AN EVALUATION OF POLISHING POND EFFECTIVENESS

by

KARL W. MUELDENER

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Approved by:

Lawrence A. Schmid

Major Professor

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INTRODUCTION

The increase in population during the last few decades has been accompanied by an increase in suburban development. Often housing developments and mobile home parks are located far from existing sewage collection systems. Therefore, there is a need for small efficient sewage treatment schemes to serve these isolated areas. One common treatment method for small populations such as those described is the extended aeration activated sludge process.

The number of extended aeration plants in operation has jumped from three in 1950 to many thousands today (24). These plants are used to treat large municipal waste flows as well as flows small enough to allow use of prefabricated units and even units to serve individual homes. With so many extended aeration plants in operation and more surely to be built, state regulatory agencies have intervened to insure proper performance.

Most states require the placement of a retention basin following extended aeration plants to further treat the plant effluent. These retention basins have many labels and will be referred to herein as polishing ponds or tertiary ponds. Required retention times vary from two days in Illinois, four days in Kansas, to thirty days in Wisconsin (15). These polishing ponds are supposed to improve the overall water quality of the plant effluent by two methods: (1) sedimentation of solids, and (2) flow equalization (quantity and quality).

Sedimentation in polishing ponds captures biological solids that occasionally pass from extended aeration plants. The operation of extended aeration plants results in these periodic releases of solids which, if not captured, would pass directly to the receiving stream (18,20).

Equalization of the flow by polishing ponds refers both to discharge quantity and quality. Often these small treatment plants discharge to small streams. Consequently, slug discharges from the treatment plant could more easily result in ecological damage than the same discharge to a larger river. By flow equalization through polishing ponds, the effects of slug releases are minimized by dilution and discharge over a longer period of time.

Disinfection and nutrient conversion also are important functions of polishing ponds, but they are not intended to be as significant as the two functions previously discussed.

Conversion of nutrients, usually to algal mass, is of questionable value in polishing ponds. This conversion of nutrients, from soluble ions to insoluble organic algal mass, is not an intended practice. The characteristics of polishing ponds simply provide an excellent location for this algal growth.

Algae are sometimes an asset and often a liability. Algae do provide an oxygen source to the pond, but this oxygen is borrowed and must be repaid. The oxygen supplied to the water is a result of algal photosynthesis. Upon death the algae will decay and demand oxygen, thereby taking back the oxygen initially loaned (32). Thus, the oxygen is an advantage, but the algae can be a liability (17).

The importance of algae in oxidation ponds is well known (6,21,26). Oxidation ponds are defined as those ponds receiving raw wastewater and should not be confused with polishing ponds which receive secondary effluents. Consequently, the importance of algae to polishing ponds must be viewed in a different manner. The heavy organic load placed on oxidation ponds would quickly result in depletion of the pond's oxygen if it were not for the algae supplying oxygen by photosynthesis.

Organic loading of polishing ponds is nearly twenty times less than that of regular oxidation ponds. Therefore, the bacteria require much less oxygen in the oxidation of fewer organics. This means less algae are required to insure aerobic conditions in the more lightly loaded polishing ponds than in regular oxidation ponds.

Some major constituents of domestic extended aeration plants effluents are alkalinities of 200 to 300 mg/l (in Kansas), suspended solids concentration of 20 to 40 mg/l, BOD_5 (5 Day Biochemical Oxygen Demand) of about 20 mg/l, total phosphorus of 10 mg/l, and total nitrogen of 30 mg/l as ammonia or nitrates (6).

Keeping in mind these various nutrient concentrations and assuming nitrogen limiting in the following equation for algal photosynthesis of:

$$NH_3 + 5.7\ CO_2 + 12.5\ H_2O \xrightarrow{\text{sunlight}} C_{5.7}H_{9.8}O_{2.3}N + 6.25\ O_2 + 9.1\ H_2O$$

approximately 270 mg/l of algae could be produced (21). This algae would exert a theoretical oxygen demand of approximately 400 mg/l based on a respiration equation (21) of:

$$C_{5.7}H_{9.8}O_{2.3}N + 6.25\ O_2 \longrightarrow 5.7\ CO_2 + NH_3 + 3.4\ H_2O$$

If such prolific growths occurred and were discharged, the quality of the water, as it passes through the pond, would be lowered. In terms of suspended solids and COD (Chemical Oxygen Demand) the algae laden effluent would be of a lower quality than raw sewage. However, the stream damage due to algae would not be as vulgar as that due to raw sewage. This is because the algae would be more diffused downstream when they decay. Therefore, the oxygen loaned by the algae is repaid over a larger area downstream (32).

Nutrients are removed from the water and incorporated into algal mass. If the nutrients, now insoluble in algal mass, are to be removed, the algae must be removed. If the algae are not removed, then nutrients are not kept from the receiving stream and insoluble organic material (algae) is dumped into the stream. Upon decay, the nutrients tied up in the algae are released once more. Stumm and Morgan (32) stated the problem as:

> "It is clear that unless algae are removed prior to the discharge of the pond effluent, the ultimate waste load will not have been diminished by this treatment. The algae which move down the stream must ultimately decay and consume the requisite oxygen, thereby releasing the nutrients."

OBJECTIVES

The overall objective of this project was to evaluate the effects of polishing ponds on the water quality of a secondary effluent. Four divisions of study helped achieve this overall objective.

One division was to determine the effect of the polishing pond system upon water quality. BOD, COD, and turbidity were measured to determine organic matter removal. Pathogenic organism removal is also a desired function of polishing ponds, and their removal was studied. Suspended solids removal and nitrogen conversion were also investigated.

A second part of the study was to determine the effect of detention time upon the performance of the polishing pond (measured as described above). Two nearly identical retention basins were available. One had a retention time of ten days while the second pond had a retention time of four days. It was theorized that the longer retention time would result in excessive algal growths, negating the worth of the pond. However, a longer retention time would probably result in more complete pathogen destruction, less solids build-up on the pond bottom and nearly complete conversion of ammonia to the more desirable nitrate form.

This second objective was not obtainable, due to the nature of the plant effluent discharged to each pond. Even though each extended aeration plant was basically the same, one plant (Walnut Grove) was extremely inefficient due to improper design and operation. The high loading of the four-day polishing pond following this inefficient plant resulted in the pond actually being an oxidation pond rather than a polishing device. Therefore, its performance as a typical polishing pond could not be evaluated. Instead, the value of a polishing pond as an emergency or temporary treatment scheme was evaluated. With the treatment plant operating poorly, the pond is the only significant device remaining to protect the receiving stream and its significance was determined. The polishing pond with a ten-day retention time followed an extended aeration plant which was very efficient. This ten-day pond was evaluated on its ability to improve an already well-treated effluent.

Thus, the study allowed evaluation of two contrasting functions of polishing ponds: (1) protection against plant upset, and (2) improving a properly treated secondary effluent.

A third objective was to determine a control measure for algae growth. Copper sulfate is effective for algae control and the required dosage for toxic conditions to algae was determined.

Solids build-up on the two pond bottoms was determined. Retrievable cans were placed strategically within the ponds and retrieved after one year. This will help determine if solids accumulation is an important factor in sizing polishing ponds.

LITERATURE REVIEW

There is little published material on the effectiveness of polishing ponds and much of the information presented is contradictory. Many articles are available concerning the effectiveness of oxidation ponds. Remembering the definition of oxidation and polishing ponds, caution should be used in generalizing oxidation pond literature to study polishing ponds.

The design of several of the polishing ponds reviewed was quite different than that employed in this study. Potten (28) reported on ponds used in the United Kingdom following an activated sludge plant. These ponds were originally designed to allow the effluent to percolate into the underlying aquifer. Hemmens and Mason (14), of South Africa, experimented with a polishing stream in hope of removing nutrients. A third variation was examined by Loehr and Stephenson (16,17). They used an oxidation pond only thirty inches deep as a polishing pond following a trickling filter treatment plant. All of these facilities are polishing devices but, due to the unique designs, are quite different from those studied herein.

MEASURE OF REMOVAL: BOD vs. COD

A "definition of terms" is necessary to properly describe water quality. Some investigators have primarily based pond performance on BOD_5 removal while others rely more on COD values as an indicator of treatment.

Reynolds (30) studied a tertiary pond in Illinois and based the value of the pond's effectiveness on BOD_5 and suspended solids reduction. Krill (15) made recommendations for polishing pond design in Wisconsin relying primarily on BOD_5 and suspended solids reductions observed in test ponds.

Others state that COD is more realistic in evaluating the performances of polishing ponds (18,23). ASTM points out limits on the BOD_5 test such as: "The five-day BOD cannot be considered as a quantitative expression without an approximation of the rate of oxidation and the ratio of five-day BOD to ultimate oxygen demand." (8) Davis expounds on ASTM's warning:

> "For example the expected decreases in BOD_5 values through the raw, primary, secondary, tertiary, etc., scheme of treatment give no indication of these organic compounds composition changes."

Bartsch (3) was even more explicit by concluding:

> "Although BOD reduction is usually accepted as a measure of treatment efficiency, this relationship is almost meaningless when it involves algae laden effluent samples. With the standard BOD_5 test and its five-day incubation in the dark, the sample will give an unduly high value because of algal respiration, death, and decay. Incubation with continuous illumination results in low or even negative BOD. These deficiencies of the BOD_5 test have not yet been remedied."

Loehr and Stephenson (17) determined that a tertiary pond will improve the efficiency of a waste treatment facility if BOD_5 is used as a measure of this efficiency. However, they noted that BOD_5 removal was not accompanied by COD removal. They suggest "that BOD_5 may not be the proper parameter to judge either tertiary pond efficiency or effluent quality." Loehr and Stephenson (16) expound on this concept in stating:

> "The decrease in BOD_5 is not as significant as it seems since no COD removal was accomplished during the summer months.

The form of the oxidizable material was changed from organic matter and bacterial calls in the influent to algae in the lagoon, but, no loss in oxidizable material occurred."

Potten (28) of Great Britain agrees with the others in stating:

"Since the solids in the final effluent are actively respiring and undergoing photosynthesis, the use of BOD_5 results as a criterion of water quality is really of little value."

Observations by Lubzack (18) lead him to conclude that:

"Performance rating of extended aeration treatment plants is more realistic when based on COD and volatile solids."

Along the same line, Middlebrooks, et al. (23), states that:

"The organic quality of the effluent from extended aeration plants is largely determined by a relatively constant soluble fraction (soluble COD) that is more accurately determined by COD test than by BOD_5 testing."

More criticisms of the BOD_5 test for algae laden waters were put forward by Fitzgerald (11). He found that different species of algae would affect the BOD_5 test in various, even opposite ways. Similarly, Raschke (29) pointed out that:

"BOD_5, COD, and suspended solids data should be interpreted with caution in respect to the concentration and composition of algal flora."

In any case, discretion should be exercised in data interpretation. Conclusions concerning effectiveness of operation should be based on several parameters. Not discussed above, but equally important, are nutrient concentrations and forms, temperature, coliform concentration, dissolved oxygen, and the concentrations of various toxins (copper, chlorine, etc.). All of the above mentioned constituents are interlocked, not only with themselves, but with the ecosystem to which they will soon be discharged. Obviously, the entire problem must be analyzed to properly evaluate the effectiveness of polishing ponds.

TREATMENT EFFICIENCY

BOD_5 Removal

BOD_5 data is the most common value used in the waste treatment profession to convey a level of water quality. It is an important consideration for many reasons. Among these is the fact that Environmental Protection Agency (EPA) standards for 1977 set a maximum BOD_5 of 30 mg/l on plant effluents. BOD_5 will also be used to determine ultimate oxygen demand in 1983. Consequently, whether or not it accurately describes treatment efficiency, it is a major consideration.

A polishing pond, detention time of 2.3 days and average depth of 5.5 feet, following a trickling filter in Illinois was evaluated by Reynolds (30) and found to be effective in reducing BOD_5. Average pond influent and effluent BOD_5 values were 30 mg/l and 18 mg/l, respectively. This is an average yearly reduction of 40 percent. The best BOD_5 removal was 43 percent from November to April. During the months of May through October, BOD_5 reduction through the tertiary pond dropped to 37 percent.

As mentioned earlier, Loehr and Stephenson (17) determined that a tertiary pond can improve overall plant treatment efficiency if BOD_5 is used as a measure of this efficiency. BOD_5 removals in the pond they studied, detention time of 1.8 to 3.3 days and 30 inches deep, ranged from 20 percent to 60 percent. The best results (60 percent) occurred during June and December. These months also were the periods of highest influent BOD_5, 19 and 30 mg/l. Lowest BOD_5 removal occurred in July and was 20 percent on an influent BOD_5 of 11 mg/l. The investigators surmised that this low July reduction was due to algae in the effluent.

Another author, Potten (28), observed for over five years a tertiary pond following an activated sludge plant. This pond had a retention time of 22 hours and a depth of approximately 1.5 meters. The average BOD_5 removal for this period averaged 30 percent on an influent with a BOD_5 of approximately 10 mg/l.

A polishing pond in Ontario, Canada, was determined to remove 34 percent of the influent BOD_5 (4). This increased the plant's total removal from 85 percent to 91 percent. Again, this pond received a low influent BOD_5 of only 14.6 mg/l, so the effluent BOD_5 was down to 9.2 mg/l after the detention period of 5.5 days.

Krill's (15) study of ponds with varied detention times showed increased BOD_5 removal with increased detention time. He studied ponds with 3, 10 and 30 day detention times and found corresponding removals of 61 percent, 69 percent and 71 percent. The average BOD_5 of the plant effluent entering the pond was 51 mg/l.

Malone and Bailey (19) found that both soluble and total BOD_5 were reduced in a polishing pond of 5 days detention. The pond influent total BOD_5 was approximately 40 mg/l, while the pond effluent total BOD_5 was roughly 20 mg/l.

COD Removal

COD removal was briefly discussed earlier in regard to a measurement of treatment efficiency. COD has been reported to be a better test than BOD_5 in detecting the presence of algae. Unfortunately, several of the papers concerned with polishing ponds made no reference to COD values. Those authors that considered COD were generally inclined to rely on COD values while discounting the validity of BOD_5 tests (3,8,17,18,23,28).

Loehr and Stephenson (17) recognized that the use of COD data indicated there was no loss of oxidizable matter through the pond. As noted earlier, they observed no loss of COD, while the BOD_5 of the same waters was reduced. Obviously, this detected the presence of algae.

Raschke (29), investigating polishing ponds, found that there were COD reductions year round. This is in contrast to Loehr and Stephenson's (17) findings of no COD reductions during the summer. The preceding authors also observed little COD reduction during warm weather. An important fact to remember is that Loehr and Stephenson studied a pond only 30 inches deep.

Black (4) observed a polishing pond in Ontario for three weeks during late April and early May and found COD values reduced from near 150 mg/l to 115 mg/l. This is a reduction of 23 percent.

Suspended Solids Removal

EPA effluent standards for 1977 set a value of 30 mg/l for suspended solids. The literature points out that polishing ponds are generally effective in obtaining this goal.

A 49 percent decrease in suspended solids was obtained in Illinois by use of a polishing pond (30). This pond reduced suspended solids from 61 mg/l in the influent to 31 mg/l in the effluent. Best removals, 53 percent, were during November through April, corresponding to the highest BOD_5 removals. The period of May through October saw the removal rate reduced to 45 percent.

Krill (15) observed polishing ponds in Wisconsin with various detention times. He found the suspended solids reduction averaged 66 percent through a three-day pond, 64 percent through a ten-day pond, and 52 percent through a 30-day pond. The mean influent suspended solids to Krill's ponds was 59 mg/l.

Work in North Carolina by Malone and Bailey (19) determined that removal of fixed solids was a benefit of polishing ponds.

Over a five-year period Potten (28) determined that suspended solids were only slightly reduced through a series of polishing ponds observed in England. Potten noted that the solids leaving the pond were primarily algae and were completely different from influent suspended solids.

Nitrogen Removal

Nitrogen is one of the basic nutrients long recognized as essential to plant growth. The discharge of nitrogen often stimulates prolific growths of algae. If the nitrogen is present as ammonia or organic nitrogen (protein) oxygen is required to gradually convert ammonia to nitrites and nitrates (31). Therefore, the amount of nitrogen present, as well as its form (ammonia, nitrite, nitrate) is a useful water quality guide.

Twelve years of observation by Potten (28) of a lagoon series receiving a fully nitrified effluent led him to the conclusion that considerable reductions occur in the nitrate concentration if the retention time is long enough. However, Potten also found no "reason to suppose that there was any appreciable reduction in the total amount of ammonia-nitrogen entering and leaving the lagoon." A malfunction of the aeration units resulted in peak loads of 8 to 9 mg/l of ammonia-nitrogen being discharged to the lagoon. The effluent of the lagoon reached a maximum of only 5 to 6 mg/l after this upset. Potten pointed out that the lagoon form of tertiary treatment provides a buffering safeguard against such failures that other systems (microstrainers, sand filters) do not possess.

Black's (4) evaluation of polishing installations in Ontario revealed nitrogen increased from 10.4 mg/l to 11.3 mg/l and free ammonia increased from 9.4 mg/l to 11.4 mg/l. However, if the pond effluent was filtered to remove algae, organic nitrogen was reduced by 50 percent.

Another researcher, Fall (10), noticed ammonia increases of 2.4 mg/l through a tertiary pond. Fall suggested this increase "is indicative of the diffusion of ammonia from the bottom sludge to the liquid flowing through the pond."

Nitrogen increases were often detected by Loehr and Stephenson (17) in their study.

Krill's (15) Wisconsin study found nitrates reduced through polishing ponds. Longer detention times gave increased nitrate removal. The ponds in Krill's study were anaerobic so the nitrates were being reduced to ammonia. This reduction was reflected in Krill's data on ammonia concentrations.

Coliform Removal

Literature on the subject of disinfection by polishing ponds is contradictory. An excellent article by Malone and Bailey (19) concerns itself primarily with bacterial removal in polishing ponds. Malone and Bailey concluded that tertiary ponds following secondary treatment plants provide excellent bacterial (coliform and enterococci) removal. In fact, these researchers suggested that tertiary pond effluents are more likely to meet stream standards for coliforms than chlorinated effluents. Malone and Bailey's data clearly indicate that coliform and enterococci removal is more complete with longer detention times. The pond influent usually had a coliform count of roughly 10^6 or 10^7 per 100 ml. After five days in the pond, the coliform count was approximately 10^4 per 100 ml.

The British team of Oakley and Cripps (25) agreed that tertiary ponds effectively removed and virtually destroyed pathogens. But, they felt that pathogens could be dealt with more economically by chlorination, ozone, or ultraviolet light.

Potten (28) also found that pathogens "virtually disappeared" in polishing ponds.

In contrast to the conclusions mentioned above, Fall (10) found that coliform removal in polishing ponds was "disappointing." He felt that chlorination will be required to meet Illinois stream standards. Loehr and Stephenson (17) also concluded that a tertiary pond is not effective in removing coliforms. They observed at least 50 percent removal of coliforms. But, this still left an effluent concentration of 10^5 per 100 ml.

Sludge Build-up and Digestion

Solids settlement is one of the basic functions of polishing ponds and it is possible that sludge build-up may limit the size of a pond. What becomes of the sludge that settles is also a point of interest.

The first cell of a multi-celled lagoon studied by Fall (10) had a solids build-up of one foot after 19 months. No sludge was found in the second cell. The sludge in the first cell resembled well-digested sludge and analysis revealed it settled to be 33 percent total solids and 60 percent volatile. Fall also stated that ammonia gas was released from the bottom sludge.

Loehr and Stephenson's (17) polishing pond did not digest bottom sludge. This pond was only 30 inches deep, which surely had a detrimental effect on sludge digestion. They collected gases rising from the sludge and determined it to be 67 percent nitrogen and 33 percent oxygen.

Potten's (28) investigation showed that aerobic conditions persisted even after a plant malfunction resulted in heavy sludge deposits (10-20 cm.). The lagoon system in Potten's study was operated in a series which allowed isolation of a pond for sludge removal. Thus, pond maintenance was possible without losing the entire tertiary system.

EFFECTS OF ALGAE

The effects of algae on polishing pond performance are quite diversified. Due to this diversity, a separate discussion of these algal influences is not feasible and previous sections have introduced the subject in some detail. Nevertheless, several important findings are yet to be presented and others reiterated.

Algal Effects on BOD_5 and COD

The effects of algae on BOD_5 and COD were discussed earlier. The literature reveals a general concensus that COD is a more accurate measure of water quality than BOD_5 for extended aeration effluents and algae laden waters (8,17,18,23,28). Some researchers stated that algae will result in high BOD_5 values due to respiration (3,17). Fitzgerald (11) was more specific and noted Chlorella will exert a variable oxygen demand dependent on the carbonaceous nature of the waste.

Loehr and Stephenson's (17) findings, that BOD_5 reductions occurred without corresponding COD reductions, suggests that a significant part of the algal mass is nonbiodegradable. This is because the COD test measures the oxygen demand of the entire algal mass while BOD_5 analysis measures only biodegradable part.

