

EXTENDED AERATION WASTE TREATMENT  
WITH LOW LOADING CONDITIONS

by

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B.S., Kansas State University, 1972

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A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

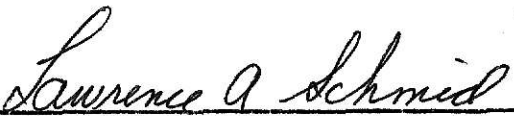
MASTER OF SCIENCE

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## INTRODUCTION

In recent years there has been a movement in the United States toward developing suburban housing units some distance from existing cities and their utility systems. With the advent of mobile home parks, the Midwest has experienced increasing movement away from city centers. These two trends have brought about an increasing need for small capacity waste treatment systems. Too often in the past, mobile home parks and housing developments have utilized separate septic tanks for each unit, regardless of the soil conditions and in spite of limited lateral field areas. Now that developers are being held responsible for providing proper waste disposal and meeting tougher effluent standards, there has been increasing interest in the extended aeration activated sludge treatment process.

Only three extended aeration plants were in use in the United States in 1950; however, by 1963 the number had increased to almost 3,000 (33). The extended aeration process has been used in small factory built plants as well as large municipal installations (6, 12). It has gained in acceptance and use as requirements have grown for a process that can handle varying flows of influents and still produce a high level of treatment. Using this process, biochemical oxygen demand ( $BOD_5$ ) removal efficiencies as high as 95 percent and above have been recorded (7, 23, 36). The extended aeration process can accept periodic

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(intermittent) loadings without becoming upset. Complete mixing of the tank contents and a large aeration volume furnish a stability that few other processes can equal (7, 9).

The extended aeration activated sludge plant is normally designed on the basis of BOD loadings in the range of 10 to 40 pounds per day per 1,000 cu ft of aeration tank volume (7, 22, 35). The aeration period is the longest of any activated sludge process, having design aeration basin detention times of 24 hours or greater. The suspended solids of the mixed liquor (MLSS) will vary from 1,000 mg/l to 10,000 mg/l as the BOD<sub>5</sub> loading applied to the process varies. As the active biological solids undergo endogenous respiration, the slow increase in suspended solids concentration in the mixed liquor allows periodic sludge removal, which often eliminates the need for on-site waste activated sludge disposal facilities.

Extended aeration plants have recently filled a need for high efficiency treatment of small volume wastes from schools, housing developments, trailer parks, institutions, and small communities. They also lend themselves to factory built designs.

The operation and monitoring of an extended aeration activated sludge plant built for a developing community, Timber Creek, near Manhattan, Kansas, is the basis of this research. This treatment plant has operated since the summer of 1972. The main objective of this research was to study operational problems encountered in the initial start-up of an extended aeration plant, and monitor the initial treatment efficiency obtained during that period. In addition, this research studied the

performance of newer system components with respect to the efficiency they contributed to the overall process. Specific components studied were the tube clarifier system, the polishing pond as a final treatment step, aeration by surface aerators, and pre-chlorination of the polishing pond influent.

## LITERATURE REVIEW

### EXTENDED AERATION PROCESS

Extended aeration is a modification of the activated sludge treatment process. Activated sludge consists of a biological floc suspended in a liquid medium containing dissolved oxygen (7). Microorganisms (activated sludge) remove and convert the organic wastes in two stages. In the first stage organic waste is partially oxidized for energy and partially synthesized into new bacterial cells. In the second stage, with continued aeration, the biological cells formed in the first stage undergo self-oxidation for further energy. The resultant end product of this process, therefore, consists of  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , energy, and inert organic residue (23).

Extended aeration proceeds further than the conventional activated sludge process into the endogenous phase since a lower organic loading is used and a longer aeration period is provided (7, 23, 32, 43). With a lower organic loading and a high microbial solids content in the aeration tank, the food to organism ratio (F/M) will be small, and the synthesis of new cells will be compensated to a larger extent by the auto-oxidation of the biomass (23, 36).

Extended aeration of the sludge mass will not completely oxidize all the sludge to carbon dioxide and water, resulting

in some net sludge accumulation. Studies have shown that there will be some biological solids that are relatively inert to biological oxidation and accumulate in the system (3, 7, 22, 23, 25, 30, 36). In a recent study conducted by Gaudy, et al., (15) to determine the length of time biological solids would continue to accumulate before biochemical failure would occur, it was discovered that sludge does not accumulate "ad infinitum." This will be more fully discussed in the review of extended aeration treatment plants.

In well operated units the microorganisms that predominate in the sludge are protozoa, rotifers, and other metazoa (3, 36). Various studies have shown that there will be cycles of growth and reduction of the amount of solids in the aeration tank, possibly caused by cell autolysis, lysis by enzymes produced by other bacteria, cell disruption by bacteriophage, and predacity by higher organisms (15, 36).

#### EXTENDED AERATION TREATMENT PLANT

Normally, extended aeration activated sludge plants are designed on the basis of biochemical oxygen demand ( $BOD_5$ ) loadings of 10 to 40 lb/day/1,000 cu ft of aeration tank volume. With these loadings and an aeration period of 20 to 30 hours, characteristic efficiencies of removal vary from 85 to 95<sup>+</sup> percent (7, 23, 36). Most previous plants have been designed without primary sedimentation and have followed the aeration basin with a separate sedimentation basin that has a 100 percent sludge recycle or greater, long detention times, and low



overflow rates (7, 23). For most efficient operation, extended aeration plants are operated as complete mixing activated sludge systems

A major deficiency of extended aeration has been the problem, encountered by many, of shock loadings and the increase in effluent  $BOD_5$  levels (23, 25, 36). Solids loss to the effluent during periods of hydraulic overload greatly diminishes the efficiency of the process. Maxwell (29) found that the extended aeration process could effectively handle hydraulic shock loadings by converting the influent organic load into bacterial cell mass even during short periods of essentially zero dissolved oxygen. However, he also pointed out that although extended aeration could biologically handle the overload, most associated clarifiers could not.

Periodic sludge wasting has been considered necessary for both eliminating solids build up in the aeration tank and helping prevent deficient effluent quality during periods of hydraulic overloading (7, 22, 23, 25, 36). Sludge wasting has traditionally been accomplished through solids loss in the effluent or a periodic sludge removal process. This accumulation of solids has been considered an inherent characteristic of the extended aeration process (43). Gaudy, et al., (15) contend that this is not necessarily true. They found that by using a properly designed sedimentation basin which did not allow any solids loss in the effluent, the solids would accumulate until there was a period of accelerated autodigestion which relieved the solids accumulation. They theorized that the

decline in solids was not the result of lysis of a portion of the population, but that a portion of the biologically inert volatile solids fraction was metabolized by an organism (or organisms) which adapted to this material. To allow this cycle to continue, there must be diversity of the population and the ecosystem must be a very complicated, ever-shifting one.

Gaudy concluded:

The extended aeration process offers a means of obviating the need for sludge treatment and disposal facilities, and results of the present work indicate that a total oxidation process is not inconsistent with sound microbiological theory.

One must remember that this reasoning would apply only to those wastes which had little or no silt or other inert material present.

