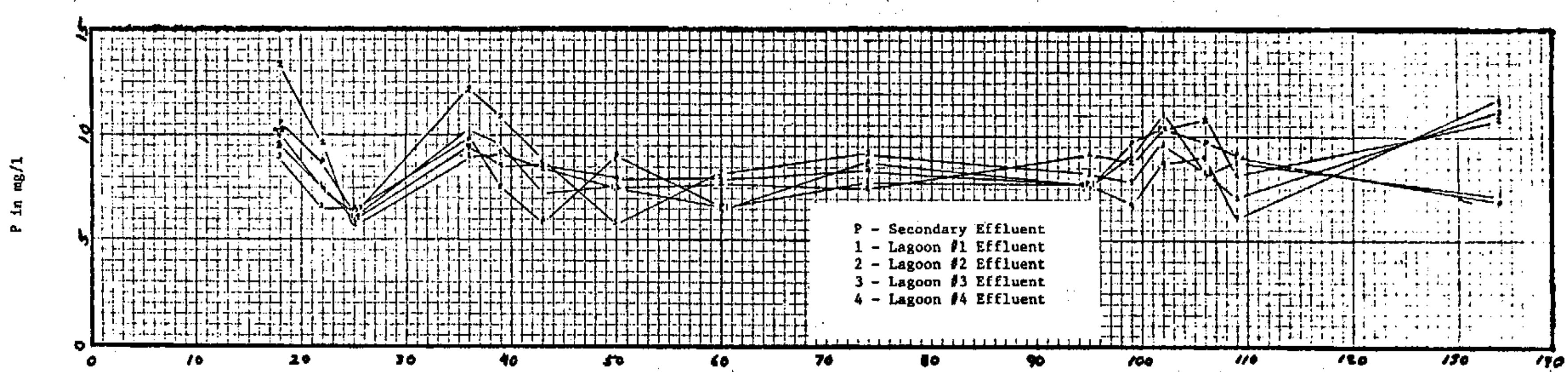


FIGURE 15 TOTAL PHOSPHORUS

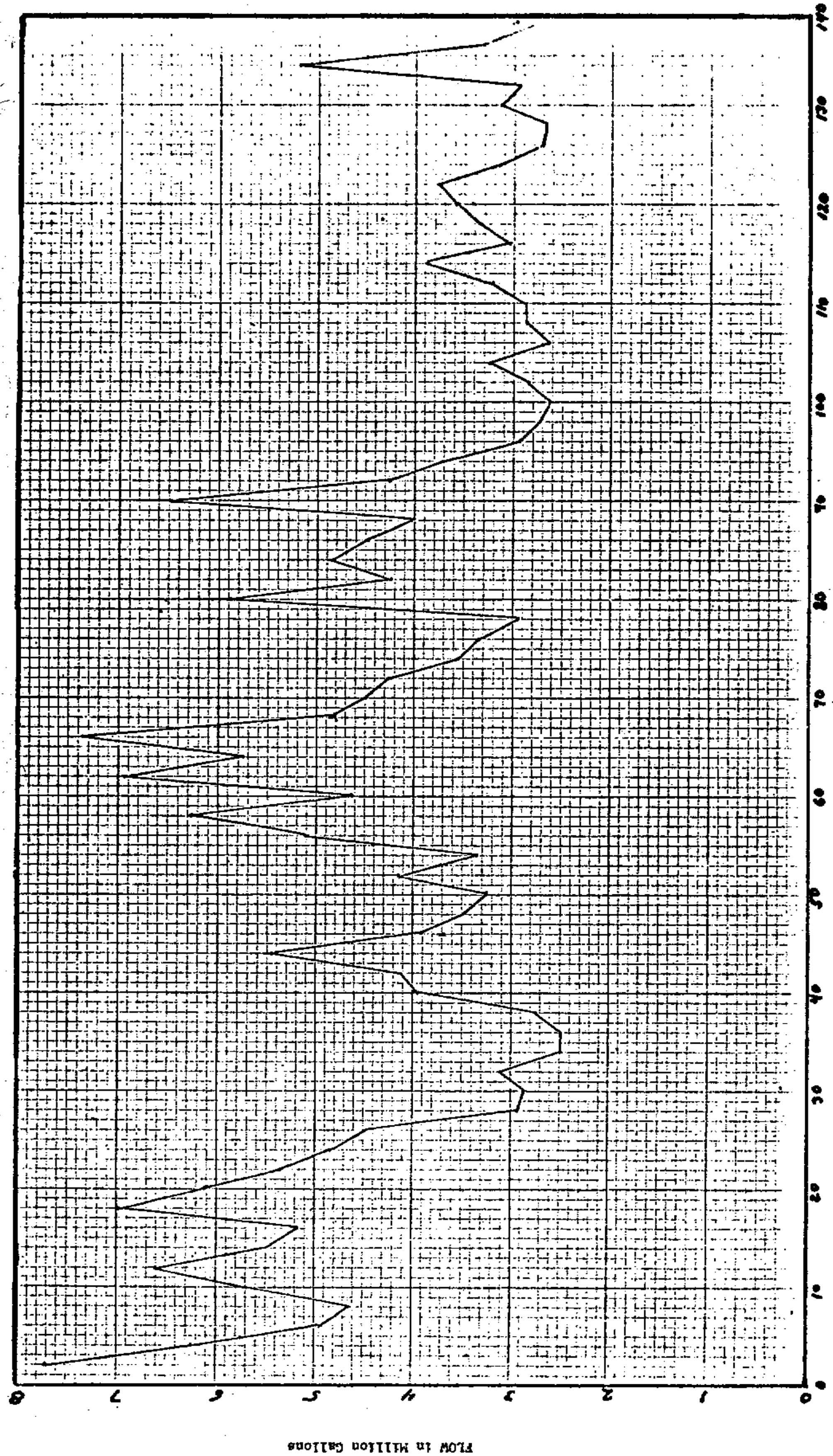


FIGURE 16 RAW SEWAGE FLOWRATE

are for raw sewage flows measured downstream from the raw sewage pump station, and therefore do not show either the exact magnitude of flows during raw sewage by-passing or the flows at any downstream sampling station on that same day.

Discussion (Part I)

Although it would not be advisable to set down definite conclusions on the basis of an incomplete study, some observations may be warranted. These comments should not, therefore, be taken as indicative of what might happen at other treatment plants. The performance of lagoons as used in this plant would surely be influenced by the quality of the influent to the first lagoon, which in this case was very low in BOD.

1. The lagoons serve the very useful function of providing a buffer between the plant and the receiving stream. This is particularly significant during those infrequent intervals during which it was necessary to permit storm flow to by-pass the treatment plant. Because the waste was itself dilute, and because of the further dilution and damping effect provided by the lagoons, such by-passing has no observable effect on the quality of the plant effluent.

2. An apparent reduction in the soluble fraction of the BOD occurred, which appears to be due to a conversion of soluble BOD to algal cell material. In some cases, this resulted in an effluent with a higher total organic carbon content than was measured in the influent.

3. At least partial oxidation of ammonia to nitrate can be expected during warm weather. This could be an important benefit if the effluent is discharged into a small stream with low summertime

flow and small oxygen reserves. In the case of this particular plant, the conversion was not sufficient to meet proposed effluent limitations.

4. It should be expected that suspended solids will increase significantly in the effluent during the summer months, particularly if all four lagoons are in operation. From this standpoint, there were times during which it would have been better to discharge from some other point in the plant.

5. Lagoons operated under aerobic conditions should not be expected to have any significant influence on the amounts of total nitrogen or total phosphorus discharged to the receiving stream.