Algae and Suspended Solids

The direct relation between algae and suspended solids has been noted by Meron, Rebhun and Sless (22). They observed that decreases in algal cell concentrations correspond to decreases in effluent suspended solids. Loehr and Stephenson (16) also found algae to be the primary cause of suspended solids in a polishing pond effluent.

If algal cells settled out before discharge, their growth would be an asset. Unfortunately, algae do not settle appreciably and are consequently discharged to the receiving stream (13).

Potten (28) determined that while the influent solids to the pond were activated sludge solids with high protozoal and bacterial content, the solids discharged from the lagoon were primarily algae, cyclops, daphnia and rotifers. He also found that approximately 50 percent by weight of the suspended solids in the effluent were algae.

Nutrient Removal

Nutrient removal by algae has been investigated by many (7,14,32). The drawback to this concept is that an efficient and economical method of algae harvesting has yet to be developed (13). Polishing ponds, as they are presently designed, do not remove algae and the insoluble nutrients in the algal mass. Stumm and Morgan (32) summed up the problem as follows:

> "Algal growth in stabilization ponds can be employed to remove the bulk of nutrients from wastes, provided that the algae are separated from the effluent prior to discharge to the stream. Satisfactory techniques need to be developed to enhance bioflocculation of algae. Chemical coagulation with metal and polyelectrolytic coagulents give promise of such developments."

Control of Algae

If algae is not removed from the effluent, control measures may be desired to limit algal photosynthesis. One approach is to interfere with the nutrient cycle by physical, chemical or biological means (32). Among the possibilities for such interference are reduction of effective light, use of algicides, and the increase of grazing by herbivores (32).

Of these methods, only algicides have been directly studied in waste treatment. Chlorination and copper sulfate have long been known to be effective as algicides (21,26). Copper sulfate is toxic to many algae at strengths which are nonlethal to fish (26). This fact, along with its low cost, have made it a popular algicide.

Palmer (26) states that:

> "The lowest concentration of copper sulfate which is toxic for a particular alga varies according to the abundance of the alga, the water temperature, the alkalinity of the water, the amount of organic material in the water, and other factors."

In alkaline waters copper sulfate will precipitate quickly as copper carbonate (26). Thus, it is effective as an algicide only for a short time following its application and is ineffective below the surface. Since the algicide is only effective on the surface of alkaline waters, Palmer gives a dosage rate as 5.4 pounds copper sulfate per acre.

Palmer (26) has summarized a list of alga and catagorized them by their relative susceptibility to copper sulfate. Listed as "very susceptible" are *Anabaena*, *Anacystis*, *Gomphosphaeria*, *Closterium*, and *Volvox*. "Resistant" species included *Chlorella*, *Chlorococcum*, *Desmidium*, *Oocystis*, *Palmella*, and *Chlamydomonas*. Species described as "very resistant" included *Scenedesmus* and *Eudorina*.

Dissolved Oxygen from Algae

Algae provide a source of dissolved oxygen to a polishing pond. Potten (28) determined that the dissolved oxygen content was higher than the BOD_5 value and often higher than the "permanganate value." Over five years, Potten observed a gradual increase in the average effluent dissolved oxygen from 7.8 mg/l to 9.1 mg/l. The average monthly lows occurred in the winter months and were never below 5.4 mg/l. The average highs usually occurred in May and were near 12.0 mg/l.

Malone and Bailey (19) also recorded dissolved oxygen when studying a polishing pond. Their results showed that:

> "During the summer months when the dissolved oxygen is likely to be the lowest in the stream, the polishing ponds are more efficient and discharge waters with an elevated dissolved oxygen."

The dissolved oxygen data of Malone and Bailey's study show dissolved oxygen values greater than 15 mg/l from late May to late September. From October through December, when the study ended, records show effluent dissolved oxygen values of less than 5 mg/l.

pH Increases by Algae

Extensive algae blooms can result in pH values as high as 10 to 11 in surface waters (26,31). This is due to the ability and need of algae to remove carbon dioxide from the water. Sawyer and McCarty (26,31) explain how this carbon dioxide removal results in shifts in the alkalinity system from bicarbonates to carbonates and eventually to hydroxides. All this shifting occurs without a change in total alkalinity. However, there is often precipitation of calcium carbonate which has been known to reduce water hardness up to one-third.

One advantage of a high pH in polishing ponds is coliform removal (27). Parhad and Rao (27) determined that E. Coli removals in ponds may be attributed to high pH values.

DESCRIPTION OF FACILITIES

TIMBER CREEK PLANT

The Timber Creek sewage treatment plant is a small extended aeration facility which provides wastewater treatment for a housing development located four miles east of Manhattan, Kansas. The housing development, Timber Creek, presently consists of 20 homes, with expansion to a maximum of 72 homes.

The treatment plant is designed for 72 homes (216 people) so it presently is providing long retention times. Secondary effluent is chlorinated and discharged to a chlorine contact basin with a 43 minute detention at design flow. Discharge to this contact basin is through a V-notch weir which provides for plant flow measurement.

The polishing pond is a vertical wall concrete tank eight feet deep with a water depth of seven feet. At design flow, detention time is four days. The pond covers 1,200 square feet, and a plan view is shown in Figure 1.

The outlet structure consists of a four-inch PVC pipe discharging from a depth of 15 inches below the water surface. This eliminates freezing problems and reduces the amount of algae discharged.

WALNUT GROVE PLANT

Walnut Grove is a mobile home park of approximately 100 units located seven miles east of Manhattan, Kansas. Secondary sewage treatment is provided by a Smith and Loveless extended aeration unit.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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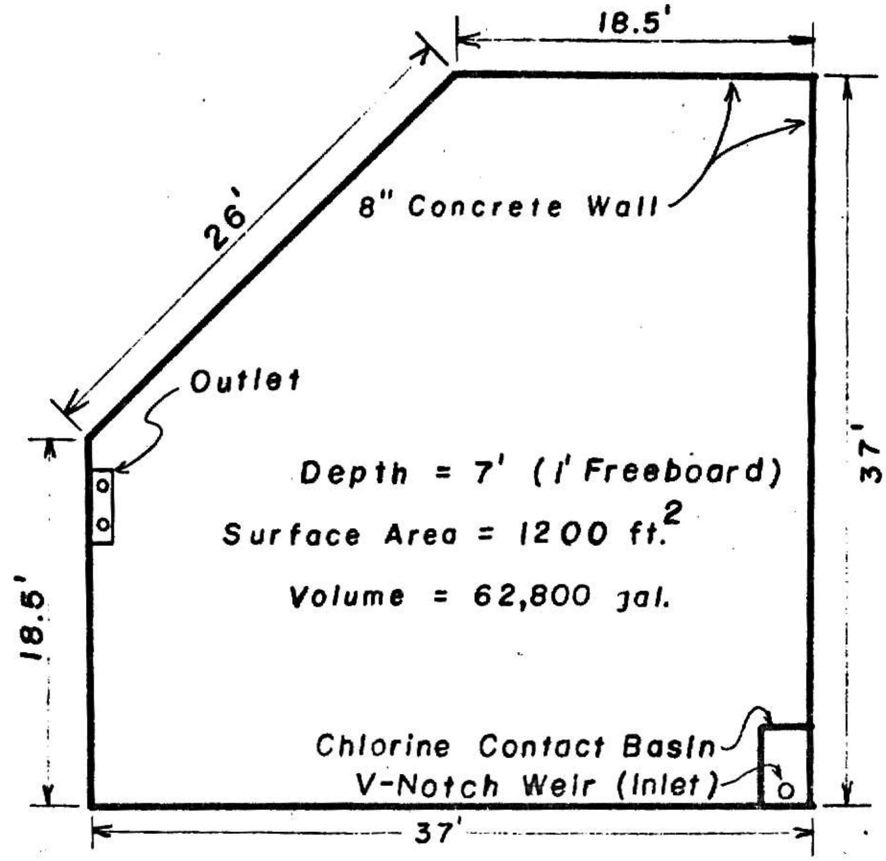

FIGURE 1. PLAN OF TIMBER CREEK POLISHING POND

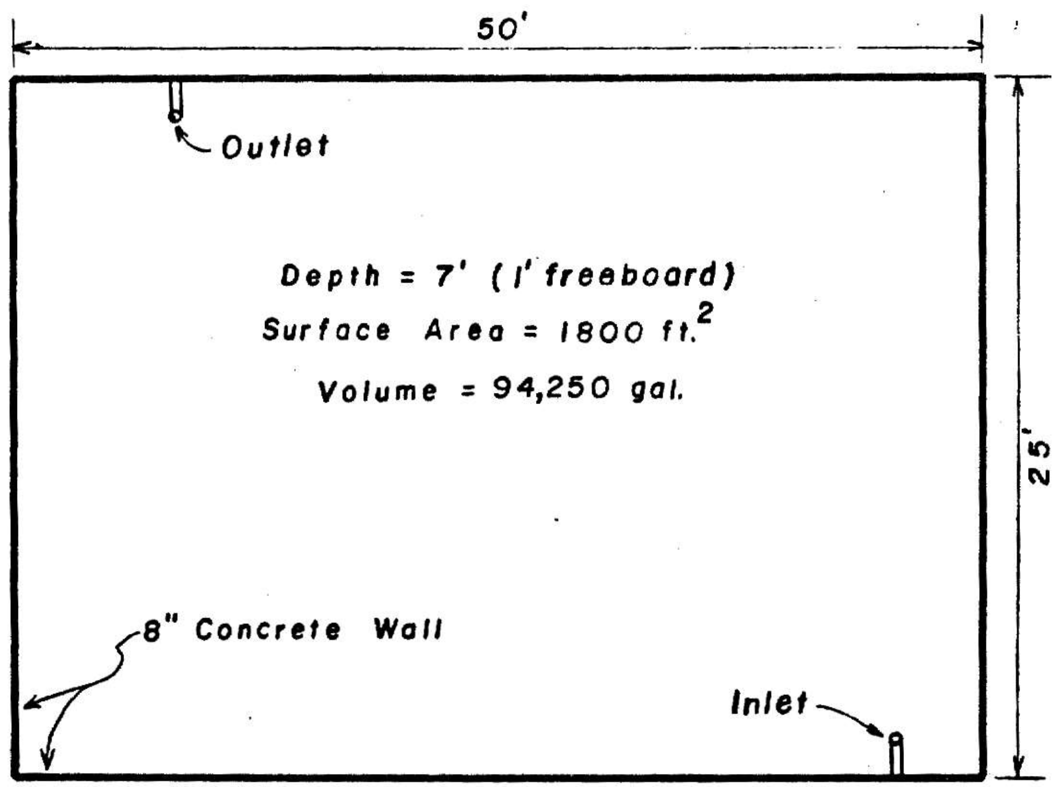

FIGURE 2. PLAN OF WALNUT GROVE POLISHING POND

The secondary effluent is discharged to a vertical concrete-walled retention basin eight feet deep with a seven foot water depth. This polishing pond provides four days detention and covers 1,800 square feet. The dimensions and inlet and outlet locations are shown in Figure 2.

The outlet structure is a four-inch PVC pipe discharging at a depth of 15 inches.

CARRIAGE WATER CHARACTERISTICS

The water at Timber Creek and Walnut Grove is pumped from wells along the Kansas River flood plain. Consequently, both waters are of similar quality with a total hardness of roughly 300 mg/l and a total alkalinity of about 400 mg/l. Sulfate and chloride concentrations are low.

PROCEDURES

SAMPLING

Grab samples of the influents and effluents of the two ponds were taken once a week. The long detention time of the aeration basins and polishing ponds justifies the use of grab samples. Samples were usually taken in the morning and analyzed within 24 hours. If storage was necessary, samples were refrigerated at 4° centigrade. All tests, except dissolved oxygen and temperature, were run at the Sanitary Engineering Laboratory at Kansas State University, Manhattan, Kansas.

ANALYTICAL PROCEDURES

Standard Methods (2) was followed in determination of COD, ammonia and suspended solids. COD values were found using the dilute dichromate reflux method. Ammonia concentrations were determined by direct nesslerization. Membrane and glass-wound filters were used to obtain suspended solids data.

BOD_5 test procedures followed Standard Methods with the exception that nitrogenous demand was inhibited. Nitrogenous oxygen demand was eliminated by adding Hach Nitrification Inhibitor (Formula 2533).

Nitrate concentrations were determined by a Hach Test Kit (Model DR-EL) using the Cadmium Reduction Method.

Copper concentrations in the Timber Creek pond effluent were also found by the Hach Test Kit using the Cuprethol Method.

Dissolved oxygen and temperature were measured at the plant site with a Yellow Springs Instrument Oxygen Meter (Model 51 A). The oxygen meter was obtained in August, 1973, and prior to that dissolved oxygen was determined by the Azide Modification of the Winkler Method.

Turbidity values were obtained with a Hach Laboratory Turbidimeter (Model 1860).

Total coliform and fecal coliform tests were run according to Standard Methods with minor changes. Millipore packaged Endo and MF-C agar was used with Millipore disposable petri dishes. Fecal coliform dishes were incubated upside down with MF-C agar in a water bath at 45.5° C for 24 hours. Total coliform dishes were incubated with Endo agar at 35° C for 24 hours.

Bottom sludge from the ponds was analyzed for total residue and volatile residue according to Standard Methods.

RESULTS AND DISCUSSION

Two polishing ponds were monitored during the year of this study. One pond, Timber Creek, followed a very stable extended aeration facility and, consequently, received well-treated secondary effluent. The other pond, at Walnut Grove, followed an extended aeration plant which was extremely inefficient in treating the wastewater. Usually, the influent to the pond had the same characteristics of raw sewage.

The objectives of this study were modified so that the Walnut Grove polishing pond could be studied as an emergency treatment device guarding the receiving stream against plant upset. Therefore, discussion will first center on the effectiveness of the Timber Creek pond in improving a well-treated secondary effluent's overall water quality, algae control and sludge deposits. Secondly, the Walnut Grove pond's effectiveness as an emergency treatment facility will be discussed.

DATA ANALYSIS

The weekly data collected was plotted graphically with respect to time. It was also averaged by months and these averages were plotted. Weekly plots were usually quite variable with many extreme peaks. Monthly averages plotted a considerably smoother line and were much easier to analyze. However, analysis of monthly averages hides some relationships which were revealed by analysis of weekly data.

Judgment based on averages can overlook extreme values which may have adverse effects. For example, an average monthly dissolved oxygen (D.O.) value might be 6 mg/l. Two weeks of 12 mg/l and two weeks of zero mg/l D.O. will give a monthly average of 6 mg/l. Depending on the situation, it is possible that two weeks of zero D.O. would have serious consequences. The point to be made here is that, depending on the constituent, not only average values, but the extreme values must be considered in making a judgment of treatment efficiency.

Average monthly values of eight parameters of the Timber Creek facility are shown graphically in Figures 3 through 10. Average monthly values for the Walnut Grove plant are shown in Figures 13 through 20.

WATER QUALITY EFFECTS OF TIMBER CREEK POLISHING POND

Detention Time

The detention time of the Timber Creek polishing pond is four days at design flow of 15,000 gal. per day. During the time of the study, the flow was much below design flow, resulting in greater detention times.

The water treatment plant has a meter which records the cumulative water use of the homes. It was assumed that most all water used in December, January and February would eventually pass through the sewage treatment plant since the season discouraged outside water usage. The average water usage of these 3 months was divided into the volume of the pond to determine the polishing pond's detention time.

Water usage during the 78 days from December 4, 1973, to February 27, 1974 = 511,090 gal.

$$\text{Average Daily Use} = \frac{511,090}{78} = 6,500 \text{ gal. per day}$$

$$\text{Pond Detention Time} = \frac{\text{Pond Volume}}{\text{Flow}} = \frac{62,800 \text{ gal.}}{6,500 \text{ gal. per day}} = 9.7 \text{ days}$$

The flow through the sewage treatment plant was also recorded by readings from a V-notch weir at the treatment plant. These weir readings are not as accurate as a meter, but they still indicate that the average flow for the 78-day period was near 6,000 gal. per day. Thus, it appears that the estimated detention time of approximately ten days is reasonable.

COD, BOD_5, and Suspended Solids

One objective of this study was to determine polishing ponds' effects on the overall water quality of a well-treated secondary effluent. COD, BOD_5, suspended solids, ammonia, nitrates, D.O., and coliform tests were the basis for making this water quality judgment of the influent and effluent of Timber Creek's polishing pond.

BOD_5, COD, and suspended solids were all reduced by the polishing pond during the colder months of October through April. Observations of the algae during these months indicated that the removals occurred when algal activity was at a minimum.

Ice cover was present during late December and January, and COD, BOD_5, and suspended solids values were all quite low during that time. Residual copper concentrations of 0.1 to 0.2 mg/l from an algal control project were also present during this period. Therefore, it may not be correct to attribute the excellent removal entirely to cold temperatures and ice cover.

During the warmer months, April to August, the pond's effluent had higher COD, BOD_5, and suspended solids than the influent. Again, algae were observed and noted to be very active during this period and probably caused the increases. This is reflected in the fact that when algae were removed during August with copper sulfate, the suspended solids, COD, and BOD_5 of the effluent were lowered.

Close interrelation was noted between COD, BOD_5, and suspended solids data. BOD_5 and COD values of the polishing pond influent and