One of the most important aspects of the extended aeration process is nitrification and denitrification. On a bench-scale study, Ludzack (22) found that nitrification took place at all temperatures tested, although below 5° C both nitrification and denitrification were very low. At 10° C or greater, complete nitrification may take place. Nitrification is the conversion of ammonia nitrogen to nitrite and nitrate nitrogen which occurs naturally with a large excess of air and low organic loadings. It may be considered both an advantage and a disadvantage of extended aeration. The advantage is that it provides a more complete treatment to the wastewater by removing the ammonia which would still exert an oxygen demand in the receiving water. Denitrification is the anaerobic reduction of nitrate nitrogen to nitrogen gas. Nitrogen gas entrapped in the activated sludge of a sedimentation basin reduces rising

sludge. A decrease in pH in the aeration tank, and rising sludge in the settling basin are the frequent problems associated with nitrification/denitrification (23). Phillai, et al., (36) suggest the following methods to prevent solids loss from denitrification:

1. Control the oxygen levels in the aeration tank.
2. Allow a short detention time in the sedimentation tank.
3. Maintain higher oxygen levels in the sedimentation tank.
4. Use a skimming device to remove the floating sludge for return to the aeration tank.

Coliform removal has always been of extreme interest for varying plant designs. Morris, et al., (33), in a study of two extended aeration plants, observed the coliform reduction to vary from 43 to 99.7 percent. The coliforms in the effluent ranged from a minimum of 2,700 to a maximum of 9,820,000/100 ml. The lowest reduction occurred during periods of storm flow as the increased flow carried solids into the effluent. In another study of the extended aeration sewage treatment plant at Harahan, Louisiana, conducted by Shaver, et al., (43) excellent overall plant performance of coliform reduction was recorded. Coliform reductions before chlorination averaged 95.8 percent (680/100 ml) during a three month study period, while the overall plant reduction, including effluent chlorination, averaged 99.8 percent (16/100 ml). The chlorine residual considered desirable in this study was 0.5 mg/l. Both of these studies indicate that excellent coliform reductions may be expected with the extended aeration process.

## STABILIZATION BY POLISHING PONDS

Numerous studies have shown the need for a final stabilization of the effluent from the sedimentation basin of an extended aeration treatment plant (13, 23, 28, 34, 36, 37, 38, 39). Primarily the necessity of a final effluent with very low solids content is the factor requiring a polishing pond. Additional benefits that are derived from polishing ponds include further reduction of nitrates, coliforms, BOD, and chemical oxygen demand (COD). Also, they provide an excellent buffer during times of overload or deterioration of the aerated effluent (31, 38). Most investigations of polishing ponds describe the problem of algal growth with the characteristic increase in effluent BOD levels (2, 13, 19, 21, 34, 38, 39, 46, 47). At first thought to be a serious restriction to the use of polishing ponds, some researchers have found the algae to provide beneficial treatment that may outweigh the BOD increase problems (11, 27).

Potten (38), Rischke (39), and Pillai, et al., (36) recommend a retention time for polishing ponds of approximately four days. As Potten noted:

It has been found that the reduction in suspended solids and BOD is greatest after a retention time of about four days, but unfortunately this is too short a time to bring about appreciable reductions in nitrate or phosphate.

Fall (13), in experimenting with aeration of a retention pond following an activated sludge plant, discovered that aeration contributed practically nothing to the removal of suspended solids and BOD. He also found that the solids removed underwent

anaerobic fermentation and resulted in a total solids removal of over 90 percent. These digested solids in the bottom of the polishing pond can concentrate to over three percent total solids with no associated odor problems nor removal of scum required. In Britain, Oakley and Cripps (34) described polishing ponds as one method of meeting the high effluent standards required by the River Authority's statutory suspended solids requirements for concentrations of 10 mg/l suspended solids and BOD. However, they stated that short retention times of four days or less, along with algae control would be required. They also contended that the standards were intended to relate to the discharge of activated sludge solids and were inappropriate to the limitation of solids having algal content. In any case, Van Vuuren and Van Duuren (47) found that, through chemical coagulation by aluminum sulfate or excess lime, algae-laden polishing ponds with a seven day retention time were very acceptable to yielding a clear and odorless effluent.

With nitrification and denitrification occurring in the extended aeration process, nutrient removal is of significance. McGriff and McKinney (26), using the symbolic relationship shown in Figure 1, have developed a process they call "Activated Algae." Nutrients are removed as follows:

There are two mechanisms responsible for the removal of nitrogen in the activated algae process, namely, Metabolic assimilation and ammonia stripping. Phosphorus is removed by two mechanisms in the process, metabolic assimilation and biological precipitation.

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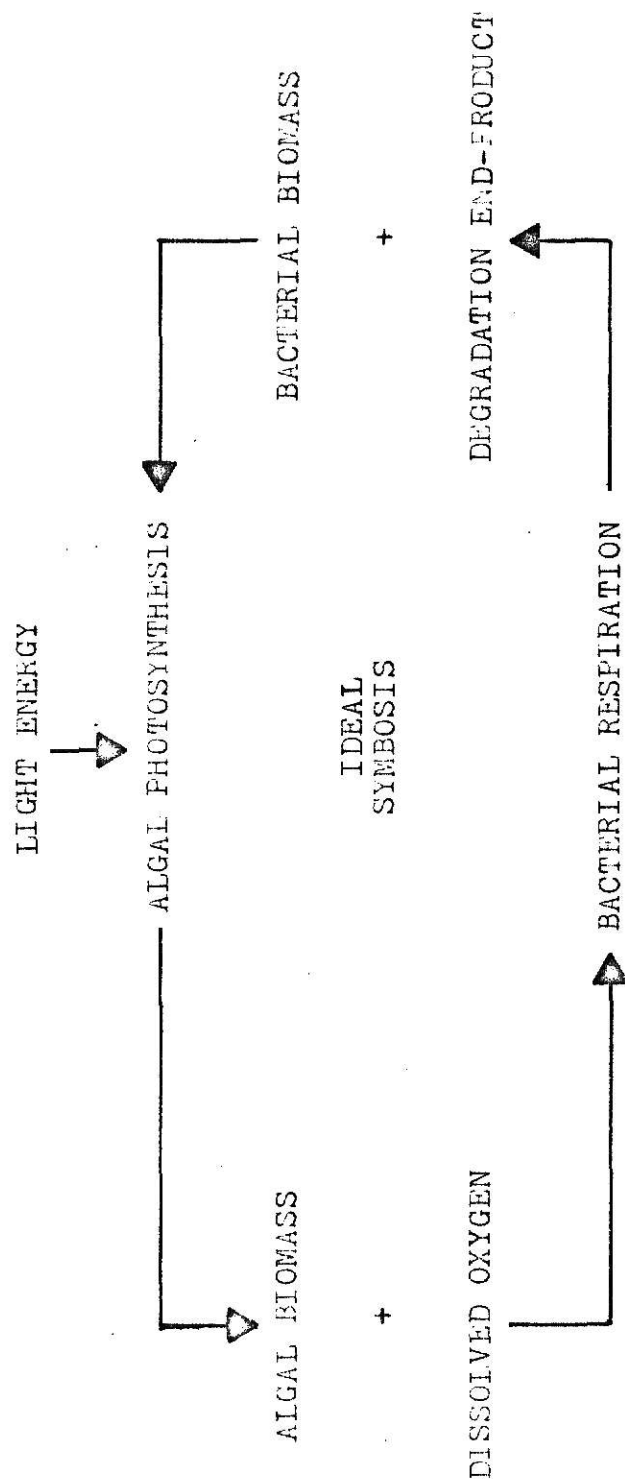


Figure 1. Activated Algae  
[From McGriff and McKinney (26)]

Although the activated algae process is proposed as a secondary-tertiary unit process (24), it describes the treatment taking place at a slower rate in polishing ponds with good algae growths and longer detention times. Bartsch and Randall (2) point out that polishing ponds are greatly affected by the weather and provide very little treatment during the winter months. They suggest design detention times be based on winter conditions.