The above observations suggest several recommendations as to the operation of a lagoon system used as a supplement to secondary treatment.

1. Lagoon systems provide a valuable aid in the protection of stream quality by acting as a hydraulic buffer and should be considered in future plant designs. If designed to do so, they could also be used as flow equalization basins, or as storm water retention basins. The excess volume would be pumped to the plant for treatment during periods of low flow.

2. Lagoon systems should be designed to operate in either parallel or series flow patterns. The plant operator should monitor each lagoon effluent and at his descretion the point of discharge should be selected. In general, this would produce series operation in winter and parallel flow in summer. A more favorable alternative to parallel flow would be to operate only a portion of the system in series, thus decreasing the detention time during the warm periods and minimizing the opportunity for objectional growths of algae.

3. It appears that algal growths are more pronounced when the secondary effluent is retained in the lagoon system for relatively long periods (i.e. for more than 1 or 2 days) during warm periods. If the secondary effluent has a low BOD, the optimum use of a lagoon may be to provide additional 24 to 48 hours sedimentation time for removal of biological solids.

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PART II

Changes in the Bacteriological Quality of Secondary Effluents by Detention in Tertiary Lagoons

John R. Moeller, Research Assistant

The purpose of this part of the study was to determine the effectiveness of a lagoon system in effecting a reduction in the numbers of coliform bacteria in a wastewater which had received secondary treatment. This information should be useful in determining the optimum point at which disinfection should take place, or if, under the most favorable conditions, bacteriological standards could be met without the use of chlorine. With the increasing restrictions on the discharge of toxic materials into streams (which included chloramines), such information might suggest procedures by which adequate disinfection could be achieved in such a manner as to minimize or eliminate any problem due to chlorinated effluents.