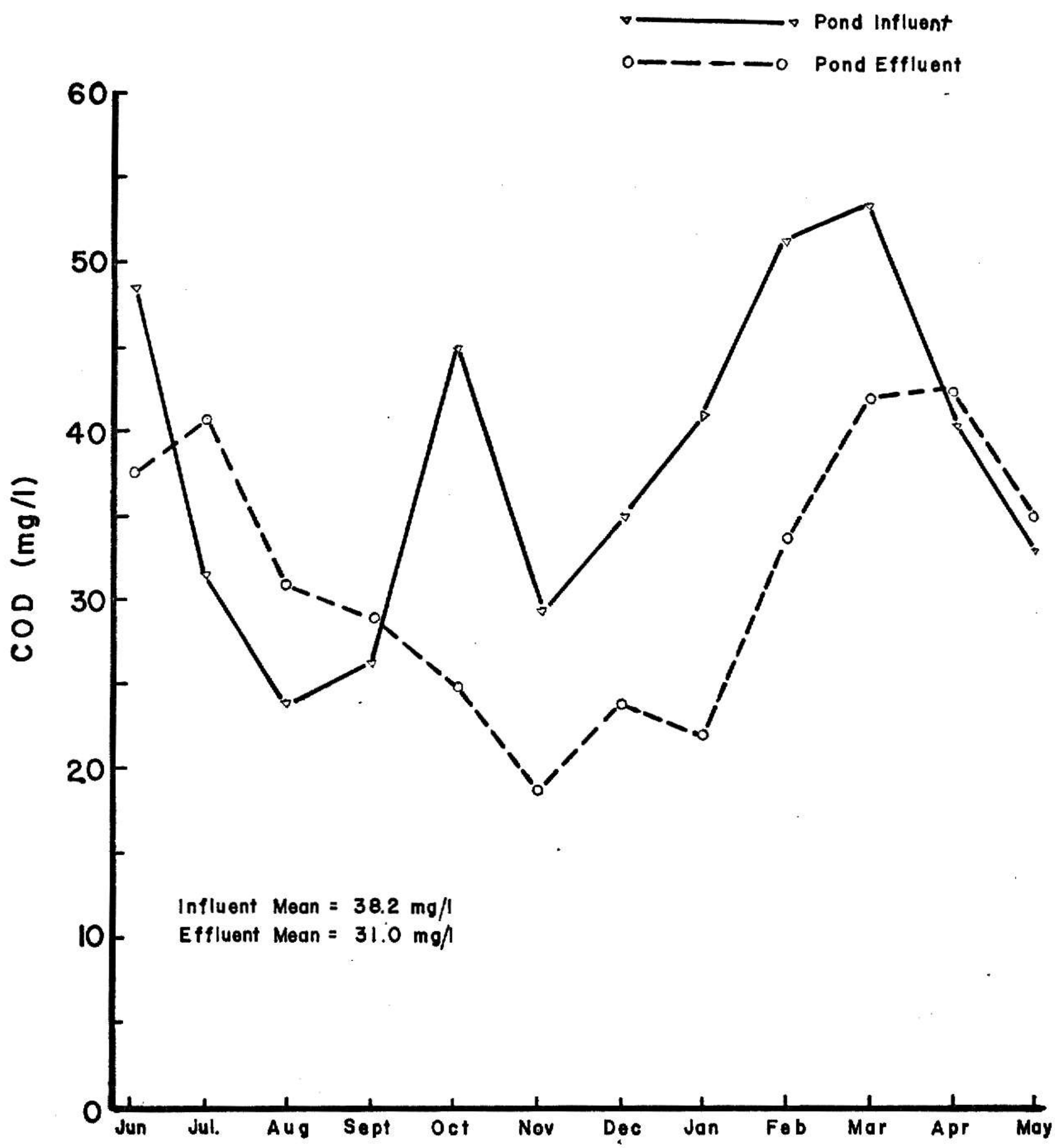

FIGURE 3. COD OF TIMBER CREEK POND

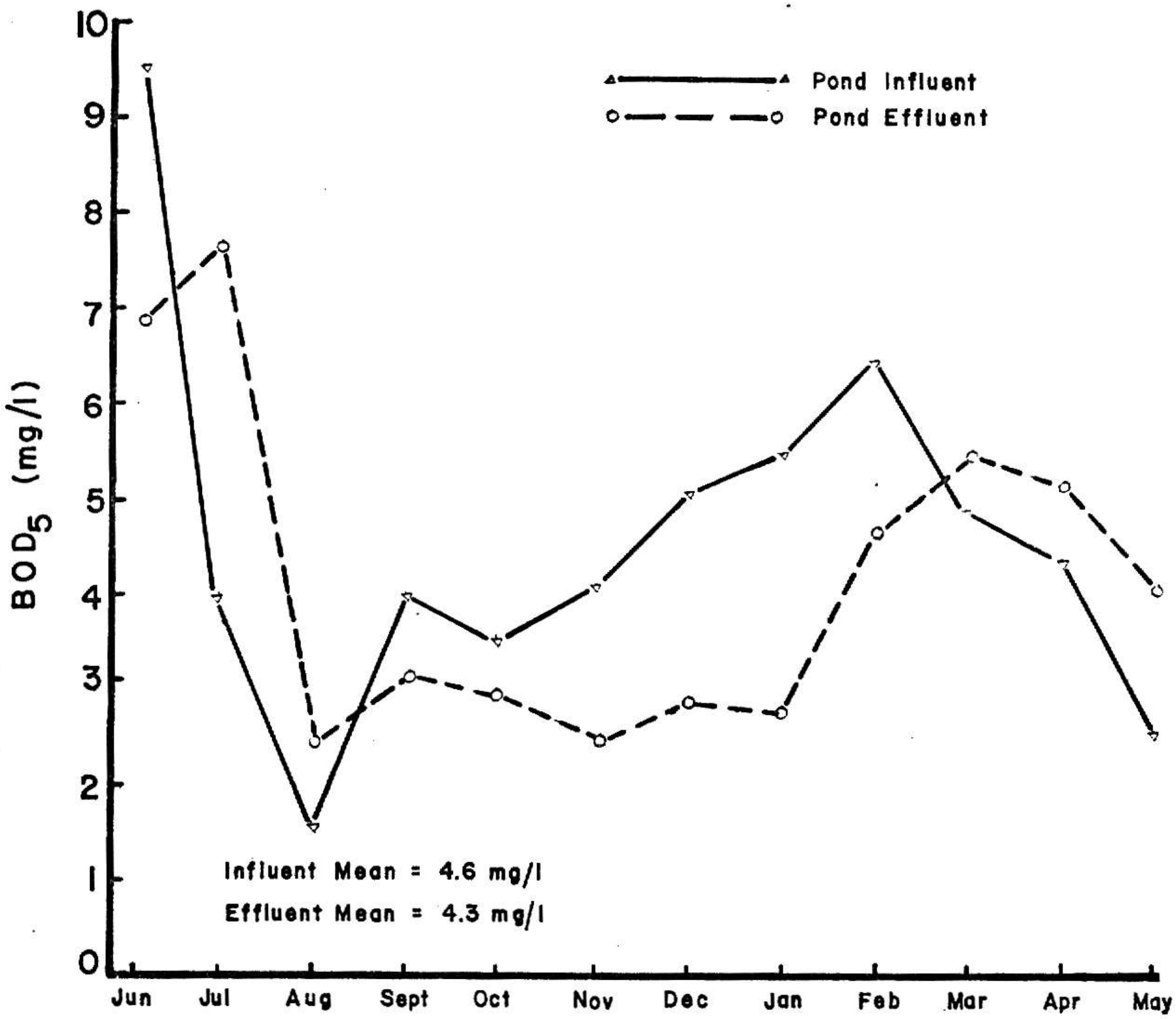

FIGURE 4. BOD_5 OF TIMBER CREEK POND

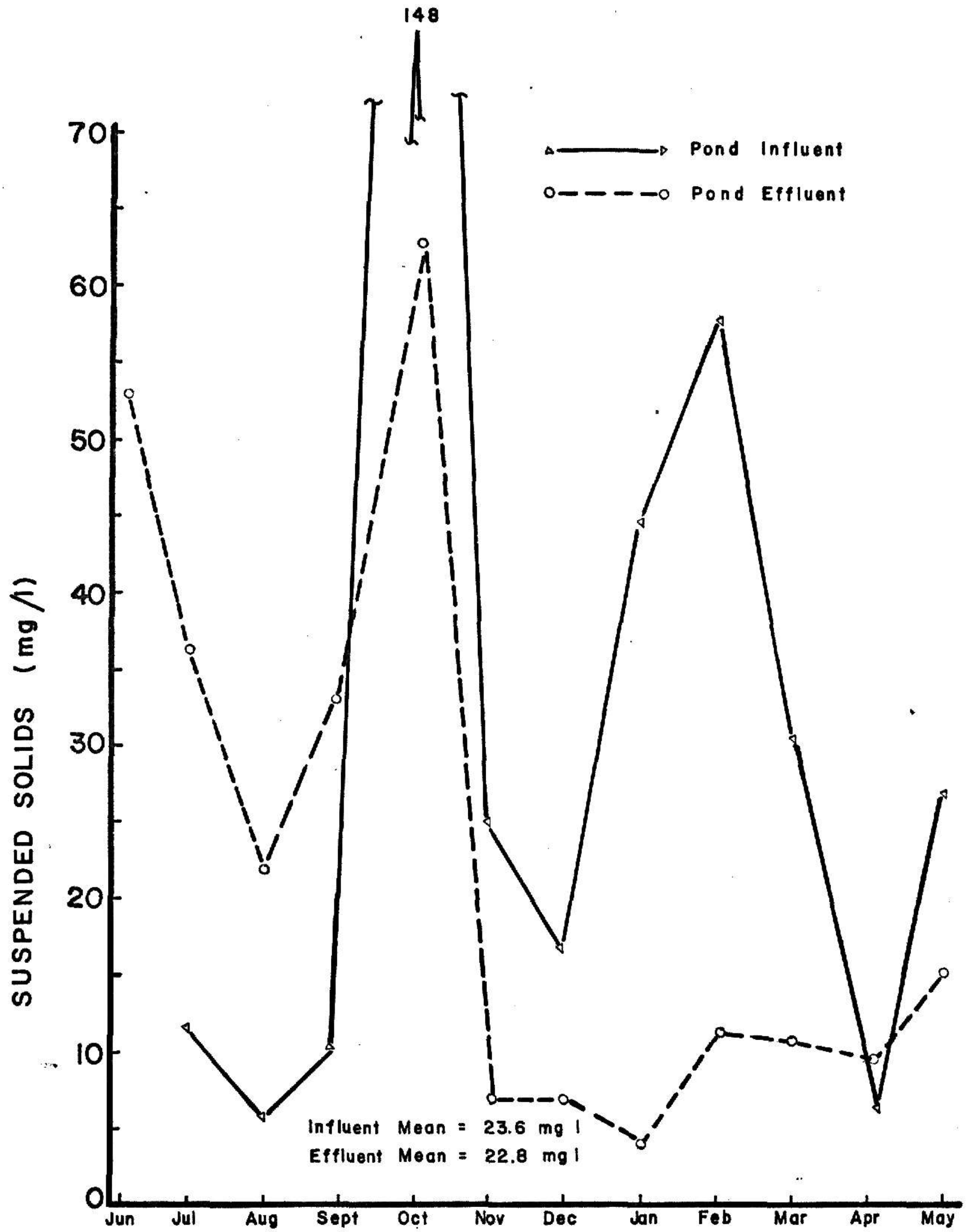

FIGURE 5. SUSPENDED SOLIDS OF TIMBER CREEK POND

effluent run almost parallel if graphically plotted (Figures 3 and 4). This indicates that BOD_5 is a constant proportion of the effluent COD. For the polishing pond at Timber Creek, the influent BOD_5 was 12 percent (standard deviation = 4%) of the influent COD, and the effluent BOD_5 was 13 percent (standard deviation = 3%) of the effluent COD. Recognizing the long detention times in the plant, the fact that BOD_5 is a relatively constant percentage of the effluent's COD indicates that treatment is proceeding to an end point where further breakdown is difficult.

During the early part of October, a three-inch rain and a five-inch rain washed silt into the aeration basin and polishing pond. Even with flushing, it took several weeks to reduce the effluent silt. This is most evident in the plot of suspended solids (Figure 5) as the plot jumps from an average 10 mg/l in September to 148 mg/l in October. The silt also appears in the COD plot of the pond influent as October's average COD, 45 mg/l, was nearly twice September's average, 26 mg/l.

However, the pond effluent COD was at a relatively low value during the month of October when influent solids and COD were at their highest. This low effluent COD value is most likely due to sedimentation, hydraulic flushing, and the composition of silt. The silt is removed by sedimentation in the polishing pond while the aeration tank continually mixes the silt until it is passed out of the sedimentation tank. Consequently, the silt shows up for a long time as suspended solids in the pond influent while it is considerably lower in the pond effluent. A garden hose was run from a hydrant to the aeration tank and, for several days, the plant was flushed to remove the silt. This dilution effect (100-300%) could also be responsible for lower concentrations. Also, silt is inert and therefore exerts little COD and no BOD_5 while raising suspended solids values.

It is important to note that during October, when the suspended solids and COD in the pond influent were high, and the effluent suspended solids were also high, the BOD_5 of the influent and effluent were low. In fact, October's BOD_5 values are near the lowest recorded. This contrast can again be, at least partially, explained by hydraulic flushing and the inert characteristics of silt. But, the important point is that, while BOD_5 values showed no change, COD and suspended solids data were more clearly indicative of the situation.

Yearly averages reveal that the polishing pond reduces suspended solids only three percent, from an influent mean of 23.6 mg/l to an effluent mean of 22.8 mg/l. BOD_5 is reduced by only seven percent from a yearly mean of 4.6 mg/l to 4.3 mg/l. Neither of these removals is large enough to be significant. However, COD values are reduced 19 percent by the pond from an influent yearly mean of 38.2 mg/l to an effluent mean of 31.0 mg/l.

Recognizing 1977 EPA standards of 30 mg/l suspended solids and 30 mg/l BOD_5, Timber Creek's plant is acceptable, except for suspended solids, during the summer. Algae, if allowed to grow, appear to cause the suspended solids to rise above the 30 mg/l maximum during the summer months. Winter conditions inhibit algal production, resulting in a pond effluent of low suspended solids. The period of November through April averaged less than 12 mg/l, even reaching 4 mg/l under ice cover.

BOD_5 values of the pond effluent were exceptionally low, exceeding 6 mg/l only twice during the entire year of study. The maximum effluent BOD_5 measured was only 7.7 mg/l.

It should be noted that the influent to the pond is also very low in BOD_5 and suspended solids, exceeding 6.5 mg/l BOD_5 only once and averaging 24 mg/l suspended solids during the year.

With these low values of BOD_5 in the pond effluent, this polishing pond never was in danger of violating the 1977 EPA maximum of 30 mg/l BOD_5. However, the upper limit of 30 mg/l suspended solids was usually exceeded during the months of June through September.

Usual operation of extended aeration plants results in the occasional passage of biological mass in the effluent. Solids passing to the effluent might be due to excessive solids build-up in the aeration tank and their subsequent spillage, or, as at Timber Creek, the passage of solids might be due to occasional plant maintenance and routine air washing of the sedimentation basin.

During weekly air washing of the sedimentation basin, solids were passed to the polishing pond for about five minutes at concentrations of approximately 1,500 mg/l. Also, during the testing of a new sedimentation-aeration module, a break in the plastic pipe resulted in over 24 hours of solids loss to the polishing pond.

In any such instances of solids loss from extended aeration plants, the solids would be discharged directly to the receiving stream if it were not for the polishing pond. The pond received the solids with no apparent effect and the pond effluent quality remained excellent. The polishing pond was clearly protecting the stream from such plant upsets.

The type of solids that enter the polishing pond are different from those leaving. The entering solids were a brown bacterial flocculated mass, while the effluent mass was primarily algae. Therefore, the pond transformed the entering wastes to a completely different composition.

Turbidity

Turbidity (Figure 6) was measured weekly to help indicate suspended solids. Effluent turbidity values jumped to their highest average,

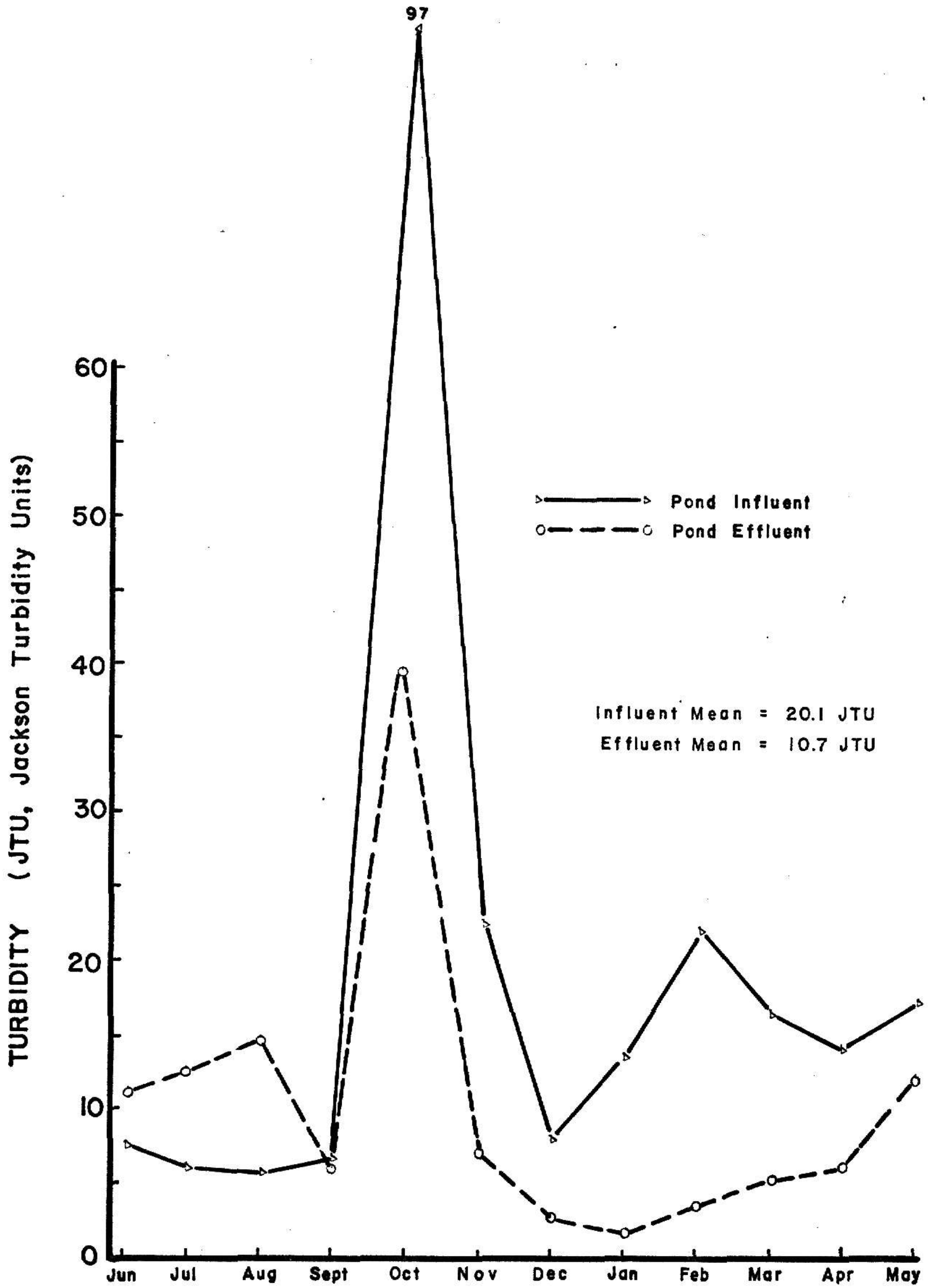

FIGURE 6. TURBIDITY OF TIMBER CREEK POND

41 JTU (Jackson Turbidity Units), during the presence of silt in October. Lowest values, near 2 JTU, were observed during the cold months of December through February. Algae appeared to raise the turbidity readings to around 20 JTU during heavy blooms. On a yearly basis, the turbidity was reduced by 53 percent, from an influent mean of 20.1 JTU to an effluent mean of 10.7 JTU. This 53 percent turbidity removal tends to indicate solids removal by sedimentation in the polishing pond.

Nitrogen Removal

Nitrogen was measured in the pond influent and effluent as both ammonia-nitrogen and nitrate and nitrite-nitrogen. Without algae removal, nitrogen removal was not expected, so the form of nitrogen present became important.

Organic nitrogen will be converted to ammonia, and this ammonia eventually will be changed to nitrate if enough time is allowed. The presence of nitrate indicates that the treatment or oxidation of organic nitrogen compounds has proceeded toward the end point. Nitrates will not produce a direct oxygen demand on the receiving stream as will ammonia. Consequently, nitrate is a much more acceptable form of nitrogen than ammonia.

The Timber Creek polishing pond was found to reduce the nitrate concentration while ammonia values increased. Monthly averages do not show the interrelation between these two nitrogen forms, but weekly data is more revealing. Weekly data show that when the pond's effluent is highest in ammonia, the nitrate concentration is at its lowest. Also, when the effluent's nitrate value is high, the ammonia concentration is low. This nitrate ammonia relationship indicates that the nitrogen is simply transformed back and forth between nitrate and ammonia, depending upon environmental conditions.