#### SETTLING TUBES

The basic theory of shallow-depth sedimentation was proposed in 1904 by Hazen (18) who recognized that removal of sediment in a settling basin is primarily a function of the surface area and is independent of detention time. He recommends the use of settling depths of approximately one inch to take advantage of his theory. For more than fifty years many attempts were made to apply his theory to sedimentation basins (8, 17). These designs usually incorporated large numbers of shallow trays generally inserted within basins of conventional design. The two limiting factors in their usage has been the unstable flows encountered with wide, shallow trays, and the equipment and spacing required for sludge removal.

Current sedimentation theory as explained by Hansen, et al., (17) relates that the path a particle takes in a settling tube is the resultant of two vectors:  $V$ , the velocity of flow through the tube, and  $V_s$ , the settling velocity of the particle. Figure 2 shows that as the settling surface is inclined, the settling path of the particle is altered. Since the component



of the settling velocity,  $V_{sh}$ , is parallel to the tube wall and opposite the flow,  $V$ , the resultant path of the particle,  $V_r$ , is toward the tube wall. When  $V$  is greater than  $V_s$ , which is the usual case, the required length of the settling surface reaches a minimum at about 25 to 30 degrees from the horizontal ( $V = 2.5 V_s$ ) and then increases, approaching infinity as the angle of inclination approaches 90 degrees.

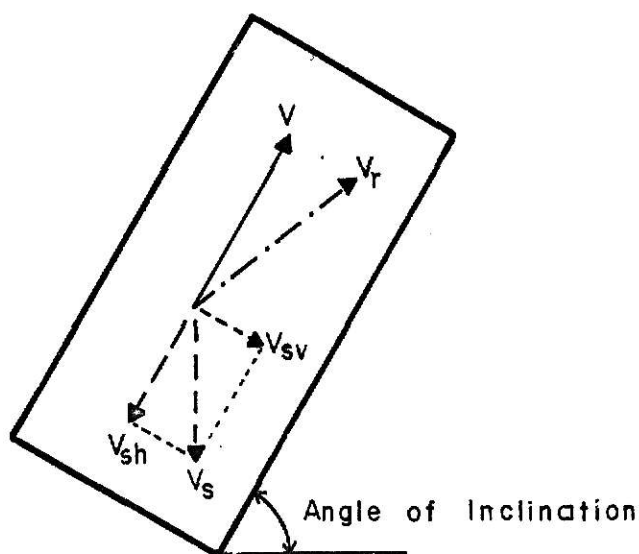


Figure 2. Velocity Vectors

Essentially horizontal tubes, with an angle of inclination of 5 degrees or less were the first to be used in sedimentation basins. Primarily they were first applied to water treatment plants, since they required periodic back washing and this could be incorporated with filter back washing. They also were used as part of the tertiary treatment during chemical clarification of secondary effluents of waste treatment plants. In research done for Neptune Microfloc, Inc. by Culp, et al., (16), tube settlers were found to provide water quality compatible

with the filtration capabilities of the mixed-media filter at filter rates in excess of 5 gpm/sq ft. These tubes were of relatively small diameter (one to four inches), only two to four feet in length, and allowed detention times of six minutes and less. The small-diameter tubes were used to allow proper flow distribution to be maintained at tube-reservoir inlet and outlet conditions. Sludge storage of twenty four hours was normally provided and the tube-cleaning cycle was easily integrated into the wash cycle.

Steeply inclined tubes, a 60 degree angle of inclination, have the advantage over the horizontal tubes in that they are self cleaning. As the solids settle in the tubes a flow pattern is established in which they are trapped in a downward flow system of concentrated solids (8). This continuous sludge recycle is ideally suited for the extended aeration process.

A rectangular module is constructed by inclining 60 degree ABS channels between thin sheets of PVC. By alternating the direction of inclination of each row of channels forming the tubes passageways, the module becomes a self-supporting beam which needs support only at its ends (8). In pilot studies reported by Hansen, et al., (17), tube loading rates of 2 to 3 gpm/sq ft of tube entrance area were used satisfactorily in improving the effluent of a contact stabilization plant. Culp (8) states:

Such tubes have a large wetted perimeter relative to the wetted area and provide a low Reynolds number. A 2-inch diameter tube, 2 ft. long, through which water is passed longitudinally at a rate of 4 gpm/sq ft of tube entrance

area, has a Reynolds number of only 20, while providing an equivalent surface overflow rate of 380 gpd/sq ft.

In Britain, Sparham (45), using wedge wire mesh clarifiers with plastic matrices, found that the suspended solids in settled effluent could be reduced by 90 percent at 1 cu m/sq m/hr and by 70 percent at 3 cu m/sq m/hr for limited periods.

#### TEST AND TREATMENT CORRELATION

Chemical oxygen demand (COD) and volatile solids data have been shown to be more realistic in evaluating the performances of extended aeration treatment and polishing ponds than biochemical oxygen demand (BOD) (22, 30).

Limitations of the BOD test have been set forth by the ASTM as the following:

1. 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 to ultimate oxygen demand.
2. The five day BOD values of different industrial wastes are not additive.
3. Efficiency of a biological treatment process may not be accurately determined on the basis of a five day BOD of influent and effluent.

. . . . For example the expected decreases in BOD values through the raw, primary, secondary, tertiary, etc. scheme of treatment give no indication of these organic compound composition changes (10).

It is of particular importance at this time to review the shortcomings of the BOD test, since this is the guideline used in state and federal regulations for discharge control of treated effluents. As Davis (10) noted, aerobic systems reaeration kinetics have been statistically proven and established for

BOD values. COD, total organic carbon (TOC), and total oxygen demand (TOD) values have yet to be applied specifically for the total evaluation of each of these criteria. He stated the following reasons for variation from the expected BOD curve: presence of oxygen in the bottle, toxic materials in the sample, incorrect temperature (not 20° C), lack of nutrients, insufficient number of bacteria at the start of incubation, waste requiring special kinds of bacteria, nitrification influence, and inadequate dilution. In addition minor deviations in any number of the integral parts of the test procedure may yield erratic results. Davis realized that the expense of TOC and TOD tests prohibits most laboratories from changing to these from BOD and COD tests, so he suggested that the application of BOD and/or COD tests be done with some consideration as to their relevance.

Fitzgerald (14) conducted BOD determinations with different species of algae present in the sample, and found that the results obtained were affected by the algae. He found Chlorella and Gloeotrichia echinulata caused an increase in bacterial respiration. Also, Chlorella and Microcystis were found to photosynthesize after long periods, seven and nineteen days respectively, after the BOD bottles became anaerobic.

Gaudy, et al., (15), in their studies of extended aeration plants, concluded that the COD determination was the best method of evaluating treatment performance. Raschke (39) found the COD test helpful in indicating toxic conditions of a polishing pond, while the BOD test was not. He also stated that both should be

used with caution in respect to the concentration and composition of the algal flora. Loehr and Stephenson (21) also reported the fact that BOD was not an accurate measure of polishing ponds, since BOD removals occurred while no COD removal took place. They concluded that the data indicated the same quantity of chemically oxidizable material entering the pond also left it. If BOD values are necessary for operational reporting methods, Rowe and Canter (40) pointed out that COD and BOD<sub>5</sub> values may be correlated for any given domestic effluent.