Several references on the survival of coliform bacteria in waste stabilization ponds have been listed at the end of this part of the report. As is usual in such cases, the conditions under which these studies were performed differed in important aspects (climate, detention time, type of prior treatment) and the results are not generally comparable. However, in a general sense, the data obtained in this study confirms the observations of other investigators that a substantial die-off of bacteria can be expected in a lagoon system. Insufficient time was permitted to establish the parameters which have the greatest influence on the survival, but some suggestions are given in the discussion of results.

Procedures

A composite sample, consisting of equal volumes of effluent from the seven overflow pipes in each lagoon was taken from each lagoon at each collection date. The fecal coliform test was run on each of the seven outflows of lagoon one as a means of checking any statistical difference. The mean coliform density for these seven samples favorably compared with that of the composite sample. Similar conclusions were drawn from analysis of the total coliform densities.

The secondary effluent and the chlorine contact basin effluent were sampled directly at their points of discharge. It has been reported that the use of membrane filtration in the examination of chlorinated water may result in an error of magnitude one and one-half to two.[7] Four of the sixty-five lagoon samples indicated residual chlorine. Naturally, the contact basin effluent always indicated a residual. Two factors made it unnecessary to change the experimental technique. The four lagoon samples which revealed residual chlorine marked rare occasions in which the secondary effluent was chlorinated before its flow into lagoon one. That treatment is unusual at this plant, and is used only when algal blooms become unwieldy, notably in August and September. Secondly, the experimental coliform counts attained from the contact chamber sample were so low that an error of magnitude ten (much less one and one-half to two) still would result in values far below the maximum numbers recommended for released effluents.

All sampling was done according to procedures recommended in "Standard Methods."[8] This included the addition of sodium thiosulfate to each sample as a means of neutralizing the effects of any residual chlorine.

Laboratory testing for both fecal and total coliform was performed using the technique of membrane filtration. The equipment, culture media, laboratory technique, and analysis of the plated samples were those recommended by the Millipore Corporation.[9] Fresh media (less than 96 hours old) were used. A statistical comparison of the ampoules and the laboratory-prepared media revealed no significant density differences.

All glassware including pipettes, dilution bottles, and filters were autoclaved before each test. Disposable plastic petri dishes were used for convenience, and to eliminate contamination from loose-fitting glass dishes. Autoclaved phosphate buffer, prepared from distilled, deionized water, was used for dilution and rinse waters.

Total coliform cultures were incubated under high humidity conditions at 35°C. Fecal coliform plates were incubated in a water bath incubator at 44.5°C. Colonies were counted under cool-white flourescent bulbs. For those samples in which two or more dilutions were used, that plate which yielded 20-80 colonies was regarded as the most probable "correct" bacterial density. Frequently, two or more plates of the same sample resulted in either no "ideal" colony count, i.e. 20-80 colonies, or more than one plate with an ideal count. In those instances, that plate which yielded the greatest coliform density was recorded.

Discussion of Results

The data collected during the bacteriological study are presented in Figures 17 and 18. Figure 17 is a log plot of the fecal coliform counts observed and Figure 18 gives the same information for the total coliform density. The data points are connected to assist in following the changes observed in each lagoon and not to imply continuity between sampling dates. As would be expected, a die-off of organisms was found as the water flowed through the lagoon system, averaging about 97 percent for the total coliform bacteria and about 98 percent for the fecal coliform group. This is substantially less than would be calculated using the relationship presented by Marais (2), which would predict a reduction of 99.99 percent through four ponds, each with a two day detention time. Examination of Figures 17 and 18 reveals an unusual correspondence between the increase or decrease in the count obtained on a given day in the system as a whole. That is, increases and decreases in bacterial densities appeared to occur simultaneously in all four lagoons (with some exceptions) and not in a sequence dependent on flow and detention time. In nearly every case, an increase in the coliform density in lagoon 1 was accompanied by an increase in the other three lagoon effluents. Similarly, a decrease in lagoon one usually was indicative of a decrease in all of the other lagoons. This observation cannot be explained on the basis of the hydraulic characteristics of the lagoon system. If detention time alone were the governing factor, a peak count in lagoon one would be seen in lagoon 2 about two days later, in lagoon 3 still later and so on. Attempts to explain this phenomenon