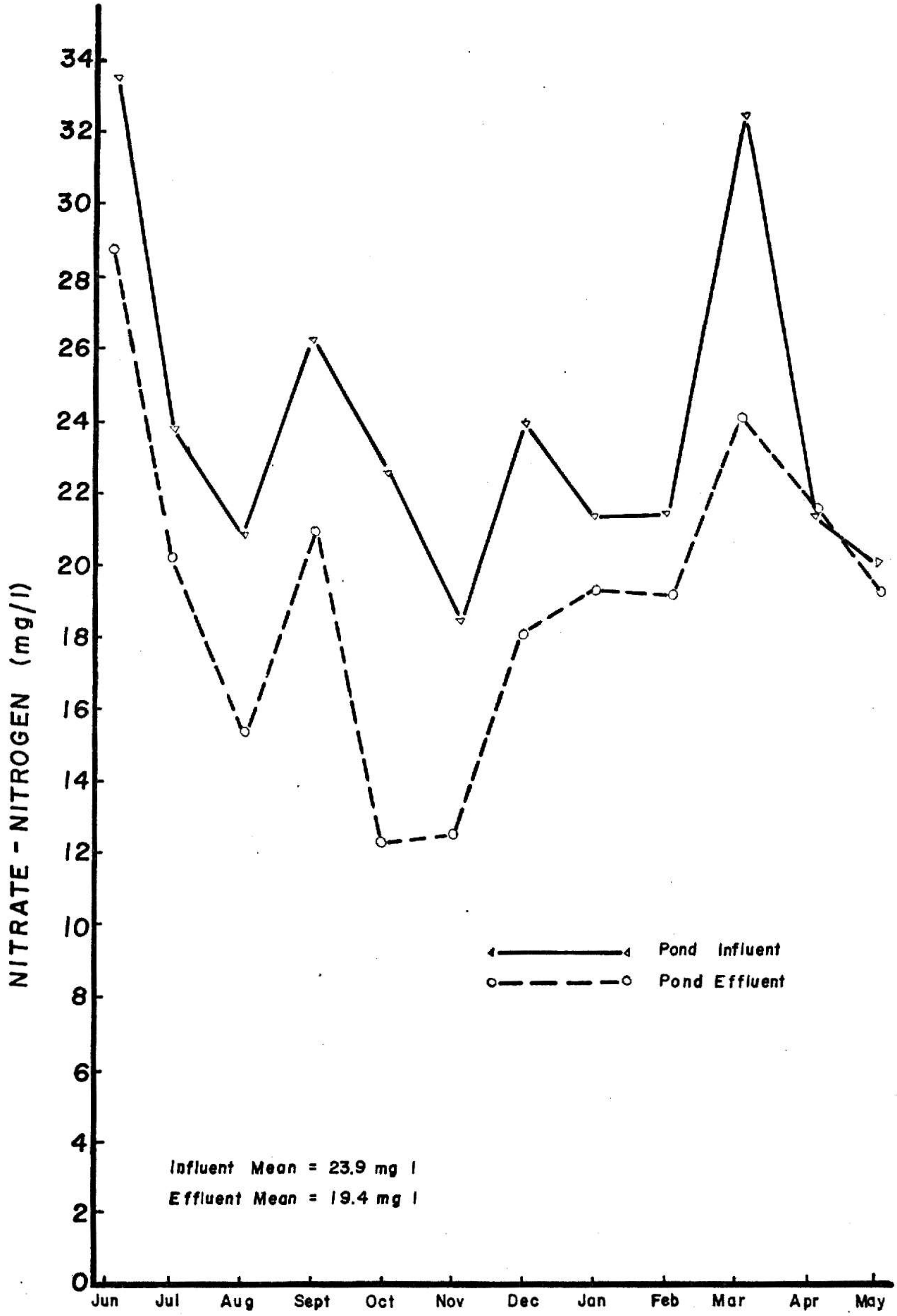

FIGURE 7. NITRATE-NITROGEN OF TIMBER CREEK POND

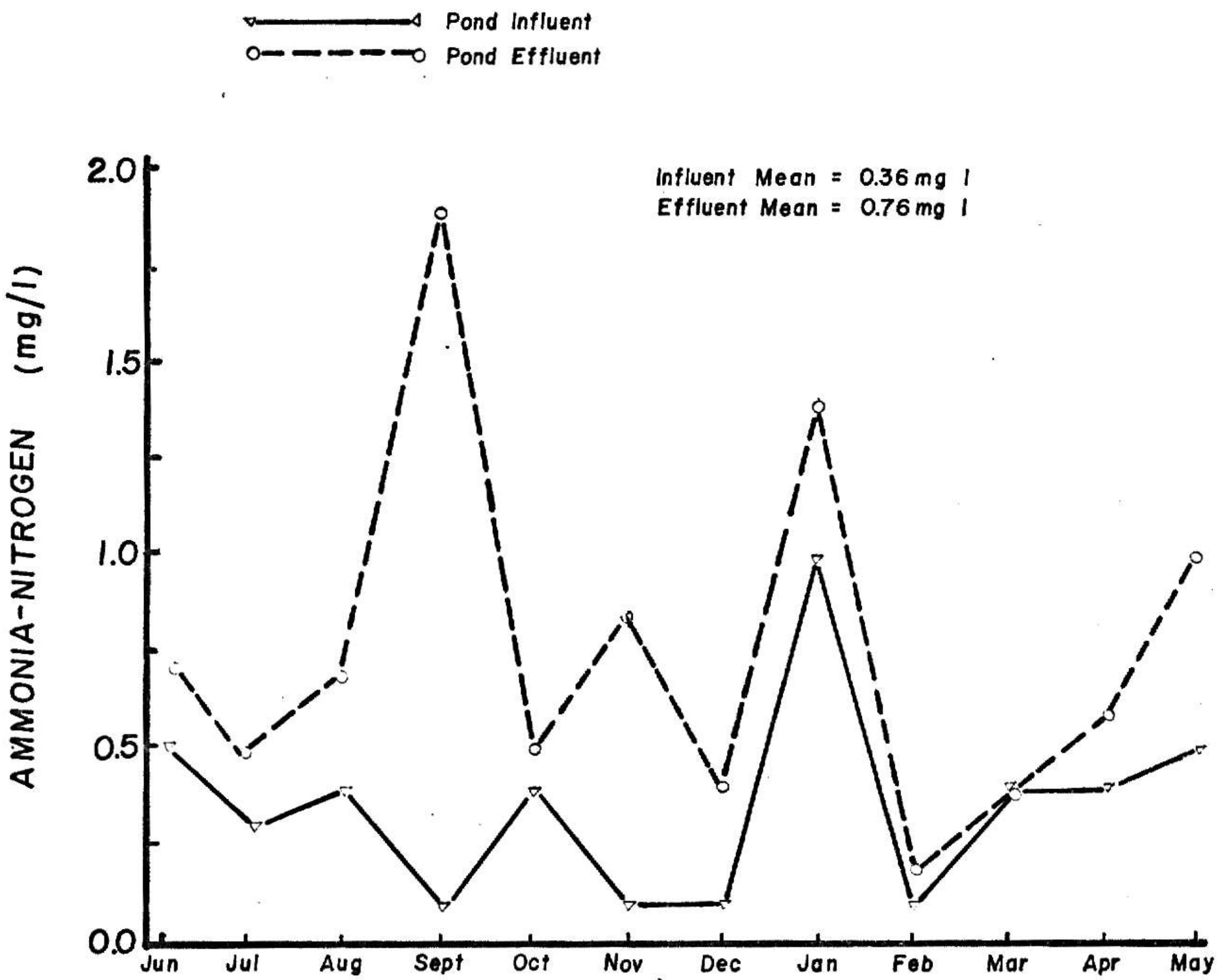

FIGURE 8. AMMONIA-NITROGEN OF TIMBER CREEK POND

The plot of average monthly nitrate-nitrogen concentrations (Figure 7) reveals that the effluent nitrate concentration follows the same path as effluent BOD_5 and COD. The two highest effluent nitrate-nitrogen (NO_3-N) average monthly values, 28.8 mg/l and 24.4 mg/l, correspond with the highest BOD_5 and COD values of the effluent. The times that NO_3-N is low, the algae appeared less dense. Lowest NO_3-N values of the effluent, near 12.5 mg/l, were recorded in October and November, corresponding to lowest effluent COD and BOD_5 values. However, these low values of NO_3-N may be attributed to the dilution caused by flushing the plant to remove silt.

The shape of the plot of effluent NO_3-N was essentially the same as the influent NO_3-N plot. The yearly mean influent NO_3-N concentration was 23.9 mg/l, while the effluent averaged 19.4 mg/l. This corresponds to an average NO_3-N removal of 19 percent for the year.

As mentioned earlier, ammonia-nitrogen (NH_3-N) concentrations in the pond effluent are shown by the weekly data to be inversely proportional to effluent NO_3-N concentrations. The plot of monthly average ammonia concentrations (Figure 8) shows that the effluent concentration is directly dependent on the influent concentration. Other than these relationships, the effluent ammonia concentration does not appear to be related to the other parameters measured.

NH_3-N was determined to be increased by 50 percent during the year of observation. The yearly influent mean NH_3-N concentration was 0.4 mg/l and the effluent mean was 0.8 mg/l. The effluent NH_3-N was measured above 1 mg/l only six times the entire year. Of these six measurements, only once did the concentration pass 2 mg/l, to 3 mg/l.

Dissolved Oxygen

Dissolved oxygen measurements of the pond influent and effluent were taken in the field with a dissolved oxygen meter. The presence of dissolved oxygen in the polishing pond not only insures the more acceptable aerobic condition, but it also helps indicate the presence of algae if the dissolved oxygen is saturated.

Average monthly dissolved oxygen values (Figure 9) show that dissolved oxygen is increased by the pond, except in October. The largest average values of dissolved oxygen, 12.5 mg/l and 19 mg/l, occured during periods when algal activity was greatest. Algae obviously are responsible for these supersaturated dissolved oxygen readings.

The lowest effluent dissolved oxygen readings were in August when algae die-off was observed. This die-off, which would not be expected in August, was caused by the addition of an algicide to the pond. During this period, readings were taken of 1.2 mg/l and 1.4 mg/l dissolved oxygen. Anaerobic conditions were never evident in the pond. The influent yearly mean dissolved oxygen was 3.4 mg/l, while the effluent mean was 7.7 mg/l.

Coliform Removal

Coliform test results were quite varied, with total coliform concentrations ranging from 0 to 10^6 per 100 ml, and fecal coliforms from 0 to 10^5 per 100 ml. Averages will be of little value in this instance, so another method of coliform evaluation is needed.

Weekly fecal and total coliform data from Timber Creek were statistically correlated into frequency-concentration relationships. The results are presented graphically in Figures 11 and 12. These graphs show that fecal coliform concentrations in the pond effluent are equal to, or less than, 200 per 100 ml, approximately 66 percent of the time.

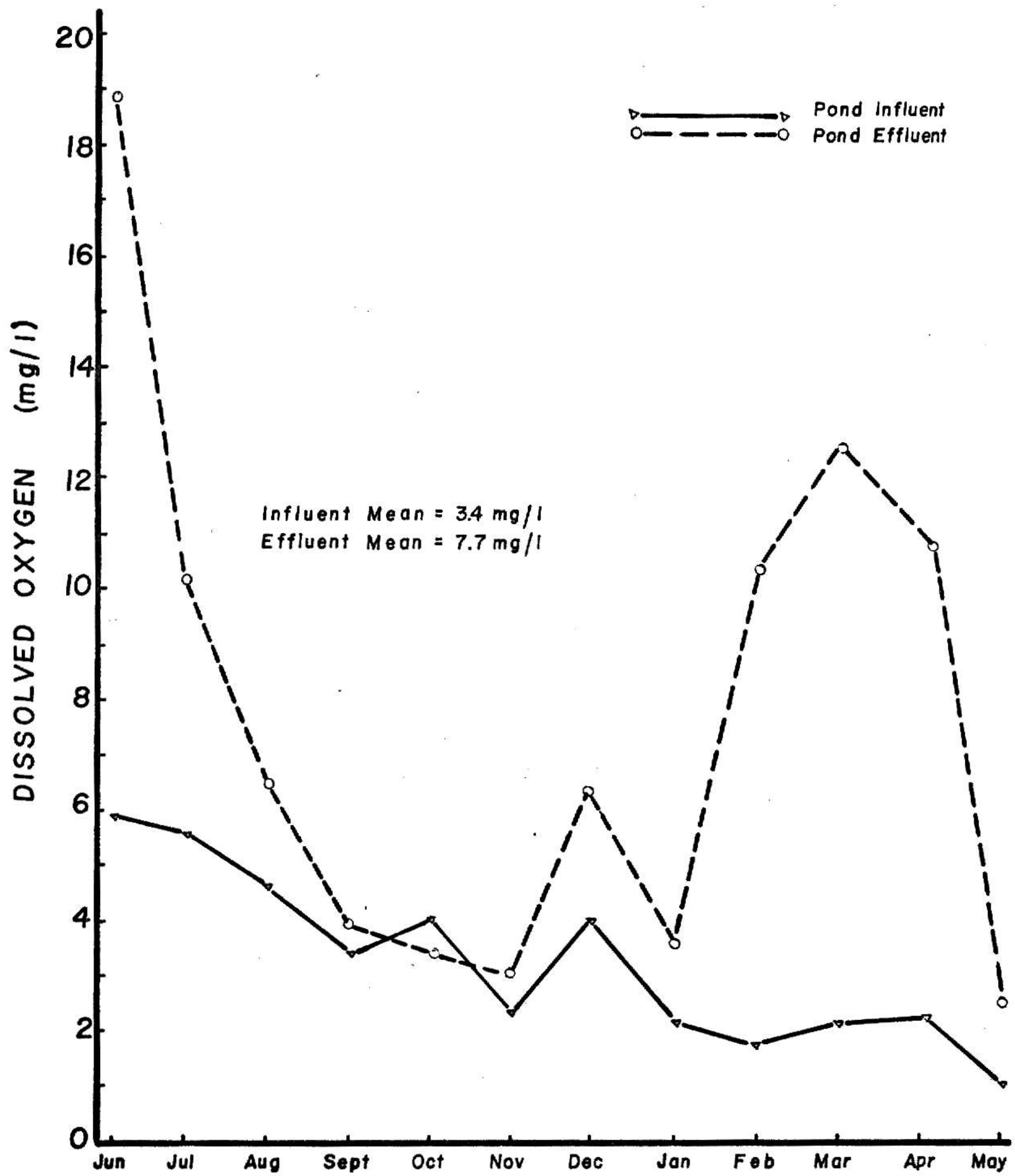

FIGURE 9. DISSOLVED OXYGEN OF TIMBER CREEK POND

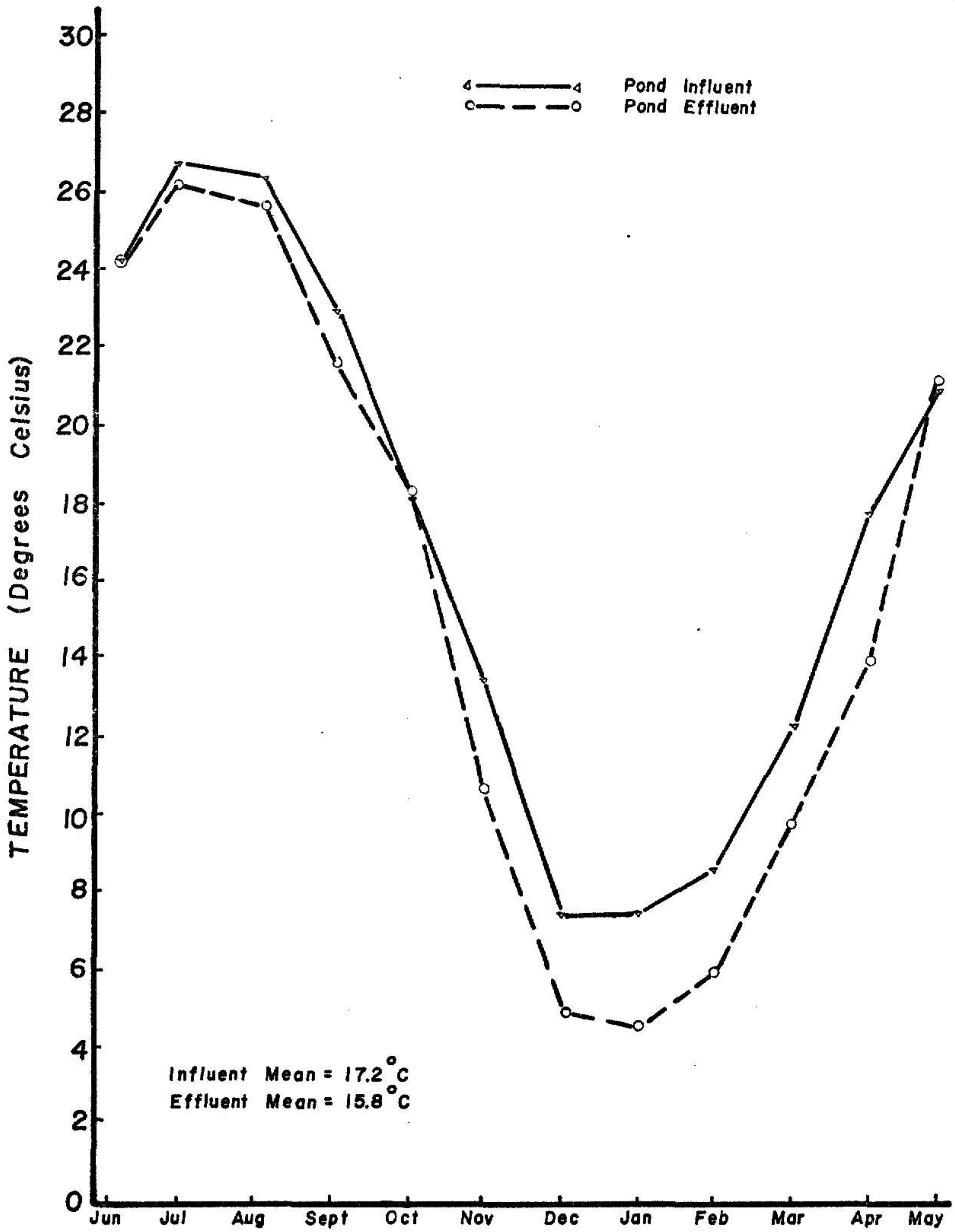

FIGURE 10. TEMPERATURE OF TIMBER CREEK POND

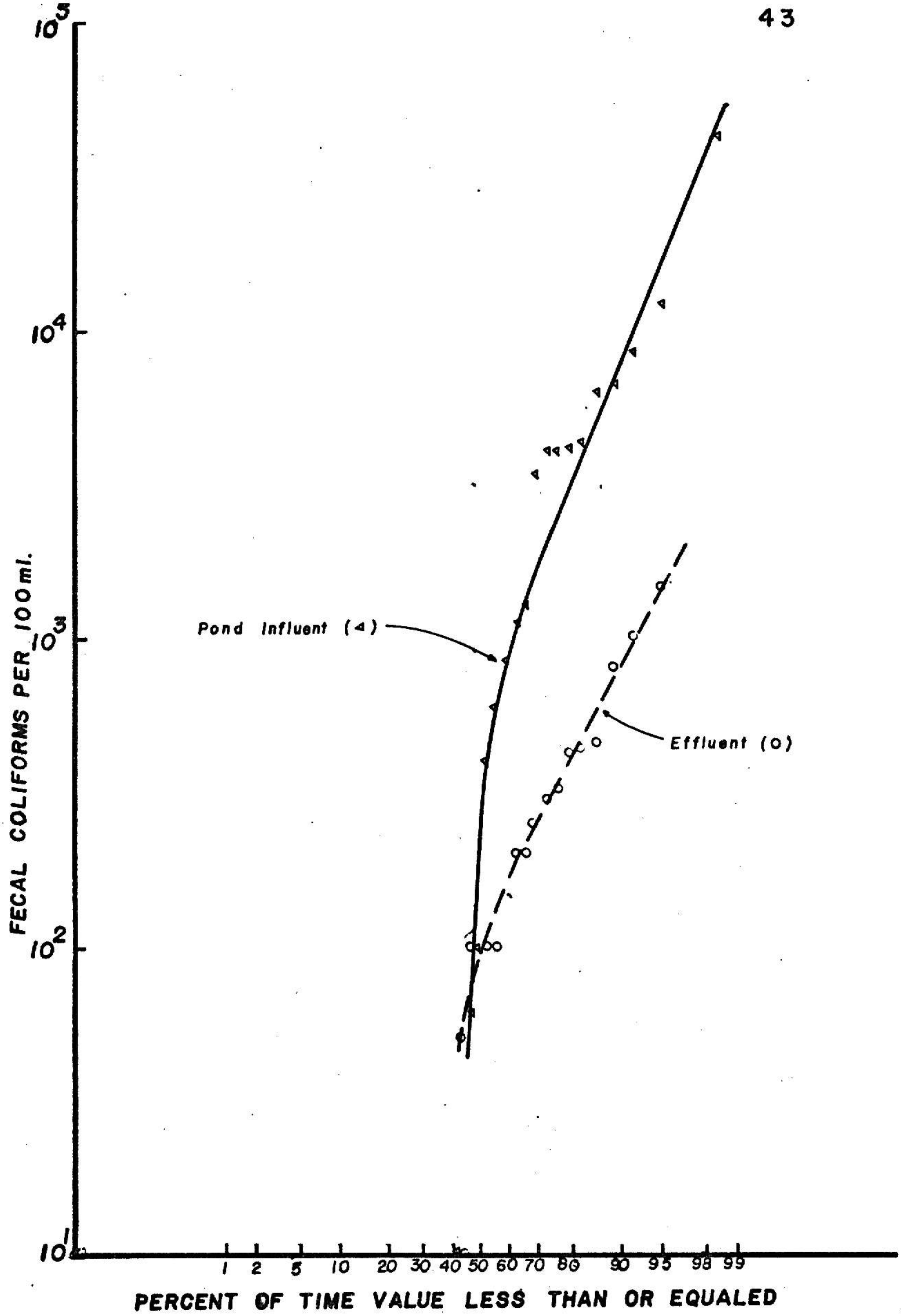

FIGURE 11. FREQUENCY-CONCENTRATION RELATIONS OF FECAL COLIFORMS AT TIMBER CREEK

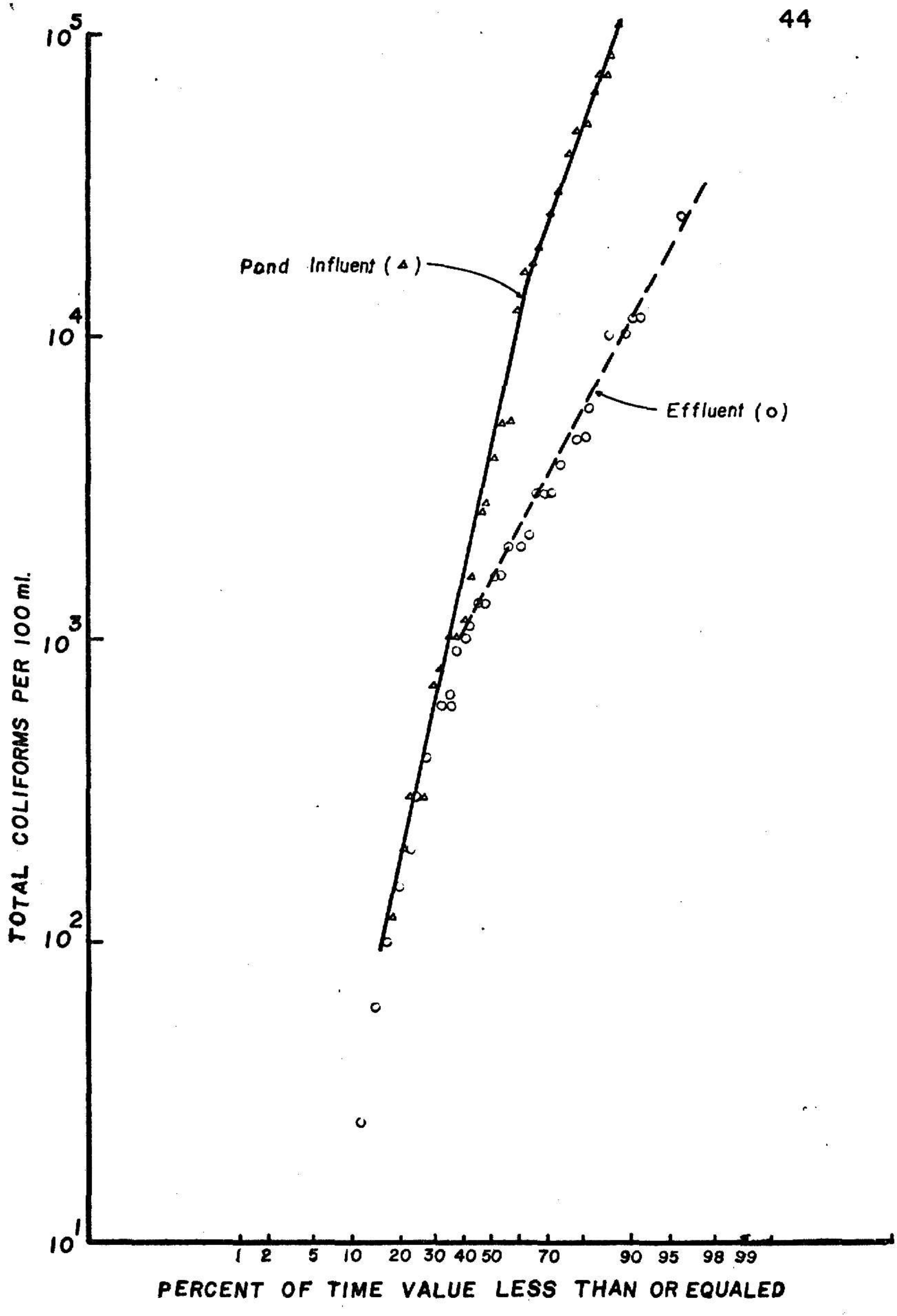

FIGURE 12. FREQUENCY-CONCENTRATION RELATIONS OF TOTAL COLIFORMS AT TIMBER CREEK

This indicates a slight fecal coliform reduction through the pond since the influent fecal concentration was below 200 per 100 ml only 51 percent of the time. The fecal coliform concentration of 200 per 100 ml (monthly average) is mentioned since it is the 1977 standard adopted by the EPA.