## DESCRIPTION OF FACILITIES

### GENERAL

In early 1971, an innovative idea for a proposed housing subdivision was developed. It was to include all utilities, streets, and recreational areas as part of the total development. For increased desirability, it was to be located away from the city and near a picturesque stream. As a consequence, the development needed to include water and wastewater treatment plants.

By late 1971, a site was purchased approximately four miles east of Manhattan, Kansas. The new development was named Timber Creek. An overview and site location is shown in Figure 3. The development was projected to include 72 housing units within two to three years. Therefore, the water and wastewater treatment facilities were designed accordingly. Both facilities were built during the spring and summer of 1972, and were first used in June of 1972. From that time there has been a slow increase in usage from the first home with a family of four people to the present number of 13 homes with 38 people. The usage at this time represents approximately 20 percent of the design load of both plants.

### DESCRIPTION OF WATER TREATMENT PLANT

The main development is located west of Elbow Creek, an intermediate Kansas stream, but the water treatment plant

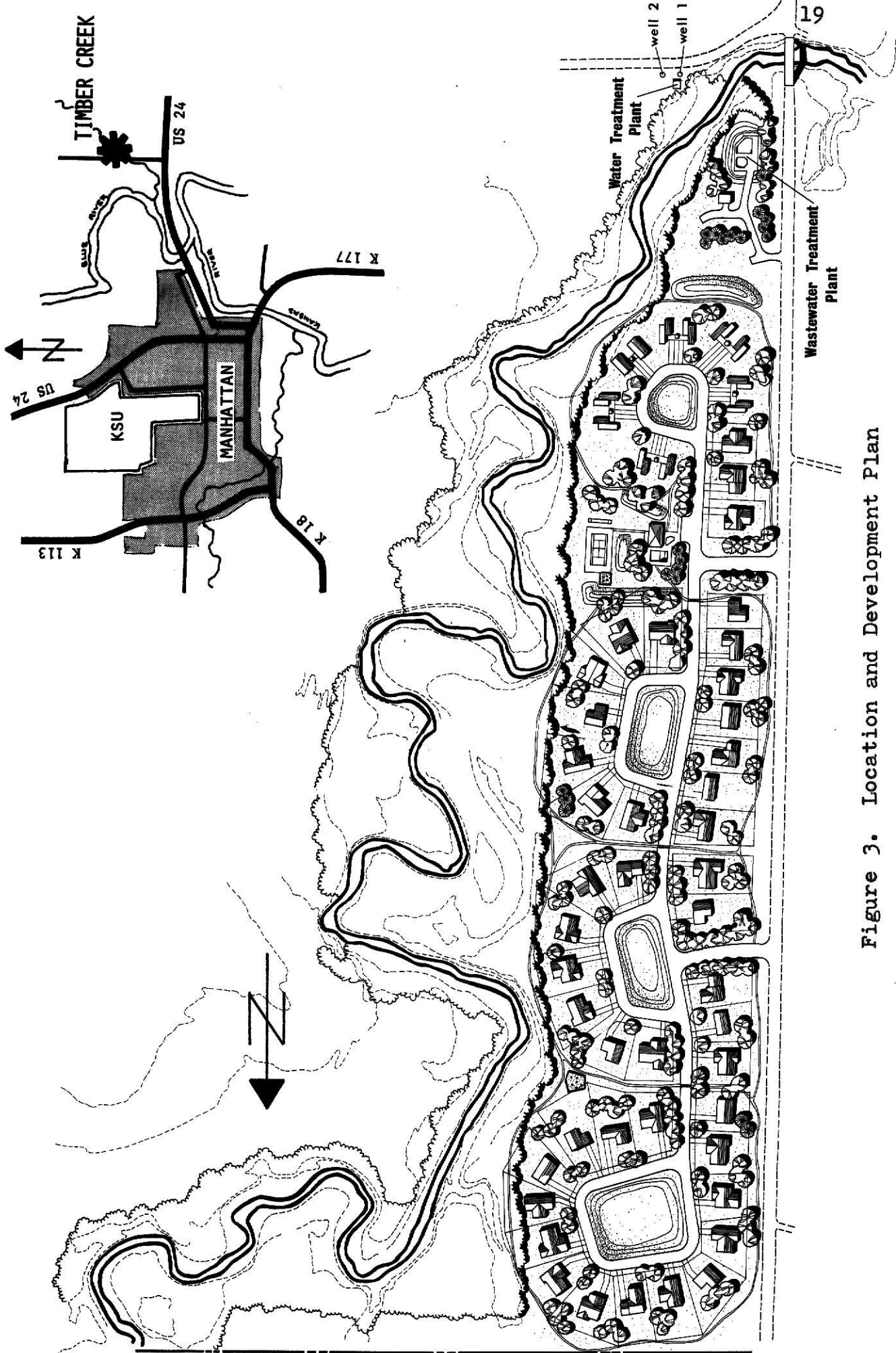


Figure 3. Location and Development Plan

is located across the creek. Location of the best aquifer available dictated this arrangement.

Two wells were dug to a depth of approximately 60 feet. There is a very good aquifer of sand and gravel of about seven feet in depth. Both wells have excellent recharge rates and do not affect each other to any extent. A 3 hp submersible pump is utilized in each well which will deliver at least 60 gpm at 30 psi of pressure. The average water demand was calculated as follows (42):

Assumptions:

3 people per residence  
70 gallons per capita per day

Average water demand:

$72 \times 3 \times 70 = 15,120 \text{ gpd (or) } 10.5 \text{ gpm}$

The maximum day average and the peak hourly flow were calculated in accordance with consumption figures taken from a 1963 report on residential water use carried out at the Johns Hopkins University (20). The maximum daily demand (including lawn watering) for a 72-unit development at a density of four per acre is approximately four times the average flow, and the expected peak hourly flow is approximately seven times the average flow. In summary the following values were used (42):

Average flow	10.5 gpm
Maximum day average	42 gpm
Peak hour on maximum day	73 gpm
Sustained design well pumping capacity provided	120 gpm or 1.67 gpm/residence



The water analysis after 24 hours of pumping indicated the following (42):

Total hardness	390 mg/l
Calcium hardness	300 mg/l
Alkalinity	440 mg/l
Nitrates	nil
Sulfates	20 mg/l
Iron	1.7 mg/l
Manganese	1.6 mg/l
pH	6.75

The hardness of the water dictated that water softening would be required. This is provided by a commercial ion exchange column with brine regeneration. The water flows from the pumps through the softener, then is chlorinated by in-line injection just before the storage tanks. Pressure and storage are provided by four 500-gallon pressure tanks. The brine backwash from regeneration is held in a 750-gallon concrete tank and is slowly released into the creek by a 1/4 inch diameter orifice.

#### DESCRIPTION OF WASTE TREATMENT PLANT

The waste treatment plant employs the extended aeration modification of the activated sludge process. This plant includes effluent chlorination following the activated sludge process and a polishing pond before the effluent is released to the receiving stream, Elbow Creek.