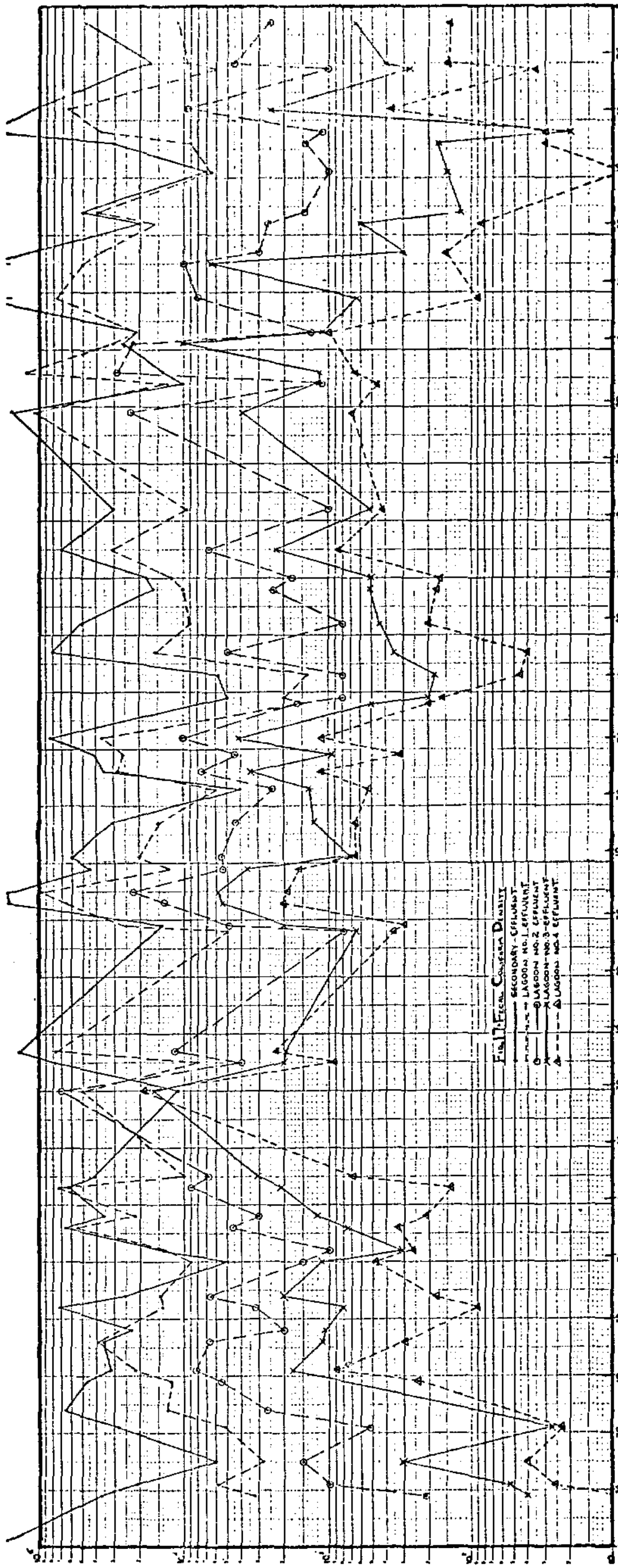
Fig. 17. Fecal Coliform Density
SECONDARY - EFFLUENT
LAGOON NO. 1 EFFLUENT
LAGOON NO. 2 EFFLUENT
LAGOON NO. 3 EFFLUENT
LAGOON NO. 4 EFFLUENT
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY

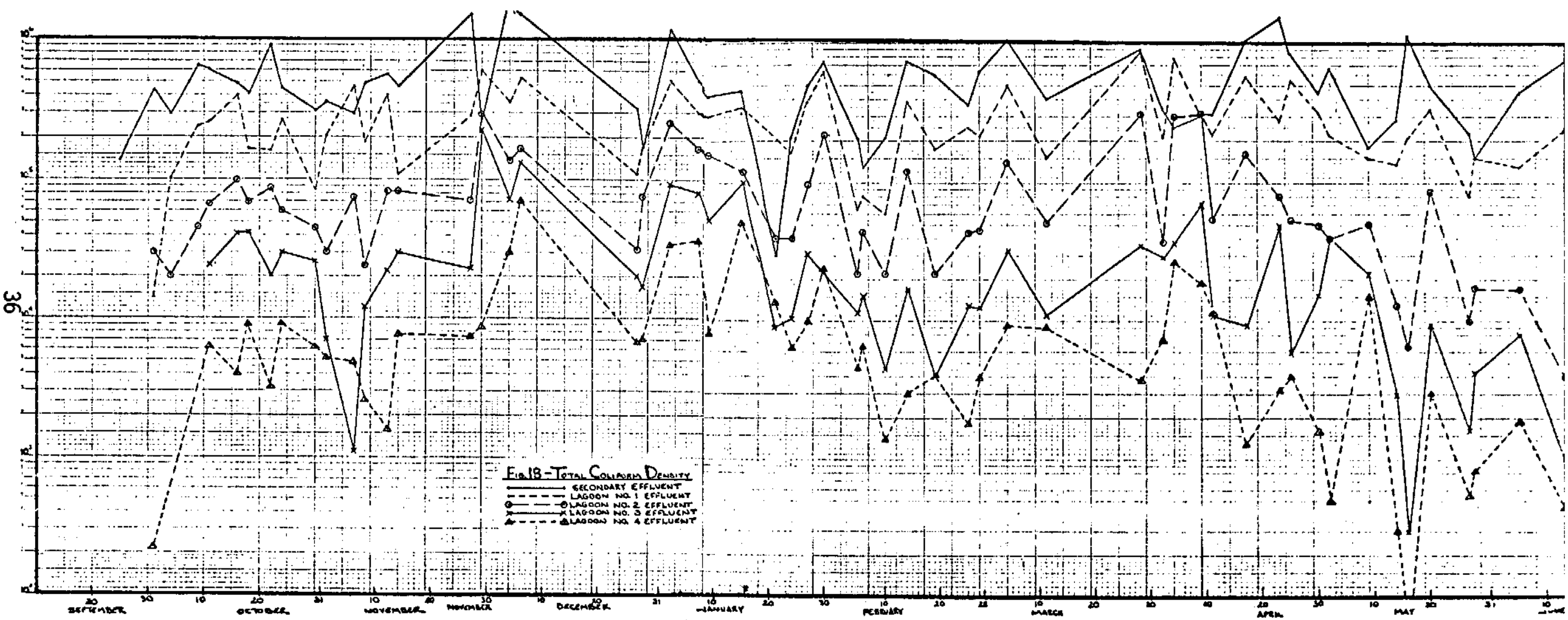
Fig. 13 - Total Coliform Density
SECONDARY EFFLUENT
LAGOON NO. 1 EFFLUENT
LAGOON NO. 2 EFFLUENT
LAGOON NO. 3 EFFLUENT
LAGOON NO. 4 EFFLUENT
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE

on the basis of temperature, pH, or suspended solids concentration were not conclusive, but the available data indicate that it is unlikely that any of these alone could be used as the basis for a suitable explanation. Whatever it is which is causing the effect seen must be influencing all four lagoons simultaneously. It is suggested that this may be the amount of ultraviolet radiation which penetrates into the water, combined perhaps with the mixing action of the wind and warming of the water by the sun. The limited amount of work which has been reported on the disinfection of water by ultraviolet radiation suggests that, under the right condition, this could be a significant factor, and it was this aspect which was to have been studied if the project had been continued to its conclusion. There is also some evidence to suggest that the same factors do not predominate in each of the four lagoons, but that the various influences may be functioning in different degrees from one basin to another.

Conclusions

(1) With the exception of one sample which was taken after the plant had by-passed a portion of the inflow for over 24 hours, the fecal coliform density in the effluent from lagoon four was never found to exceed 2020 organisms per 100 milliliters. The total coliform density frequently was in excess of 1000 per 100 milliliters, and occasionally as high as 30,000. Following the chlorine contact chamber, the counts were generally less than 1 per 100 milliliters, far below the standards suggested for primary contact recreation. The fecal coliform count in lagoon four effluent only twice failed to meet the standard of 2000 per 100 ml.

for general use, and only seven times failed to meet the standard of 1000 per 100 ml. for secondary contact recreation. In over one-half the samples taken, the standard of 200 per 100 ml. for primary contact recreation was met, without chlorination.

(2) Increases and decreases in bacterial numbers appear to occur simultaneously in all four lagoons, and not in a sequence dependent on flow and detention time. It is suggested that this effect is due to variations in the intensity and duration of sunlight.

(3) The lagoon system was found to be quite effective as a buffer between the raw waste and the receiving stream in times of emergency.

(4) No consistent pattern could be established between bacterial numbers and suspended solids concentrations (or other parameters such as pH. BOD, presence of algae, etc.). It appeared that in lagoon 1, the bacterial count increased as the suspended solids concentration increased, while in the other lagoons the opposite appeared to be true. This suggests that different factors may be the primary influences in the separate lagoons.

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