A weekly average of 400 fecals per 100 ml is allowed by the same EPA standards. Of the 34 weekly tests, this weekly standard was met only 56 percent of the time by the pond influent, while the effluent was below the weekly standard 80 percent of the time.

The frequency-concentration plot also reveals that the fecal coliforms are not noticeably removed by the pond until their concentration exceeds 100 per 100 ml. Figure 11 shows that there is a 60 percent chance of having 1,000 or less fecals per 100 ml in the pond influent, while there is a 92 percent possibility of the same number in the effluent. This indicates the likelihood of removal at these higher concentrations.

Chlorination of the pond influent was practiced during the year of this study. A chlorine solution made from HTH chlorine was placed in the wastewater flow by a Wallace-Tiernan variable flow solution feed pump. Field tests for total chlorine residual in the pond influent were conducted every three to four days. The readings were often zero, with the largest residual measured at 7.5 mg/l. No chlorine was ever detected in the pond effluent.

At the times chlorine was detected in the pond influent, there seldom were any fecal coliforms present. Fecal and total coliform counts were highest when no chlorine was detected in the influent. This inverse coliform-chlorine relationship was expected. The large numbers of coliforms released by the pond tend to indicate the Timber Creek polishing pond with pre-chlorination is not effective in adequately reducing coliform concentrations unless better attention is paid to obtaining a free chlorine residual after chlorination. The fact that free chlorine was never obtained in the pond effluent indicates that the pond is effective in preventing chlorine from being discharged to a watercourse.

Sludge Deposits

In June of 1973, weighted cans were placed on the pond bottom to determine solids build-up and characteristics. One year later the cans were retrieved. The depth of sludge was noted and tests made to determine total and volatile residue.

The build-up of solids on the pond bottom was not large enough to control pond design. Three cans in the middle of the pond detected solids depths of 3 1/2 inches. A can near the inlet was overtopped, indicating solids depth of greater than 12 inches. Near the outlet, approximately 30 feet from the inlet, only 2 1/2 inches of sludge depth was measured.

Total residue tests on the sludge revealed it was very thick and well digested. Near the inlet, the total residue was 154 grams/l (15 percent solids), while at the outlet it was 88 grams/l (9 percent solids). The cans in the middle of the pond contained sludge of 106 grams/l (11 percent solids). The percentage of the total residue that was volatile was a low 18 percent, indicating the sludge was being digested.

Dominant Algal Genera

During the study, attempts were made to identify the algae found in the pond effluent. Forty-two observations were made and Chlorella was found in all but one, except when no algae were found. This green alga was usually present in greater numbers than other genera, especially in late winter and early spring. Chlorella clearly was the most common alga present.

The next genus to appear most often was the flagellate Chalamydomonas, as it was identified 14 times throughout the year. Chalamydomonas was most prevalent during the first five months of the year.

The green alga Chlorococcum and the flagellate Euglena were also common. Chlorococcum was noted during at least nine of 42 observations, Euglena was detected on seven occasions.

Oscillatoria, a blue-green alga, was common in late April, early May and throughout August. Nitzshia, a diatom, was found once during December and again in January and was very evident during late April and early May.

Other genera that were noted in the spring include Ankistrodesmus, Pyrobotrys, Anacystis, Anabaena, Volvox, Chlorogonium, Cateria, and Cocconeis. Oocystis, Scenedemus, Spirogyra, Coelastrum, and Rhizoclonium were all identified in the effluent during the summer months. Other than the previously mentioned dominant genera of Chlorella, Chalamydomonas, and Nitzshia, only the surface blue-green algae Gomphosphaeria and Anacystis were found during the fall. Winter observations detected the same dominant genera plus the green surface alga Sphaerocystis.

It is interesting to note that the dominant algae found in Timber Creek polishing pond were either greens or flagellates. Blue-green algae appeared from time to time, but seldom in great numbers.

Algae Control With Cupric Sulfate

Recognizing the problems caused by algae in polishing ponds, attempts were made to control algal development. A common algicide, cupric sulfate, was applied to the polishing pond at Timber Creek during August and

September, 1973. Application of the algicide was by spraying the pond surface with a water dilution. Spraying was done with a common hand pump weed sprayer.

One pound of cupric sulfate was applied on August 13 when a quarter of the pond was covered by an algal mat. After 24 hours, the mat had broken up and the water appeared clearer. But, 48 hours after the chemical addition, August 15, a strong lime green color reappeared in the pond, indicating another algae bloom.

On August 20, another pound of cupric sulfate was sprayed on the polishing pond. The bloom appeared to be slowed, but not stopped.

Two more pounds of cupric sulfate was applied two days later, August 22, when the pond effluent was noticably green due to algae. The algae bloom was not affected by this two-pound addition.

Finally, on August 24, another pound of cupric sulfate was applied. This one pound dose, the fourth pound in five days, appeared to stop the algae growth since the water became quite clear. Three days later, August 27, the effluent copper concentration was near 1.2 mg/l. On August 29, the pond was still clear and the algae growths on the pond walls had peeled off to 12 inches below the water surface. The effluent copper concentration on August 29 was 0.8 mg/l.

Another pound of cupric sulfate was applied on August 29 to prolong the algae kill. For two more weeks, until September 12, the copper concentration was 0.4 mg/l and the pond was clear, although the walls were again being covered with algae. The copper concentration dropped to 0.2 mg/l by September 18, and the presence of algae became apparent. By September 24, the pond was bright green in color from algae.

Three pounds of cupric sulfate were applied again on September 25. A heavy rain that evening washed silt into the pond, causing a brown color to predominate. Even after these heavy rains, the copper concentration was 1.1 mg/l on September 27. By October 5, the copper concentration had dropped to 0.5 mg/l, but no algae could be found in the pond effluent.

The brown color of the pond had not yet disappeared when another heavy rain washed more silt into the pond, making it even more turbid. This brown color made visual site observation of the algae in the pond impossible. Microscope observations were used to help detect the presence of algae.

The copper concentration remained at 0.5 mg/l until October 12. Hydraulic flushing helped lower the concentration to 0.2 by October 19. When the copper concentration first dropped to near 0.2 mg/l, algae were observed on the pond surface. During the last part of October and the months of November and December, few, if any, algae were found by microscopic inspection of the pond effluent. The copper concentration remained at about 0.1 mg/l through the winter.

Many factors can control the rise and fall of algal blooms. Thus, it is difficult to predict what amount of algal control was due to the cupric sulfate additions and what control was due to natural factors. However, dosages of 1.1 mg/l or greater seemed to be effective in reducing the algal mass. Exactly how much cupric sulfate should be added to get a concentration of at least 1.1 mg/l is extremely variable, depending on the water's alkalinity and the existing standing crop of algae. At the Timber Creek pond three or four pounds of cupric sulfate was found to leave a residual of approximately 1 mg/l of copper.

Theoretically, without interference dosages of three and four pounds of cupric sulfate would yield 1.4 and 1.9 mg/l, respectively, of copper in the pond. Evidently, only five to 50 percent of the copper was removed from the water by precipitation as copper carbonate or other mechanisms.

Assuming a cost of commercial cupric sulfate, as "bluestone," of approximately $50 per 100 pounds, the control of algae with cupric sulfate would be very inexpensive.

Identification of algal cells in the pond effluent was attempted weekly. Before the cupric sulfate was applied, several algae, Scenedemus, Oscillatoria, and Spirogyra, were present that are very susceptible to the toxic effects of copper. When the algae were visibly reduced, none of these genera were present and not noted again until the following spring. However, other algae, Coelastrum and Gomphonena, which are also susceptible to copper, were found in the effluent when the copper concentration dropped to 0.2 mg/l. The presence of these algae while the copper concentration was 0.2 mg/l seemed to indicate that 0.2 mg/l was below the copper toxic level for these algae.

The recommended maximum surface water copper concentration is 1.0 mg/l (6). With concentrations of greater than 1.0 mg/l required to control algae, adequate dilution must be provided upon discharge to the stream so the stream copper concentration will remain well below 1.0 mg/l. If dilution is not available, or if, for any reason, copper levels rise near 1.0 mg/l in the receiving stream, alternate methods of algae control should be considered.

In the spring of 1974, the polishing pond was not treated with algicide in order to observe the natural algal cycles. Several blooms occurred during March and April which were visable for several weeks.

During late April and May, Cladocerans were noticed in the pond. The Cladoceran population became quite large and the algae blooms were less frequent and of shorter duration.

In July, 1974, the polishing pond was chlorinated to kill the Cladocerans and witness the results. The result was a profuse algal bloom which was still continuing in early August.

These observations appear to indicate that control of algae may be possible by development of a herbivore population, and that supplemental chemical control should be geared to not upsetting the predator herbivore populations.

EMERGENCY TREATMENT BY POLISHING PONDS

Sewage treatment plant failure may result from many causes: power outages, equipment breakdown, poor design, or poor operation. No matter what the cause, the result of plant failure is discharge of pollutants to the receiving stream, unless an emergency treatment facility is available.

Plant failure is exactly what occurred at the extended aeration sewage treatment plant at Walnut Grove Mobile Home Park. The reasons for the failure are a combination of poor design and operation, compounded by several power outages. During the year of this study, the aeration basin contained a mixed liquor that was a watery light brown in color rather than the usual rich dark brown. The dissolved oxygen in the aeration basin was often measured as zero mg/l. The sedimentation basin was always turbid, turbulent, and anaerobic, as biological solids were continually passed out of the basin into the polishing pond. COD, BOD_5, and suspended solids concentrations into the polishing pond were quite large, averaging 265 mg/l, 84 mg/l, and 167 mg/l, respectively, for the year. Pond influent ammonia averaged 16 mg/l for the year, while influent nitrates averaged only three mg/l. Considering that this plant received only domestic wastewater, the above concentrations show that very little treatment occurred in the aeration plant.

However, there was conversion of part of the raw wastewater to a filamentous biological mass. Even after this conversion, the plant effluent (pond influent) was still nearly equivalent to raw sewage if measured by BOD_5, COD, and suspended solids.

Although it was attempted, the plant deficiencies were not corrected during the time of this study. So, for the entire year of this study, the polishing pond received poorly treated wastewater.

Detention Time

The Walnut Grove pond was designed to provide a detention time of four days at the full wastewater flow from 100 mobile homes. For the entire year of this study, there were approximately 100 mobile homes in the park. Assuming three people per mobile home and a per capita water usage of 70 gallons per day, and knowing the volume of the polishing pond, the detention time of the pond can be estimated.

Pond Volume = 1,800 ft^2 x 7 ft = 12,600 ft^3 = 94,250 gal.

100 homes x 3 people per home x 70 gal. per capita per day = 21,000 gal. per day

$$\text{Detention time of Walnut Grove Pond} = \frac{94,250 \text{ gal.}}{21,000 \text{ gal. per day}} = 4.5 \text{ days}$$

There is considerable groundwater infiltration which has been estimated at three gal. per min. or 4,300 gal. per day. This extra flow decreases the estimated detention time to 3.7 days.

COD Removal

The yearly pond influent mean COD concentration (Figure 13) was 265 mg/l, while the effluent COD yearly mean was 144 mg/l, corresponding to a yearly reduction of 46 percent. The highest average COD values in the pond effluent, 250 mg/l, were measured during June and April when thick algal blooms were noted in the pond. The lowest effluent COD averages came at times when algal activity was not obvious. The lowest monthly average effluent COD was recorded in September, 1973, and was 70 mg/l.

Highest recorded weekly effluent COD values were approximately 345 mg/l, while the lowest noted COD was 42 mg/l. Only twice were the pond effluent COD's higher than the influent's, and this was during algal blooms.

BOD_5 Removal

BOD_5 was reduced through the polishing pond by an average of 50 percent for the year. The pond's yearly influent mean BOD_5 (Figure 14) was 84 mg/l, while the effluent averaged 42 mg/l. The highest effluent BOD_5, 133 mg/l, was recorded in April when algal activity was heavy. However, during June when algal activity was again quite evident, the BOD_5 was only 60 mg/l. Lowest weekly effluent BOD_5 values of near 15 mg/l were measured on various occasions.

The graphical plots of Walnut Grove's polishing pond influent and effluent BOD_5 and COD are nearly parallel. If January's influent COD data are ignored, the BOD_5 divided by the COD equals 0.29 (standard deviation 0.06) for both pond influent and effluent.

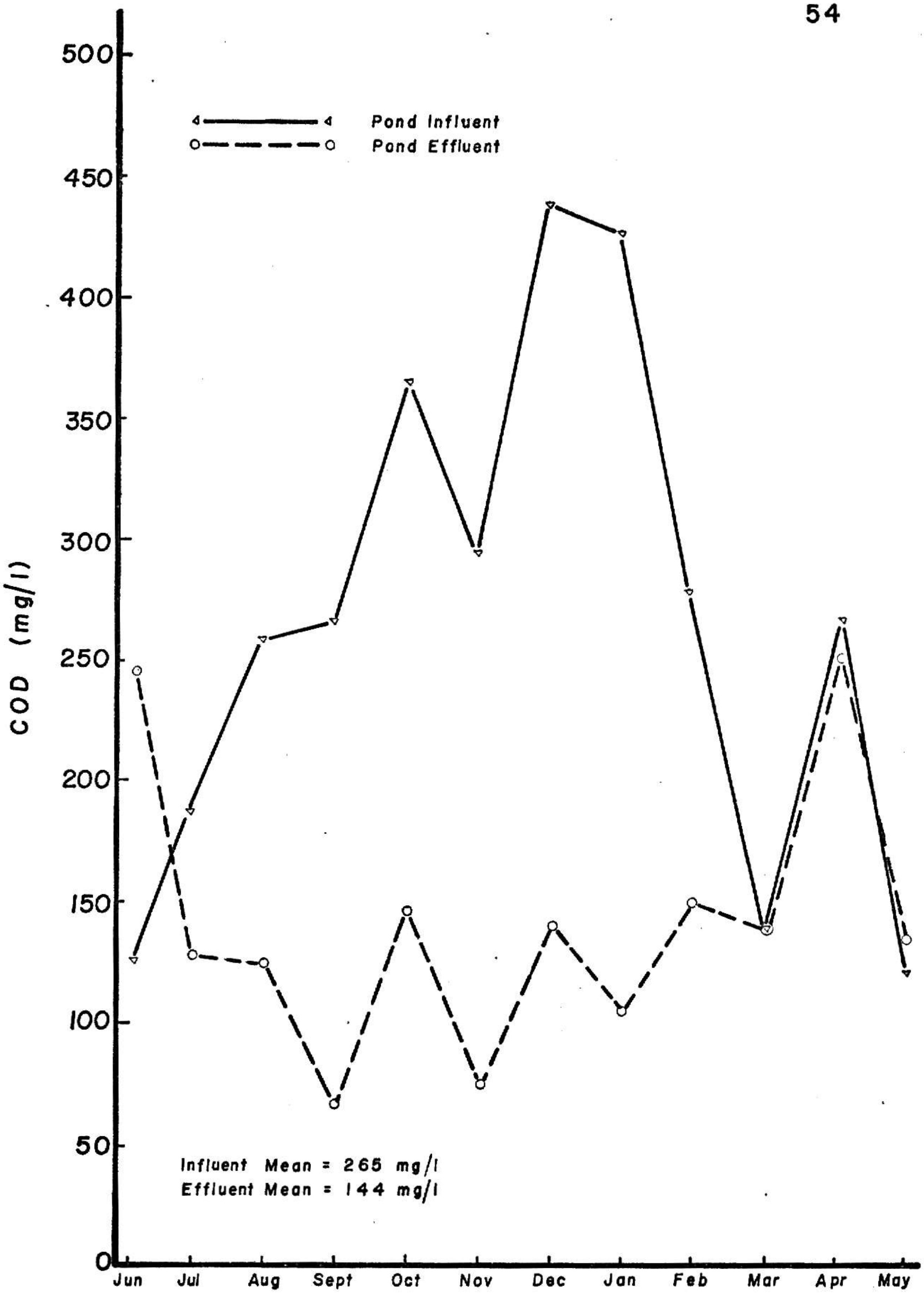

FIGURE 13. COD OF WALNUT GROVE POND

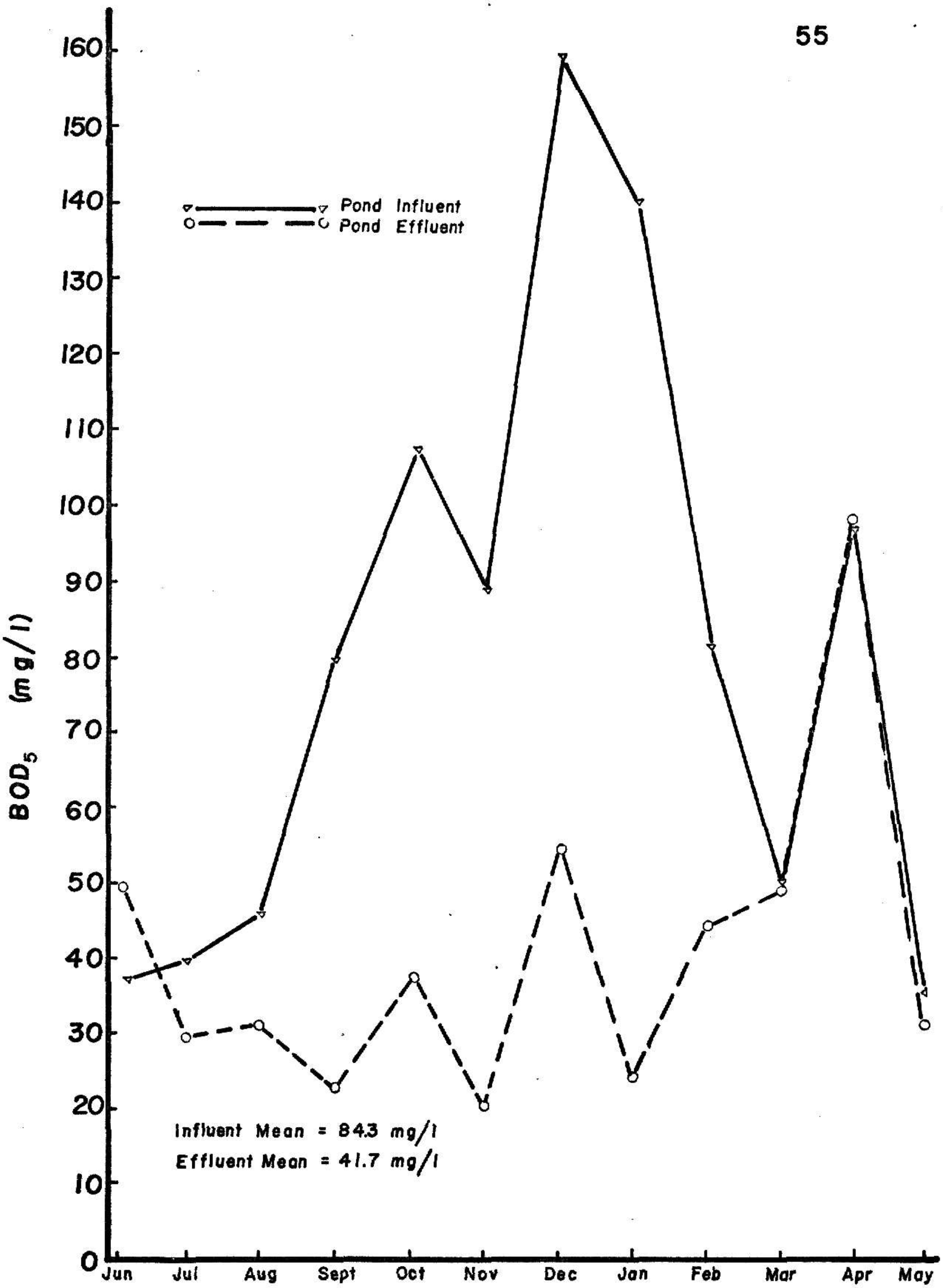

FIGURE 14. BOD$_5$ OF WALNUT GROVE POND

Suspended Solids Removal

Suspended solids were also removed in Walnut Grove's pond. The yearly influent mean suspended solids concentration (Figure 15) was 167 mg/l, while the effluent mean was 68 mg/l, corresponding to a 59 percent reduction.