The site chosen for the treatment plant is at the south end of the property, thus allowing the collection system to utilize the natural slope and eliminate any need for lift stations. All state requirements for separations from property lines, wells, and residences are met. The liquid level of the plant is seven feet below natural grade and the area is naturally

screened by trees on three sides with the fourth side being screened by a seven foot constructed earthen berm. The nearest residence is more than 350 feet distant, with plantings and a maintenance building acting as a screen. Therefore, the facility is not visible from the development, nor is there any odor. As of this writing, there has been no odor problem at any time.

Except for operating equipment, the treatment plant was totally constructed on site. A photograph of the plant is shown in Figure 4, and an operational schematic diagram of the unit is shown in Figure 5. Figure 6 shows samples of flow through the plant. This is further described by the following detailed breakdown of the waste flow through the plant.

#### AERATION BASIN

The aeration basin, Figure 7, is constructed of concrete with 8 in. thick walls and a 4 in. thick floor. Eight foot sidewalls are used to allow for conventional basement-type construction. It is rated at 20,000 gallons capacity.

Raw sewage enters directly into the basin via an 8 in. sewer line. There is no pretreatment, and only a wire basket at the inlet, as shown in Figure 8, provides for collection of large solids which might be present in the sewage. The basin was designed on both a 24 hour retention time and on the basis of a  $BOD_5$  loading of 15 lb/1,000 cu ft, which is the Kansas requirement, the latter being the controlling factor. The actual retention time provided for the design flow is 32 hours.

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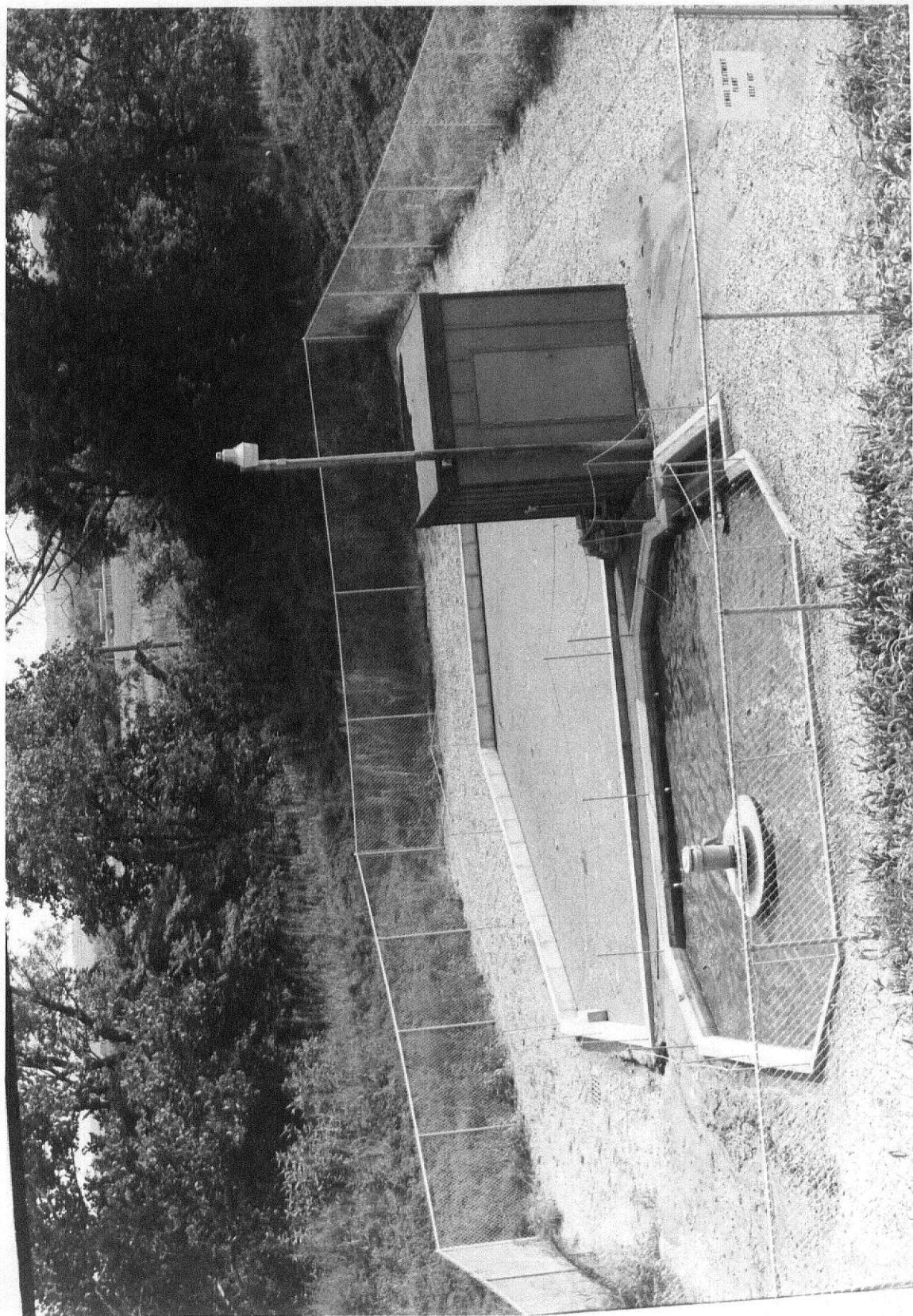


Figure 4. Photograph of Treatment Plant

- 1 Sampling Point of MLSS
- 2 Sampling Point of Aerated Effluent (BCD)
- 3 Sampling Point of Aerated Effluent (Other)
- 4 Sampling Point of Final Effluent