Effluent suspended solids appeared directly proportional to the presence of algae. The highest effluent suspended solids measurement of approximately 250 mg/l was during a heavy algal bloom. The lowest average monthly values of 35 to 40 mg/l were recorded when algae were not visible in the pond.

Turbidity was used to help indicate the suspended solids concentration (Figure 16). For the year turbidity was reduced 54 percent by the pond, from an influent mean of 52 JTU to an effluent mean of 28 JTU. This 54 percent reduction tends to indicate solids settlement in the pond.

Nitrate and Ammonia Removals

Nitrate-nitrogen was often zero in the pond effluent. Influent nitrate-nitrogen for the year (Figure 17) was 3.4 mg/l, while the effluent averaged 1.4 mg/l. This is an average removal of 59 percent for the year. During November, the effluent nitrate-nitrogen jumped to its highest value of five mg/l, with one weekly measurement of 21 mg/l. These November values correspond to rises in the influent nitrate-nitrogen levels. With the exceptions of February and March, the effluent nitrate-nitrogen concentrations are directly proportional to the influent nitrate-nitrogen concentrations.

While nitrates were reduced 59 percent by the Walnut Grove pond, ammonia-nitrogen was increased 16 percent. Effluent ammonia-nitrogen

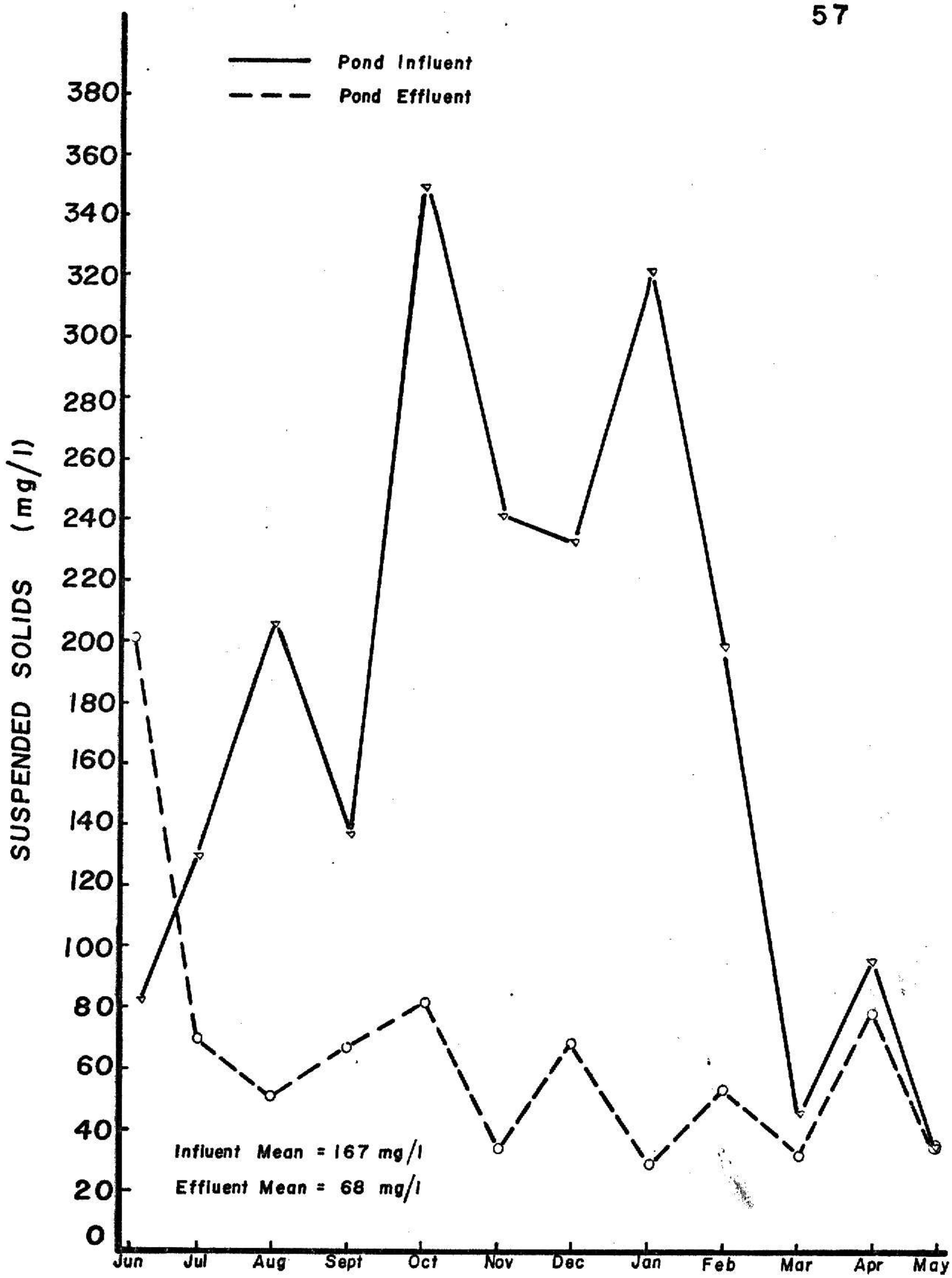

FIGURE 15. SUSPENDED SOLIDS OF WALNUT GROVE

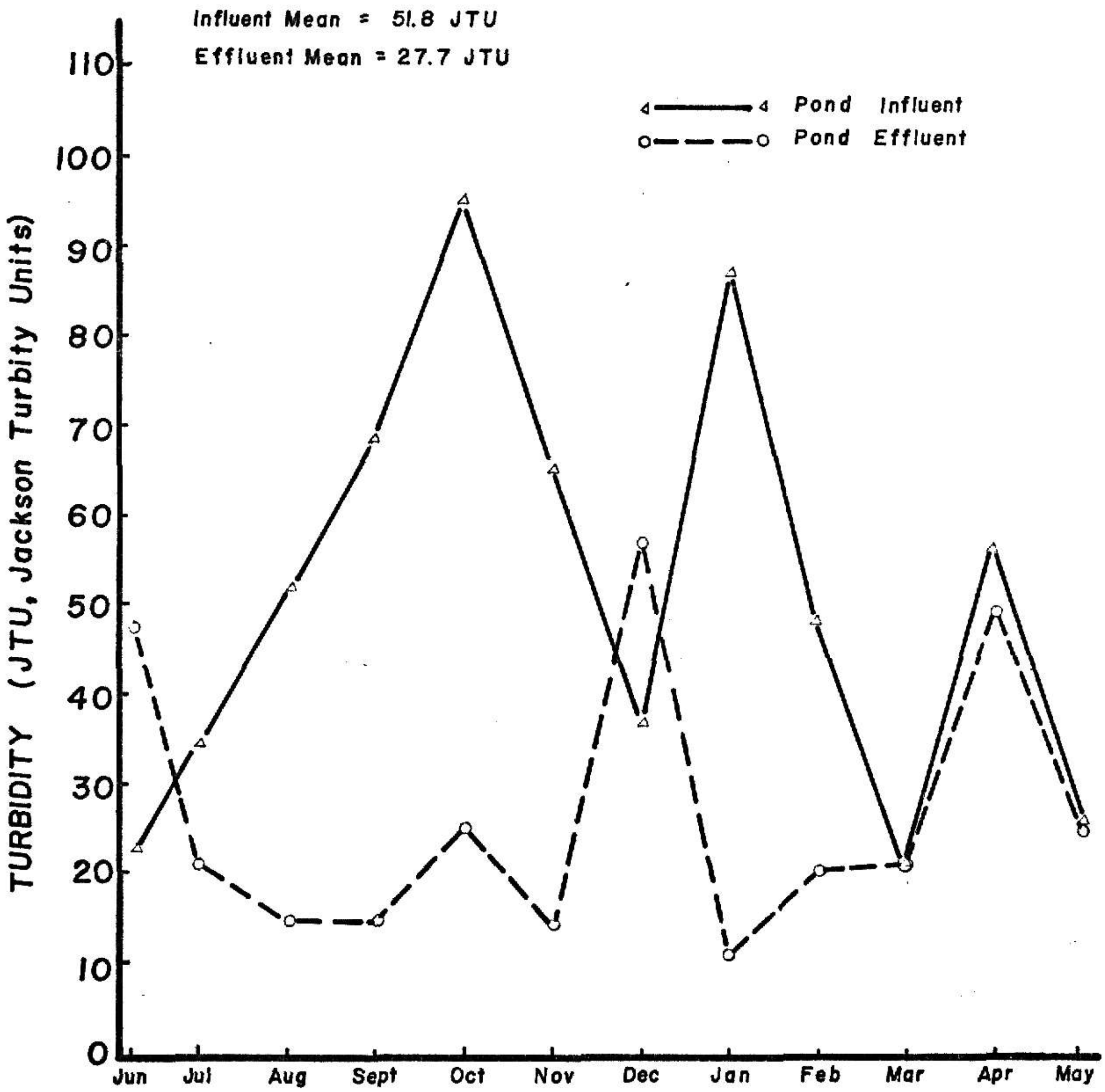

FIGURE 16. TURBIDITY OF WALNUT GROVE POND

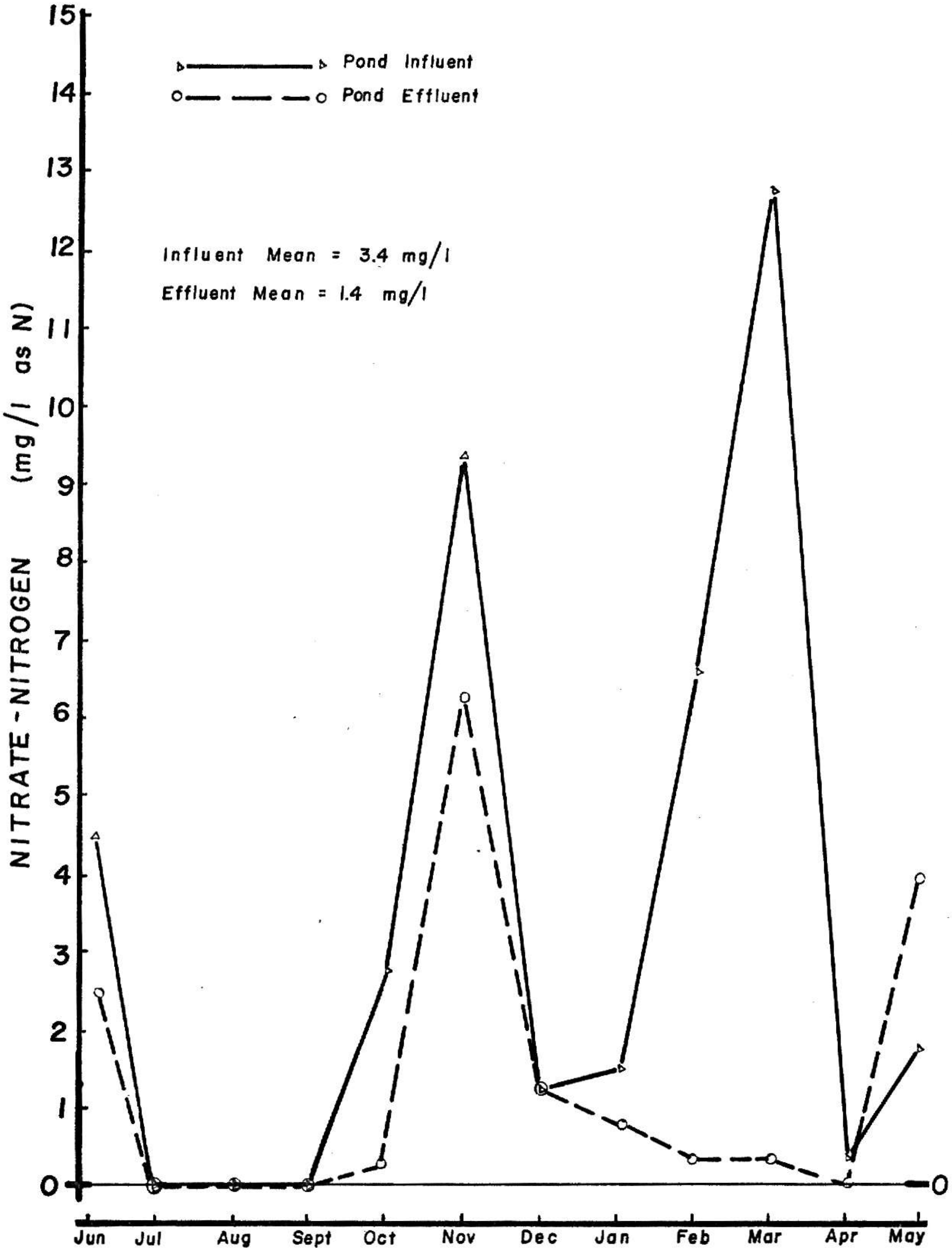

FIGURE 17. NITRATE-NITROGEN OF WALNUT GROVE PONI

averaged 18.5 mg/l for the year, while influent ammonia-nitrogen concentrations averaged only 15.5 mg/l (Figure 18). The effluent ammonia-nitrogen concentrations were again proportional to influent ammonia-nitrogen concentrations. Extreme effluent values ranged from an average monthly low of 11 mg/l ammonia-nitrogen to an average high of 35 mg/l.

Dissolved Oxygen

Dissolved oxygen was seldom detected in Walnut Grove's polishing pond effluent. The pond was putrid and any oxygen found in the effluent was most likely due to algal photosynthesis in the upper one foot of the pond.

Any oxygen found in the pond influent is due to weir turbulence since the sedimentation basin was always anaerobic. The influent averaged 0.9 mg/l dissolved oxygen for the year, while the effluent averaged 0.4 mg/l (Figure 19). This 0.4 mg/l is misleading, for the pond was definitely anaerobic, except for the top foot or two.

EPA Standards

Proposed EPA effluent limitations for BOD_5, 30 mg/l, were met only four months of the 12-month study. Monthly suspended solids averages met the proposed 1977 EPA maximum value of 30 mg/l only once. However, the plant effluent without the polishing pond, the pond influent, never met either standard. The pond effluent from Walnut Grove was obnoxious, but not nearly as obnoxious as the inefficient plant's effluent which the pond received.

Sludge Deposits

As at Timber Creek, cans were placed in Walnut Grove's polishing pond to measure solids accumulation over the year. The cans were