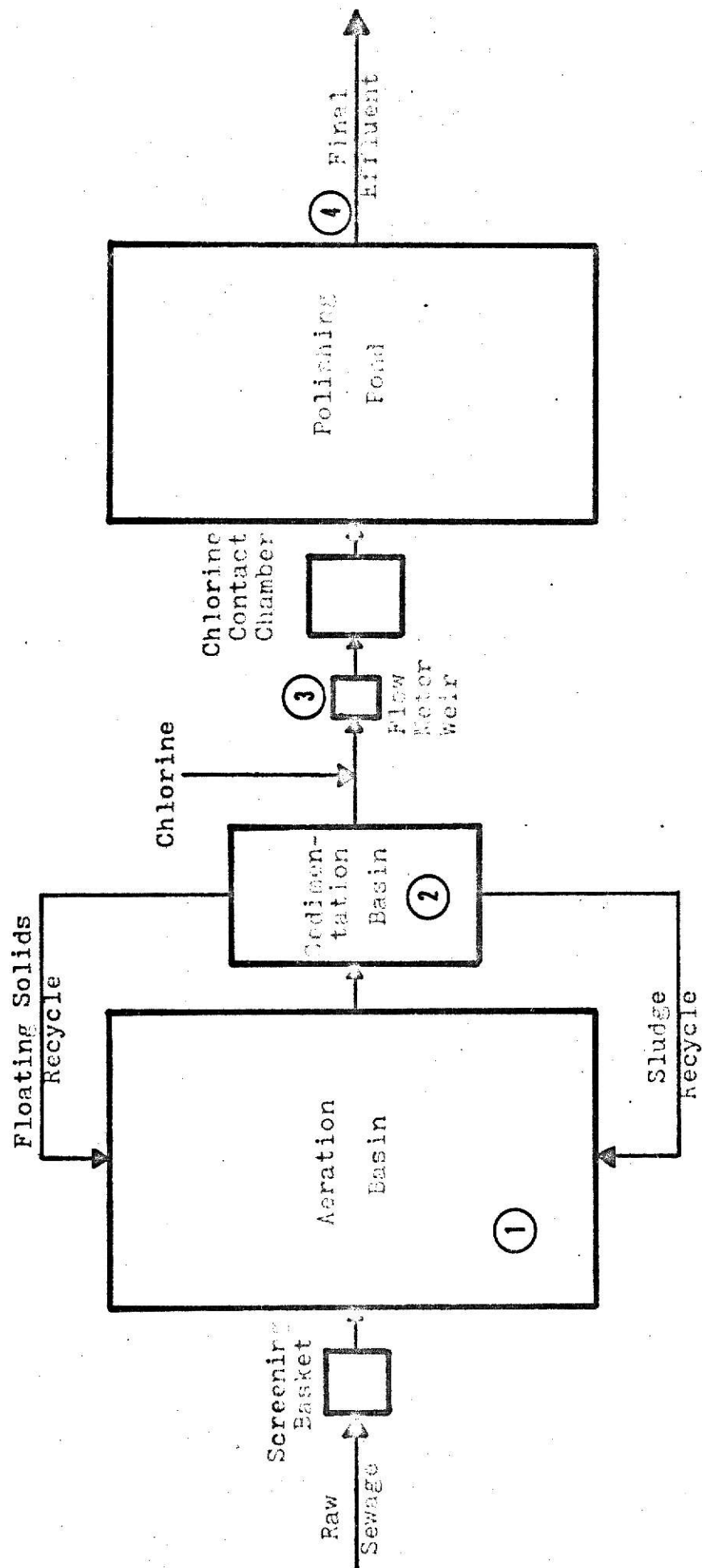


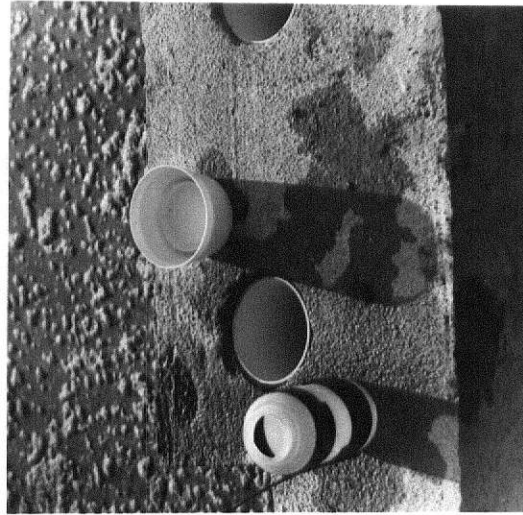
Figure 5. Schematic of Plant Operation



Mixed Liquor



Aerated Effluent



Final Effluent

Figure 6. Flow Samples



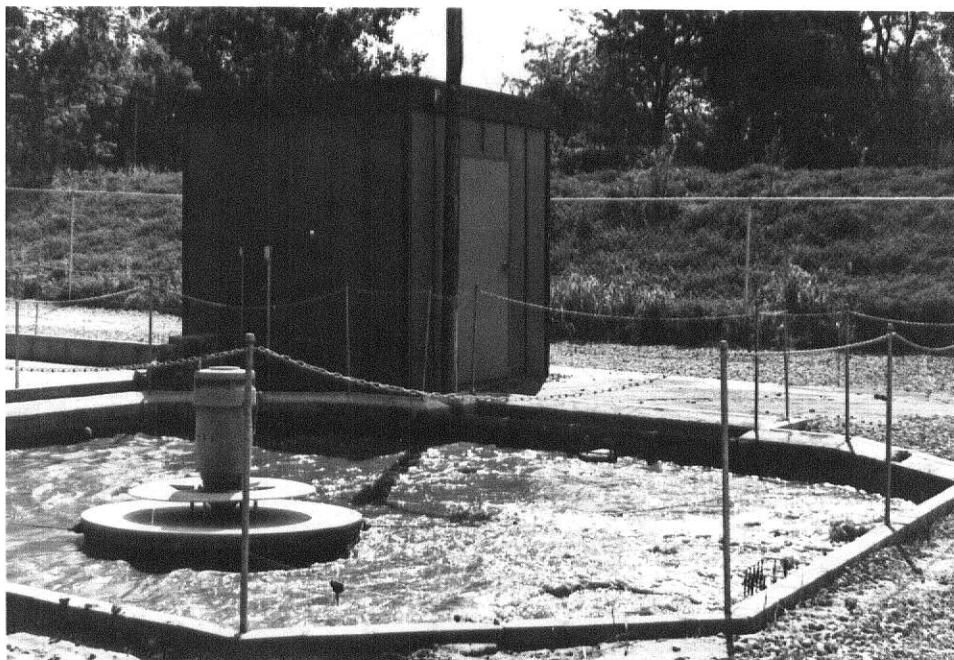


Figure 7. Aeration Basin



Figure 8. Screening Basket

The following is a summary of the design calculations (42).

#### Design Assumptions

3 people/home (total population, 216)

Sewage contribution: 70 gal/capita/day or 15,120 gpd

BOD<sub>5</sub> contribution of 0.18 lbs/capita/day

Aeration tank sized on basis of BOD<sub>5</sub> loading

BOD<sub>5</sub> per day: 216 population x 0.18 lbs/capita =  
39.0 lbs BOD<sub>5</sub>

Volume required:  $39.0/15.0 = 2,600$  cu ft

Aeration tank sized on basis of 24 hour retention

Volume required:  $15,120 \text{ gal}/7.48 \text{ gal per cu ft} =$   
2,000 cu ft

Actual tank volume: 2,680 cu ft or 20,000 gallons  
capacity

#### AERATORS

Two systems of aerators are provided for the aeration basin. There is a single Wells 3 hp Aqua-Lator which is a floating aerator, and a Sutorbilt Blower air compressor with a 2 hp motor, which provides compressed air through simple drilled pipe diffusers. Both systems are shown in Figures 9 and 10. Originally, the floating aerator was designed as the primary source of air, while the air compressor was designed as a back-up system. For reasons that are discussed later, this has been changed so that the reverse is true.

The floating aerator was designed as the primary unit for several reasons. One of the reasons was its simplicity of operation. Maintenance consists only of checking the oil level