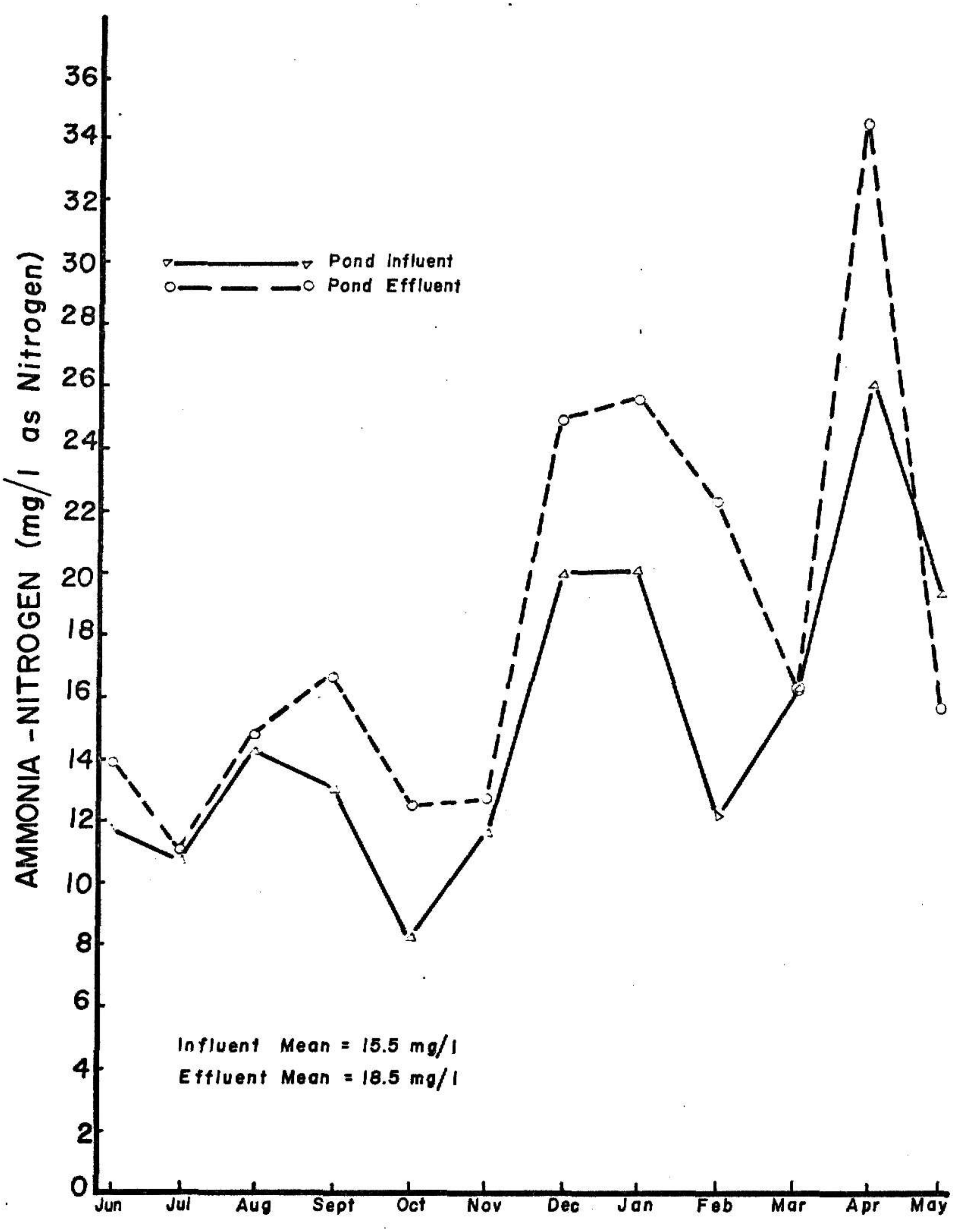

FIGURE 18. AMMONIA-NITROGEN OF WALNUT GROVE PON

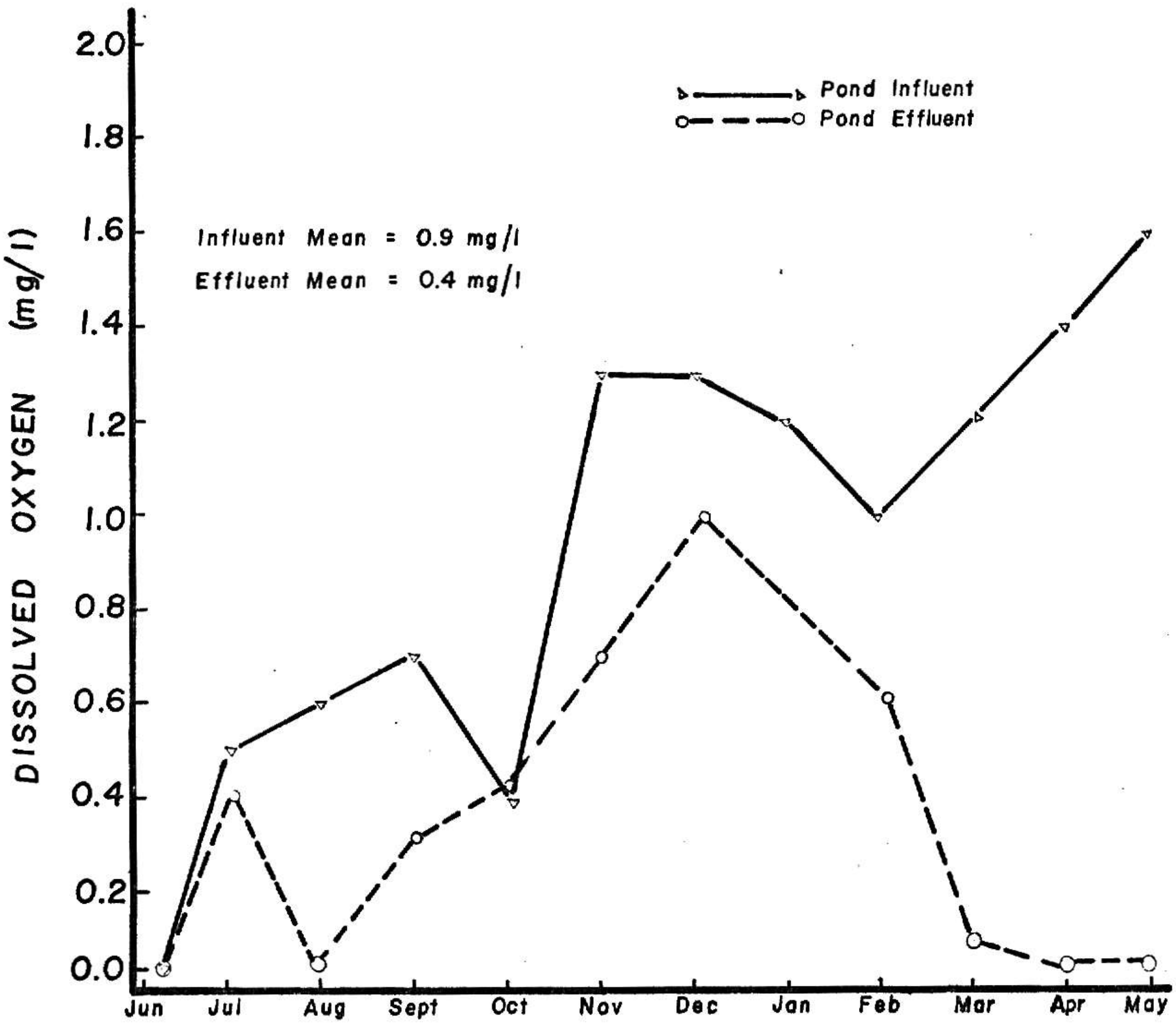

FIGURE 19. DISSOLVED OXYGEN OF WALNUT GROVE POND

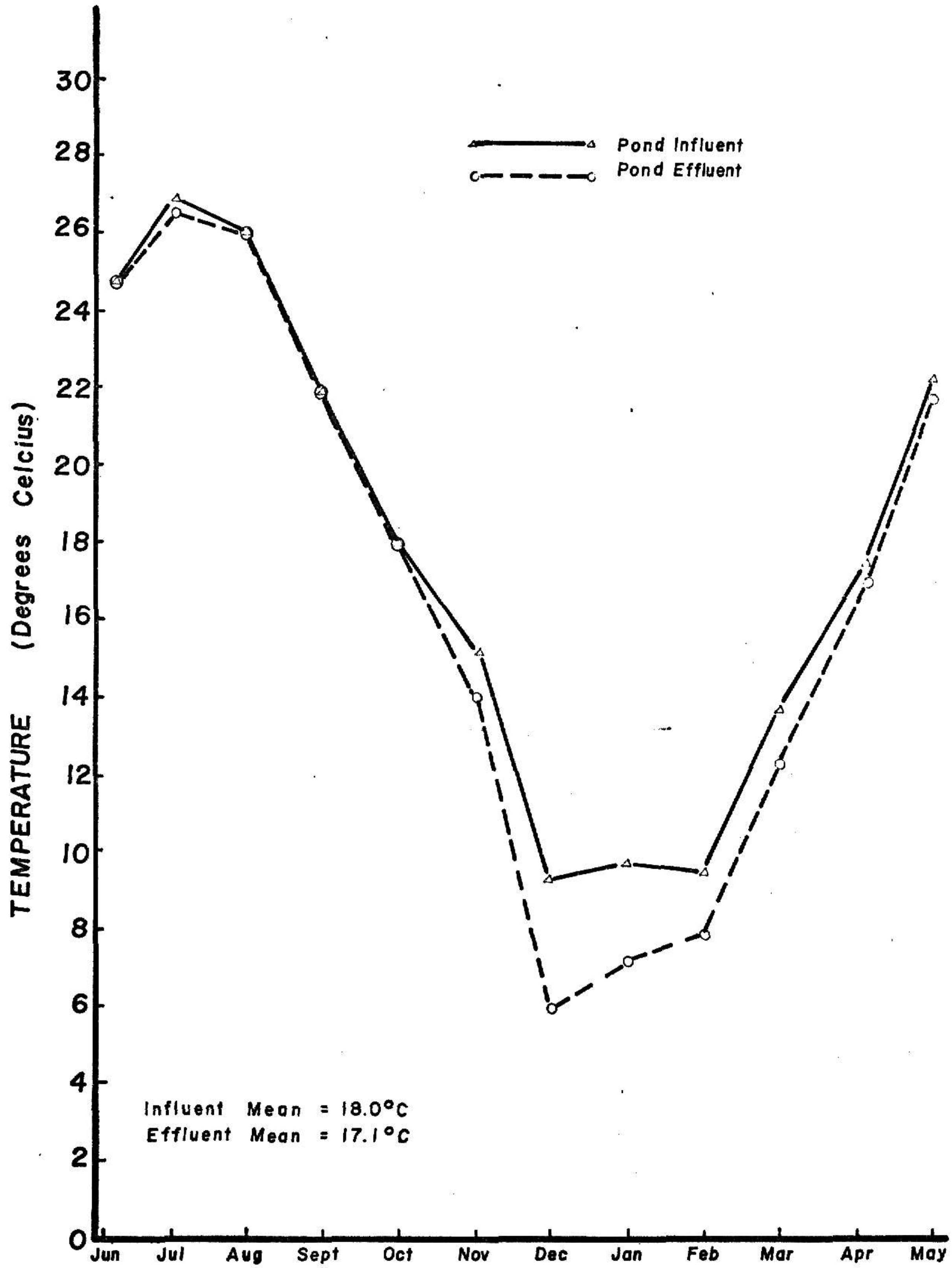

FIGURE 20. TEMPERATURE OF WALNUT GROVE POND

retrieved and tests were run to determine solids concentration and the percentage of volatile solids.

Walnut Grove's pond was often covered with a layer of floating sludge up to four inches thick. In an effort to improve the pond's appearance, the operator installed an airlift pump to remove the floating sludge by returning it to the aeration tank. Since this floating sludge rose from the bottom and was removed, an accurate measurement of bottom sludge depth was not possible.

The cans indicated that there was greater than 12 inches of sludge on the pond bottom. Total residue was determined to average 33 grams/l (3.3 percent solids). The percentage of the residue that was volatile was 70 percent. Sludge characteristics of three percent solids and 70 percent volatile solids are not reflective of a well digested sludge.

It appears that, if a polishing pond is used for emergency treatment on a continuous basis, sludge deposits and subsequent rising sludge may become serious operating problems.

Coliform Removal

Fecal and total coliform data from Walnut Grove were plotted in frequency-concentration form and are shown in Figures 21 and 22. Weekly effluent fecal coliform concentrations were below the EPA maximum of 200 per 100 ml only three times in 26 tests, or 12 percent of the time. The frequency-concentration plot can be used to estimate that the pond influent and effluent were below the EPA standard only ten percent of the time. The high coliform values at Walnut Grove can be attributed to short detention times and the absence of chlorination facilities.

The frequency-concentration plots show influent and effluent fecal concentrations to be about the same, in the range from 0 to 10^4 per

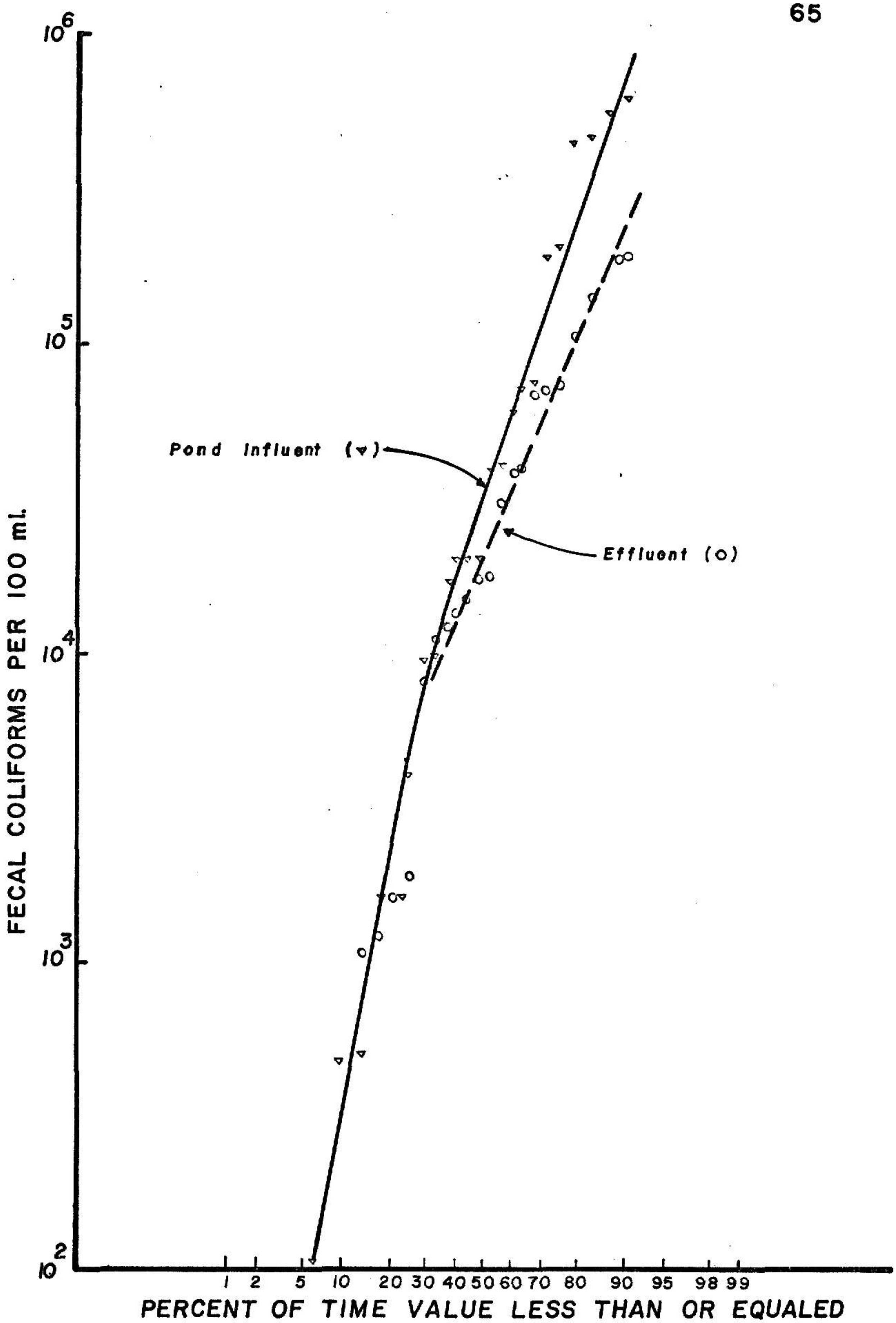

FIGURE 21. FREQUENCY-CONCENTRATION RELATIONS OF FECAL COLIFORMS AT WALNUT GROVE

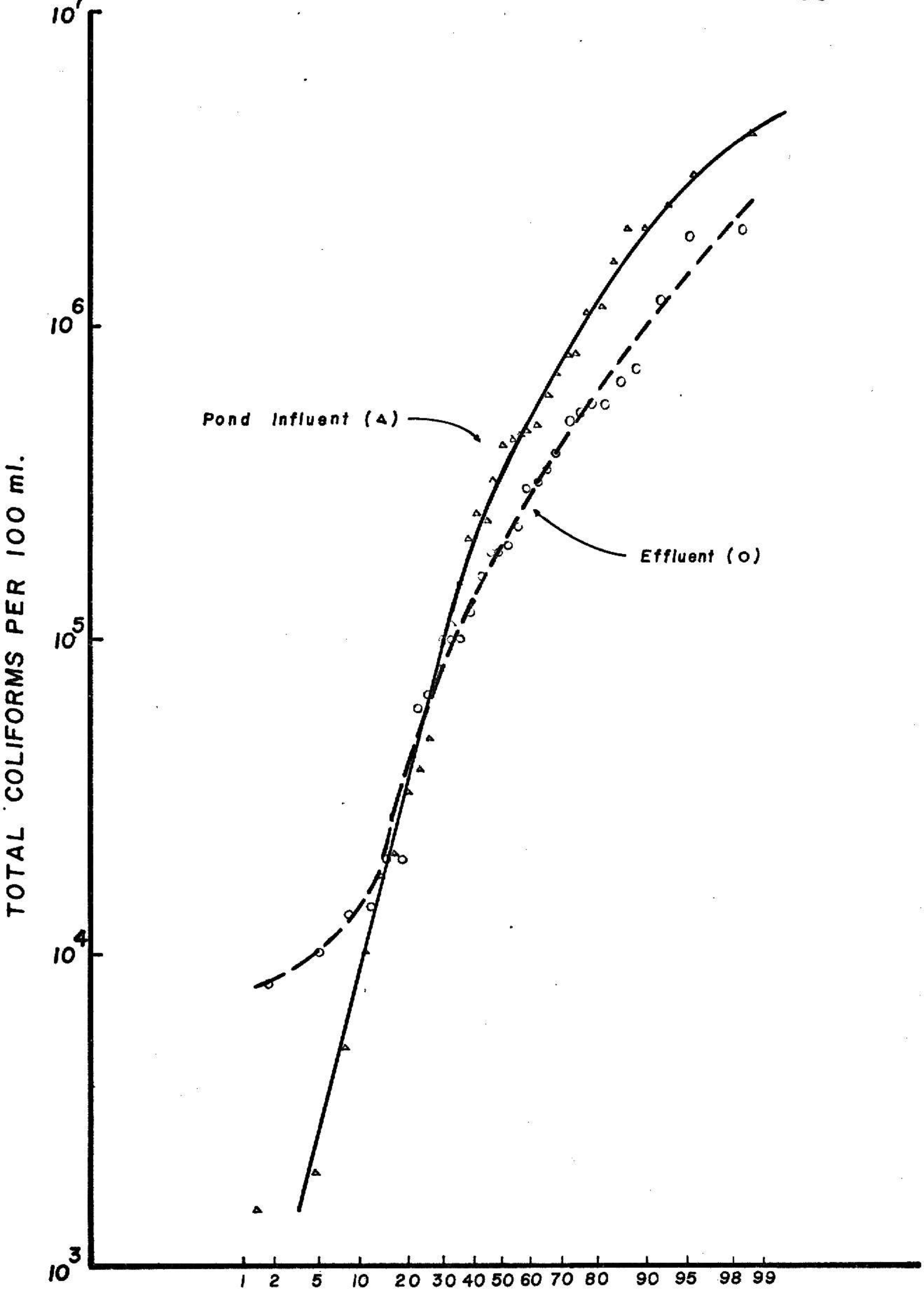

FIGURE 22. FREQUENCY-CONCENTRATION RELATIONS OF TOTAL COLIFORMS AT WALNUT GROVE

100 ml. Above 10^4 per 100 ml, there is less chance of a large number of fecals in the effluent than in the influent. Since the largest number of data points are above the 10^4 per 100 ml level, it therefore appears likely that there is a small reduction in fecal coliforms through the Walnut Grove pond. Even with this small reduction through the pond, the effluent fecal coliform concentrations were never near acceptable levels (based on EPA standards).

Total coliform levels were extremely high with influent and effluent concentrations below 10^4 per 100 ml only four times. Highest influent total coliform counts were above 3×10^6 per 100 ml, while the highest effluent count was 2×10^6 per 100 ml.

The frequency-concentration graph, Figure 22, indicates that noticeable total coliform removal occurs when the total coliform count moves above the 10^5 per 100 ml level. As before, this tends to indicate total coliform removal is significant only with large concentrations of total coliforms. If EPA standards are to be met during emergency treatment in a polishing pond, alternate methods of disinfection should be employed.

Algae

As at Timber Creek, Chlorella was most often found in the Walnut Grove pond effluent. Chlorella was found every month of observation and was usually the most numerous alga. Chlamydomonas, Euglena, and Chlorococcum were also commonly found in the pond effluent. Euglena was found every month but April, while Chlorococcum was not identified in September and April. Chlamydomonas was not present in August, September, and October.

Besides the above mentioned algae, many other genera were found. During the first three months of the year Anacystis, Anabaena, Lepocinclis, Nitzchia, and Sphaerocystis were all found. The months of April through June gave rise to Anabaena, Chlorogonium, Diatoma, Nitzchia, Palmella, and Volvox. Coelastrum, Spirogyra, Oocystis and Eudorina were all found during July, August, and September. During October, November, and December, Anacystis, Coelastrum, Gomphosphaeria, Nitzchia, Pyrobotrys, and Sphaerocystis were identified.

CONCLUSIONS

A polishing pond receiving a well treated secondary effluent reduced COD, BOD_5, and suspended solids only during the colder months of October through April. The warmer period of May to September gave rise to profuse algal blooms which appeared to raise the COD, BOD_5, and suspended solids concentration of the pond effluent. Average yearly removal was not significant since the summer increases in COD, BOD_5, and suspended solids counteract winter reductions.

Polishing pond effluent nitrate and ammonia concentrations are directly proportional to the influent concentrations. Nitrate levels were found to decrease by 20 percent through a polishing pond, while ammonia levels increased by 50 percent. The 50 percent increase in ammonia concentration is not serious since the effluent concentration averaged less than one mg/l NH_3-N.

A polishing pond provides a source of emergency treatment in case of treatment plant failure. Minor upsets and malfunctions are absorbed by the pond without noticeable effects in the pond or the pond effluent. Prolonged major plant malfunctions result in an overloaded polishing pond and anaerobic conditions. However, even an overloaded polishing pond with four days detention was found to reduce COD, BOD_5, and suspended solids by approximately 50 percent.

Total and fecal coliforms are only slightly reduced in four- and ten-day polishing ponds. This slight removal is evident only at coliform concentrations much greater than those recommended by the EPA. If coliform removal is a primary concern, polishing pond systems must be supplemented with disinfection equipment. Chlorination before the waste enters the pond would be preferred. Results from the Timber Creek pond showed that bacterial regrowth in the pond was not a problem, as effluent concentrations were lower than influent concentrations. Chlorination prior to the pond allows use of the pond for dechlorination, preventing discharge of toxic chlorine to the receiving waters.

Copper sulfate was determined to be an inexpensive and effective algicide for use in a polishing pond. Residual dosages of 1.0 to 1.5 mg/l copper are required to remove algae during heavy algae blooms. Once the algae have been removed, copper concentrations of 0.3 or larger prohibit their return.

In waters with alkalinities near 400 mg/l, copper sulfate dosages which should yield 1.4 to 1.9 mg/l by volume will give residuals of near 1.1 mg/l, with significant residuals for at least one week, at this detention.

Considering the recommended limit of one mg/l copper in surface waters, and the low cost of copper as "bluestone," copper sulfate is recommended as a method of algae control in polishing ponds. However, if stream dilution of the discharge is not adequate to keep the stream copper concentration below one mg/l, alternate control methods should be investigated.

Sludge build-up was measured at 3 1/2 inches per year in a pond receiving a well-treated secondary effluent. This bottom sludge was well digested at 80 percent inert solids. It appears that solids accumulation will not be a serious problem in normal polishing ponds.

Sludge deposits in excess of 12 inches were measured in a polishing pond serving as an emergency treatment device. Floating sludge that rises from the bottom is likely to be an unsightly problem arising during emergency treatment.

In conclusion, state regulatory agencies requirement of a polishing pond, following an extended aeration sewage treatment plant, is justified. On a yearly basis there is little pollutant removal in a normal polishing pond. However, this does not reflect the important function of stream protection, in case of plant upset, fulfilled by the polishing pond. This protection alone is sufficient to justify the presence of polishing ponds.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. A study of the effects of detention times on polishing pond performance was originally an objective of this study. Unfortunately, it could not be evaluated since the Walnut Grove plant was continually upset. Further studies could help determine a detention time that would provide optimum performance from polishing ponds.

2. An effective method of coliform removal is needed to increase disinfection with polishing ponds. Prechlorination and post-chlorination should be more carefully evaluated to determine the best method for maximum disinfection.

3. Removal of algae is an area that deserves considerable study. By harvesting algae it would be possible to remove nutrients from the sewage and gain a possibly useful resource. Efficient and economical methods of harvesting algae are needed to make this possibility a reality.

4. If algae harvesting is not practiced then a method of removal or control of algae would be beneficial. Again economical and efficient methods of alga removal and control should be studied.

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APPENDIX

TABLE 1. WEEKLY COD DATA (mg/l)

Date	Timber Creek Polishing Pond Influent	Timber Creek Polishing Pond Effluent	Walnut Grove Polishing Pond Influent	Walnut Grove Polishing Pond Effluent
Jun 6	99	40	92	158
14	35	50	101	215
20	30	20	175	265
27	30	40	135	346
Jul 3	26	32	222	153
11	29	41	137	102
18	41	45	187	172
22	30	53	216	128
Aug 6	21	31	178	94
15	28	35	455	193
22	25	39	65	84
29	22	20	340	58
Sept 5	21	23	444	94
12	25	28	73	75
18	35	26	81	66
24	26	40	475	42
Oct 5	33	25	320	80
12	70	30	128	74
19	44	28	315	100
26	33	17	700	343
Nov 2	42	20	196	44
6	24	20	224	68
17	29	13	700	94
20	32	15	156	64
30	20	16	31	85
Dec 6	31	24	500	167
14	45	26	463	111
19	29	23	640	158
27	35	23	129	172
Jan 5	62	29	418	111
13	31	17	480	81
17	34	20	451	120
23	37	22	364	123
Feb 1	29	16	27	152
6	45	30	245	119
14	74	42	394	152
20	59	42	374	184
27	49	35	120	160
Mar 7	54	52	169	118
13	43	34	108	150
20	44	39	141	142
28	73	44	146	163
Apr 3	77	70	210	227
13	35	52	250	213
21	23	20	300	327
27	26	28	313	227
May 5	25	26	152	193
13	51	57	141	130
22	28	27	70	104
29	27	31	120	126

TABLE 2. WEEKLY BOD_5 DATA (mg/l)

Date	Timber Creek Polishing Pond Influent	Timber Creek Polishing Pond Effluent	Walnut Grove Polishing Pond Influent	Walnut Grove Polishing Pond Effluent
Jun 6	20.0	11.0	44	60
14	8.0	4.9	22	51
20	4.2	4.4	48	23
27	5.8	7.1	33	65
Jul 3	8.8	5.6	35	29
11	1.2	3.8	21	17
18	3.8	6.7	50	39
22	2.0	14.6	52	34
Aug 6	0.9	1.1	38	48
15	2.0	2.8	54	48
22	1.6	4.0	16.8	18
29	2.0	1.9	72	14
Sept 5	4.9	1.2	83	34
12	2.2	3.1	—	15.6
18	6.1	3.9	15.6	13.8
24	2.6	4.4	138	26
Oct 5	3.0	5.2	87	17
12	—	—	—	—
19	4.6	2.1	67	17.5
26	2.8	1.8	168	81
Nov 2	3.4	2.2	45	23.4
6	1.5	2.5	167	22.8
17	7.5	1.5	115	14.4
20	—	3.4	54	24
30	3.8	2.8	60	18
Dec 6	4.6	2.5	195	63
14	4.4	2.2	123	16.2
19	5.6	3.5	186	66
27	5.7	3.3	132	75
Jan 5	6.2	4.2	186	16.6
13	7.6	4.0	122	10.8
17	4.3	1.4	140	30
23	4.0	1.5	110	42
Feb 1	5.6	3.6	41	35
6	—	3.9	80	50
14	6.0	5.5	129	47
20	6.0	5.6	104	—
27	8.5	4.8	50	54
Mar 7	4.2	7.2	36	31
13	5.1	5.5	35	51
20	5.0	4.3	50	53
28	5.1	5.2	65	64
Apr 3	10.0	7.2	122	100
13	3.4	8.5	115	133
21	2.0	1.8	62	77
27	2.2	3.4	87	83
May 5	2.8	3.0	38	40
13	2.6	10.1	58	33
22	3.3	2.5	25	33
29	1.6	1.7	26	26

TABLE 3. WEEKLY NITRATE-NITROGEN DATA (mg/l as N, includes Nitrite)

Date	Timber Creek Polishing Pond		Walnut Grove Polishing Pond	
	Influent	Effluent	Influent	Effluent
Jun 6	40	35	6	9
14	30	23	1	0
20	32	29	5	0
27	32	28	6	1
Jul 3	29	23	0	0
11	15	11	0	0
18	34	28	0	0
22	17	19	0	0
Aug 6	9	11	0	0
15	21	14	0	0
22	27	18	0	0
29	26	19	0	0
Sept 5	25	21	0	0
12	32	26	0	0
18	—	—	—	—
24	22	16	0	0
Oct 5	25	11	0.5	0
12	16	16	7	0
19	—	—	—	—
26	27	11	1	1.3
Nov 2	31	15	30	5
6	10	12	—	—
17	21	10	2	5
20	21	15	0	0
30	9.5	11	5.5	0
Dec 6	—	—	—	—
14	24	13	1	0.5
19	26	21	2.5	2.5
27	22	21	0	0.5
Jan 5	32	30	1	0
13	15	17	4	3
17	18	12	0	0
23	21	20	1	0
Feb 1	24	22	4.5	0.5
6	22	20	2	0.5
14	18	17	10	0
20	23	19	10	0
27	—	—	—	—
Mar 7	30	25	18	0
13	33	28	32	1.0
20	23	20	0	0
28	44	25	1	0
Apr 3	28	29	0	0
13	24	24	1.5	—
21	13	16	0	0
27	21	19	0	0
May 5	22	24	0	0
13	23	20	0	0
22	22	20	7	9
29	13	14	0	11

TABLE 4. WEEKLY AMMONIA DATA (mg/l as N)

Date	Timber Creek Polishing Pond		Walnut Grove Polishing Pond	
	Influent	Effluent	Influent	Effluent
Jun 6	—	—	—	—
14	—	—	—	—
20	0.6	1.0	10.6	14.0
27	0.3	0.5	13.0	14.0
Jul 3	0.4	0.3	10.0	11.5
11	0.3	—	12.0	13.0
18	0.2	0.2	10.5	8.0
22	0.4	0.6	10.8	11.0
Aug 6	0.6	1.2	17.5	24.0
15	0.4	0.9	10.0	11.3
22	0.2	0.6	9.5	10.2
29	0.4	0	20.0	14.0
Sept 5	0	1.8	13.0	22.0
12	0.2	1.9	11.8	19.0
18	0.1	3.5	16.8	18.2
24	0.3	0.5	10.0	7.8
Oct 5	0	0.6	12.0	17.6
12	0.1	0.2	12.0	16.2
19	0.7	0.1	1.2	6.8
26	0	1.0	7.8	9.6
Nov 2	0.3	1.4	7.4	12.2
6	0	1.0	1.8	6.0
17	0	0.4	20.3	16.7
20	0	0.7	11.8	12.0
30	0	0.3	17.4	17.4
Dec 6	—	—	—	—
14	0.2	0.7	20.0	26.0
19	0	0	15.3	17.3
27	0	0.4	28.0	32.0
Jan 5	1.4	0.5	20.6	24.0
13	1.3	3.0	22.4	22.0
17	0.9	0.3	21.3	28.7
23	0.2	0.3	20.3	28.3
Feb 1	0	0.3	14.0	25.0
6	0.4	0.6	20.6	20.3
14	0	0	10.4	21.3
20	0.3	0.1	12.0	20.3
27	0.1	0.2	13.3	23.3
Mar 7	0	0	11.0	15.7
13	0.5	0.5	38.3	23.3
20	0.3	0.6	21.6	22.3
28	0.6	0.4	4.0	3.0
Apr 3	0.4	0.4	31.6	40.0
13	0.6	0.4	15.0	21.7
21	0.3	1.0	27.7	33.3
27	0.4	0.7	29.7	43.7
May 5	0.4	0.4	35.6	22.3
13	1.1	—	—	—
22	0.5	1.4	15.0	16.0
29	0.1	1.1	7.0	9.0

TABLE 5. WEEKLY SUSPENDED SOLIDS DATA (mg/l)

Date	Timber Creek Polishing Pond		Walnut Grove Polishing Pond	
	Influent	Effluent	Influent	Effluent
Jun 6	—	10	50	190
14	—	—	160	260
20	—	70	100	180
27	12	12	20	180
Jul 3	10	20	80	80
11	10	40	64	32
18	10	7	176	80
22	13	80	200	92
Aug 6	—	22	230	110
15	12	17	324	50
22	1.7	9.0	24	28
29	4.5	40.5	248	21
Sept 5	6.0	5.6	392	156
12	8.5	1.0	12	40
18	13.5	19	64	50
24	9.0	110	80	28
Oct 5	54	90	480	45
12	330	92	138	42
19	155	60	220	24
26	54	9.6	564	220
Nov 2	52	7.0	122	24
6	28	8.2	216	19
17	16.8	3.8	504	23
20	20	6.2	185	25
30	8.8	7.4	184	82
Dec 6	11.8	7.6	416	96
14	21	10	236	30
19	21	4.8	230	96
27	15	3.7	53	60
Jan 5	60	4.0	428	19
13	84	6.4	300	30
17	18	2.2	280	36
23	18	2.6	284	36
Feb 1	53	4.0	84	26
6	6.8	7.5	188	25.5
14	73	13	—	83
20	60	13	208	60
27	48	15	71	52
Mar 7	29	16	72	41
13	20	9.0	40	40
20	18	9.3	40	34
28	54	10	32	22
Apr 3	76	28	72	40
13	7.5	6.0	110	90
21	7.0	1.2	64	120
27	6.0	2.3	140	70
May 5	37	26	28	34
13	43	32	48	42
22	13	1.3	12	24
29	15	3.0	38	20

TABLE 6. WEEKLY TURBIDITY DATA (Jackson Turbidity Units, JTU)

Date	Timber Creek Polishing Pond		Walnut Grove Polishing Pond	
	Influent	Effluent	Influent	Effluent
Jun 6	—	—	—	—
14	6.5	16	26	43
20	12.0	9.5	19	46
27	5.0	9.3	25	55
Jul 3	4.4	18	33	23
11	6.5	19	25	17
18	4.5	3.0	30	22
22	10.0	12	52	26
Aug 6	7.0	16	36	13
15	13	15	85	25
22	3.0	14	14	10
29	2.2	—	73	15
Sept 5	1.5	3.4	120	16
12	4.0	3.5	6.2	15
18	19	9	20	17
24	4.9	11	130	15
Oct 5	35	8	160	14
12	240	80	27	16
19	80	58	75	18
26	31	17	160	57
Nov 2	44	14	48	17
6	23	11	51	17
17	14	4	140	19
20	27	4.5	36	13
30	5.5	5.0	54	10
Dec 6	—	—	—	—
14	5.5	36	70	10
19	6.2	1.9	26	135
27	13	—	16	27
Jan 5	18	3.3	115	7
13	27	1.2	90	7.6
17	7.3	1.1	78	14
23	3.7	1.4	68	15
Feb 1	39	1.8	34	16
6	7.0	2.4	54	16
14	28	4.6	70	28
20	22	5.5	63	28
27	16	6.0	23	21
Mar 7	18	7.6	26	17
13	7.5	5.5	17	26
20	14	6.2	20	21
28	30	7.2	25	25
Apr 3	40	15	60	62
13	7.6	9.2	60	60
21	6.2	1.2	50	40
27	4.5	1.8	59	40
May 5	27	27	23	50
13	25	18	20	23
22	12	2.3	5.4	13
29	7.3	2.0	23	18

TABLE 7. WEEKLY D.O. DATA (mg/1)

Date		Timber Creek Polishing Pond Influent	Timber Creek Polishing Pond Effluent	Walnut Grove Polishing Pond Influent	Walnut Grove Polishing Pond Effluent
Jun	6	—	—	—	—
	14	6.2	17.6	0	0
	20	5.2	24.8	0	0
	27	6.4	14.7	0	0
Jul	3	4.6	18.5	0.3	0.2
	11	6.0	10.0	1.0	0.2
	18	6.4	6.0	0.1	0.6
	22	5.2	6.4	0.5	0.5
Aug	6	6.0	4.0	1.0	0.1
	15	4.9	6.2	0.8	0.4
	22	4.4	14.4	0.4	0
	29	3.3	1.2	0	0
Sept	5	3.8	1.4	0	0
	12	4.0	2.6	0.4	0
	18	4.0	2.0	0.3	0
	24	2.0	10.0	1.9	1.0
Oct	5	3.6	2.0	0	1.6
	12	3.6	4.0	0	0
	19	7.0	4.5	0.8	0
	26	2.2	3.1	0.7	0.3
Nov	2	—	3.1	1.2	0.9
	6	—	—	1.7	0.8
	17	1.8	2.7	1.2	0.4
	20	2.8	3.3	1.8	0.8
	30	2.5	3.1	0.8	0.7
Dec	6	4.8	6.2	1.8	0.6
	14	4.1	7.2	1.5	0.8
	19	3.0	6.7	0.7	2.2
	27	4.2	5.3	1.2	0.3
Jan	5	4.8	5.3	0.9	0.9
	13	2.7	4.1	0.4	0.2
	17	0.4	2.7	1.0	0.6
	23	0.9	2.3	2.3	0.8
Feb	1	0.6	4.6	0.6	0.2
	6	2.2	7.7	1.3	1.4
	14	1.6	12.5	0.6	0.5
	20	2.0	12.3	2.5	0.9
	27	2.8	15.0	0.2	0
Mar	7	1.4	15.0	0.6	0.4
	13	2.6	8.3	0.5	0.5
	20	3.6	11.6	2.3	0
	28	—	—	—	—
Apr	3	2.4	15.0	1.2	0
	13	2.4	15.0	1.6	0.4
	21	2.5	5.8	1.1	0
	27	2.0	7.6	1.6	0
May	5	0.6	7.5	2.6	0
	13	—	0.8	1.7	0
	22	1.3	0.8	1.2	0
	29	1.4	1.4	0.8	0

TABLE 8. CHLORINE AND COPPER DATA (mg/l)

Timber Creek Polishing Pond	
Date	Chlorine in the Influent
Jun 6	—
14	—
20	.25
27	7.5
Jul 3	2.5
11	1.5
18	0
22	0
Aug 6	4.0
15	2.5
22	0
29	0
Sept 5	0
12	0
18	0.2
24	0
Oct 5	0.2
12	—
19	—
26	0
Nov 2	0.1
6	0.1
17	0.15
20	—
30	0
Dec 6	.1
14	0
19	0
27	0
Jan 5	—
13	—
17	—
23	0
Feb 1	.25
6	.4
14	.1
20	0
27	—
Mar 7	.1
13	.1
20	0
28	0
Apr 3	.1
13	0
21	0
27	.1
May 5	0
13	.1
22	0
29	0

Timber Creek Polishing Pond	
Date	Copper in the Effluent
Aug 27	1.20
30	0.80
Sept 3	0.50
5	0.35
7	0.45
12	0.35
15	0.25
21	0.05
24	0.03
27	1.10
Oct 5	0.50
12	0.55
19	0.25
26	0.20
Nov 17	0.10
20	0.25
30	0.10
Dec 19	0.15
27	0.15
Jan 5	0.15
13	0.10
17	0.10
23	0.05
Feb 1	0.10
14	0.15

TABLE 9. WEEKLY TOTAL COLIFORM DATA (Coliforms/100 ml)

Date	Timber Creek Polishing Pond		Walnut Grove Polishing Pond	
	Influent	Effluent	Influent	Effluent
Jun 6	200	60	—	—
14	1,150	1,600	580,000	500,000
20	120	10,000	450,000	670,000
27	0	25	110,000	60,000
Jul 3	1,000	4,000	—	—
11	0	0	100,000	80,000
18	—	—	—	—
22	0	0	—	66,000
Aug 6	0	—	—	—
15	1,000	1,000	600,000	120,000
22	—	4,600	8,000	—
29	5,000	13,000	10,000	14,000
Sept 5	84,000	2,000	48,000	13,000
12	—	0	—	10,000
18	—	—	—	—
24	700	650	38,000	158,000
Oct 5	—	—	—	—
12	—	—	—	—
19	26,500	150	5,000	0
26	4,000	3,000	20,000	20,000
Nov 2	2,600	100	2,000	—
6	107,000	0	1,500	8,000
17	5,200	2,000	2,000,000	560,000
20	128,000	25,500	860,000	530,000
30	2,750	13,000	440,000	720,000
Dec 6	29,000	2,000	—	—
14	73,000	2,200	1,150,000	390,000
19	73,000	3,000	4,100,000	580,000
27	0	1,100	230,000	1,920,000
Jan 5	—	200	2,400,000	100,000
13	40,000	13,000	32,000	190,000
17	1,600	600	250,000	—
23	17,000	5,900	17,500	—
Feb 1	0	300	58,000	20,000
6	300	400	700,000	188,000
14	0	600	2,000,000	1,200,000
20	16,000	3,750	320,000	200,000
27	—	—	—	—
Mar 7	47,000	1,300	250,000	100,000
13	300	1,600	190,000	320,000
20	50,000	1,300	—	—
28	—	—	—	—
Apr 3	—	—	—	—
13	62,000	900	3,000,000	2,000,000
21	800	3,000	—	—
27	—	—	—	—
May 5	—	—	—	—
13	—	—	—	—
22	19,000	130,000	1,600,000	340,000
29	12,000	4,500	1,100,000	225,000

TABLE 10. WEEKLY FECAL COLIFORM DATA (Coliforms/100 ml)

Date	Timber Creek Polishing Pond		Walnut Grove Polishing Pond	
	Influent	Effluent	Influent	Effluent
Jun 6	——	——	——	——
14	——	——	——	——
20	——	——	——	——
27	0	0	20,000	71,000
Jul 3	0	100	——	——
11	0	0	0	0
18	400	140,000	——	——
22	0	200	40,000	30,000
Aug 6	0	0	9,800	1,600
15	0	0	56	0
22	——	——	——	——
29	——	10	——	——
Sept 5	1,100	100	——	——
12	0	0	480	1,240
18	0	0	1,600	11,000
24	——	——	——	——
Oct 5	——	——	——	——
12	——	——	——	——
19	850	140	——	——
26	60	0	——	——
Nov 2	0	425	——	——
6	0	0	500	50
17	0	100	——	——
20	4,000	1,450	205,000	193,000
30	——	——	——	——
Dec 6	10	50	3,500,000	2,000,000
14	6,200	0	530,000	105,000
19	8,400	1,000	1,800,000	140,000
27	0	100	39,000	69,000
Jan 5	42,000	440	610,000	75,000
13	6,600	1,500	4,000	12,000
17	100	300	438,000	188,000
23	3,400	800	——	1,900
Feb 1	——	——	——	——
6	——	——	——	——
14	——	——	71,000	32,800
20	4,240	250	20,000	13,500
27	1,250	200	5,000	18,000
Mar 7	4,050	0	9,500	1,050
13	0	0	1,600	17,500
20	——	——	——	——
28	——	——	——	——
Apr 3	——	——	——	——
13	4,000	0	75,000	40,000
21	0	450	1,050,000	1,200,000
27	0	0	460,000	300,000
May 5	——	——	——	——
13	——	——	——	——
22	600	320	190,000	8,000
29	12,000	100	17,000	15,000

AN EVALUATION OF POLISHING POND EFFECTIVENESS

by

KARL W. MUELDENER

B.S., Kansas State University, 1973

AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Polishing ponds are often required following extended aeration activated sludge sewage treatment plants. These polishing ponds are installed to further treat the secondary effluent by sedimentation and flow equalization. The quiesent pond conditions combined with the readily available nutrients in the secondary effluent often results in profuse algal blooms which can result in a lowering of the overall water quality through the pond.

Two polishing ponds were monitored for one year to evaluate their effectiveness. One pond, with a detention time of 10 days, received a well treated secondary effluent. This pond lowered the water quality in the summer, while improving it in the winter. For the entire year on an average, there was no water quality improvement through the pond. Sludge build-up was not found to be a problem in this 10 day pond. Coliform reduction was poor through the pond. Copper was found to be effective as an algicide from 0.3 to 1 mg/l. Copper residuals were detected for several weeks indicating little precipitation of copper as copper carbonate.

The second polishing pond followed an inefficient treatment plant. This pond, detention time of 4 days, provided emergency treatment that would not have been available without the pond. The pond reduced BOD_5, COD, and suspended solids by about 50 percent.

It was concluded that polishing ponds serve a useful purpose simply by providing emergency treatment during periods of plant upset.