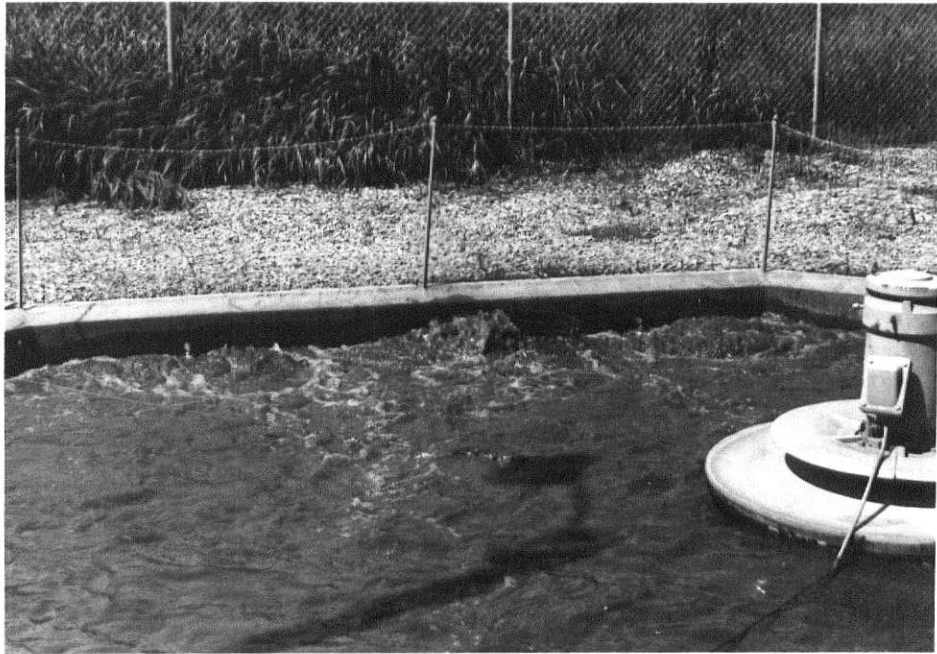


Figure 9. Air Diffusers in Operation



Figure 10. Surface Aerator in Operation

every six months. It also can be easily moved about by its supporting cables. Another reason for choosing the floating type aerator was the problem of the noise associated with the gear reducers required for the slower operating speed of the fixed unit. It was also thought that the floating aerator would provide better mixing than the diffusers, and since mixing is a controlling factor in extended aeration plants, this would insure better operation.

Wells, the equipment supplier, recommends that aerators be sized by a power to volume ratio of .80 hp per million gallons for mixing. Using this criteria, 1.6 hp would be required for this installation. Wells' available units were a 1 hp unit, so the 3 hp unit was selected.

The air compressor unit is housed in the utility building, and is a standard type normally supplied with factory-built waste treatment plants. Three pipe diffusers are provided on each side of the tank, with another diffuser system in the sedimentation basin for cleaning the settling tubes. The aeration tank diffusers are designed to be readily snapped out of position for repair or replacement without lowering the liquid level in the tank. The following is a summary of the design air requirement calculations (42):

#### Surface aerator capacity

Assume 3 lbs oxygen transferred/hp/hr

Oxygen demand (using ultimate BOD)

$$39.0 \text{ BOD}_5 \times 1.5 = 58.5 \text{ lbs BOD}_L$$

$$\text{Oxygen required per hour} = 58.5/24 \text{ hours} = 2.43 \text{ lbs}$$

Horsepower required

$$2.43/3 \text{ lbs oxygen per hour} = 0.81 \text{ hp}$$

The three horsepower provided is sufficient

Diffused aerator capacity

Kansas requirement is 1,500 cu ft/lb BOD<sub>5</sub>

$$1,500 \times 39.0 \text{ BOD}_5/1,440 \text{ minutes per day} = 40.5 \text{ cfm}$$

The Sutorbilt Blower with a 2 hp motor operating  
at 2,000 rpm provides 40 cfm at 3.5 psi

#### SEDIMENTATION BASIN

Sedimentation is provided by the use of Neptune Micro-floc settling tubes, Figures 11 and 12. The basin was constructed as part of the aeration basin and is separated from it by an aluminum baffle. The effluent flows under the baffle and upward through the tubes. As it flows through the 60 degree sloped tubes, the solids settle on the bottom of the tubes and slide to the bottom of the sedimentation basin. This also has a 60 degree sloped smooth surface which returns the solids to the aeration basin, thereby providing for sludge recycle from the clarifier. The effluent then flows to the chlorine contact basin by a submerged collection pipe placed immediately above the tubes. This collection pipe is easily removed so that the tubes may be lifted out when necessary.

Scum recycle to the aeration basin is provided by a scum removal device illustrated in Figure 13. This device uses the velocity currents of the aeration basin to remove scum from the sedimentation basin. It can be seen in operation in Figure 14.

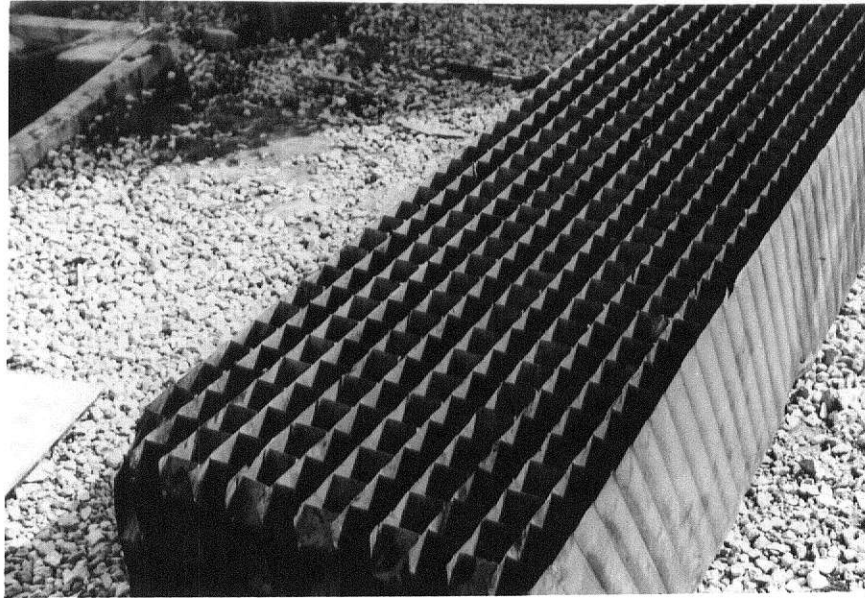


Figure 11. Settling Tubes



Figure 12. Settling Tubes in Place

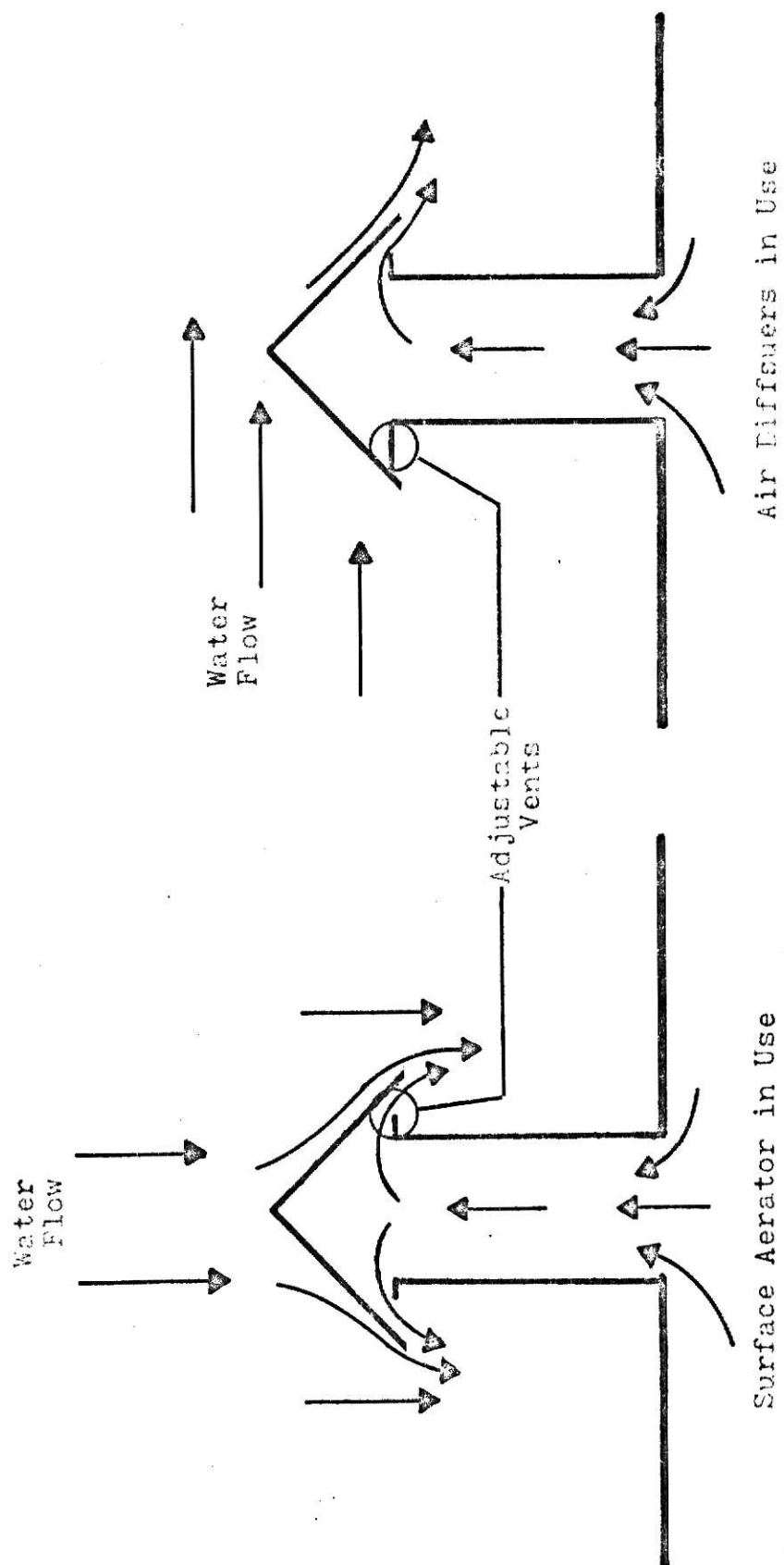


Figure 13. Surface Skimmer

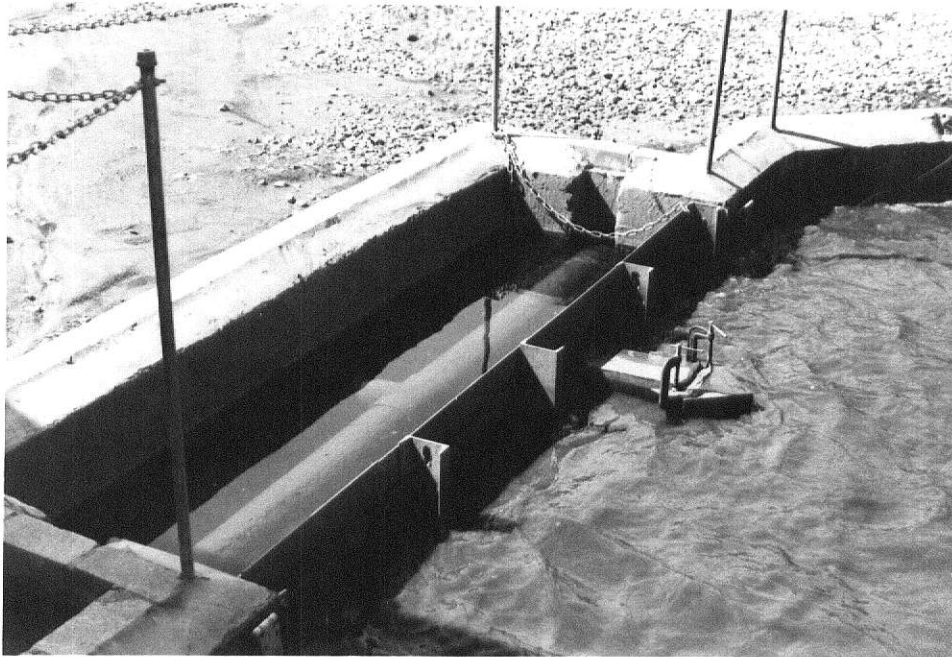


Figure 14. Sedimentation Basin with Surface Skimmer

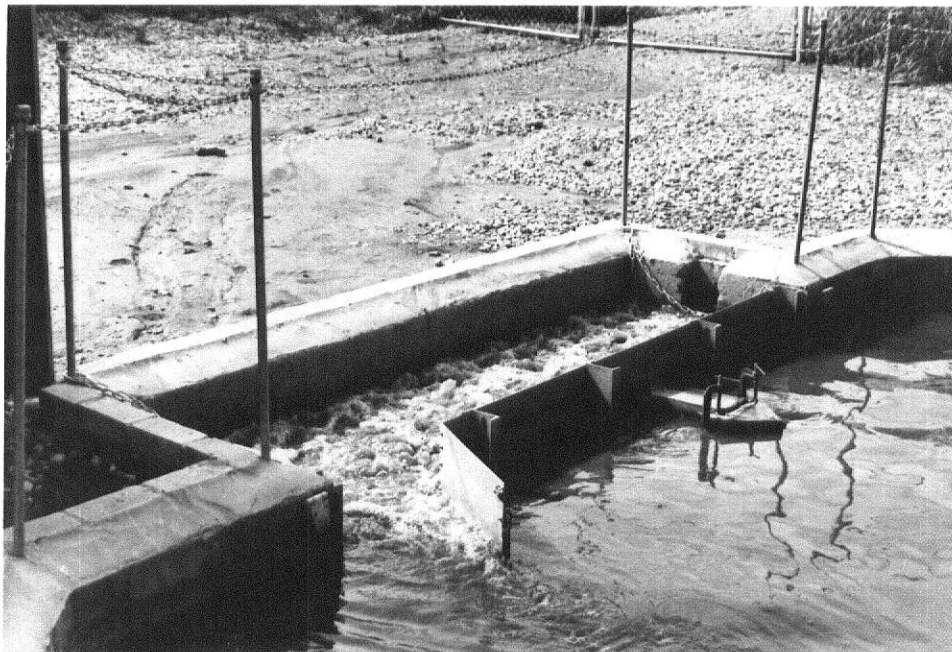


Figure 15. Cleaning of Settling Tubes



Air diffusers under the tubes provide for periodic cleaning. This process is shown in Figure 15. Part of the baffle between the sedimentation basin and the aeration basin opens so that during the cleaning process the flow of solids and water is returned to the aeration basin. During this period, aeration in the aeration basin is ceased. Since the plant design includes a settling pond, solids lost during the wash period are of little concern.

The 8 ft by 2 ft (16 sq ft) tubes were designed for an average flow rate of  $2/3$  gpm/sq ft. Although the recommended hydraulic loading rate is 1 gpm/sq ft, the design rate was decreased, due to higher sidewall interference and the possibility of higher peak to average flow ratios. This design gives a conventional overflow rate of 950 gpd/sq ft or near the 800 gpd/sq ft recommendation when no tubes are used.

#### CHLORINATION FACILITIES

Chlorination is continuous and applied ahead of the polishing pond to reduce the dangers of over-chlorination. The four day polishing pond allows a heavier chlorine dose than normal with ample time for dechlorination. A chlorine solution is injected into the line between the sedimentation basin and the chlorine contact chamber. The chlorination equipment, Figure 16, consists of a small chlorinator, a chlorine solution tank, and a small presolution bucket. This equipment plus the granular dry chlorine are housed in the utility building. The solution was prepared and the chlorine tank filled as described in the section on plant operation under Experimental Procedures. The

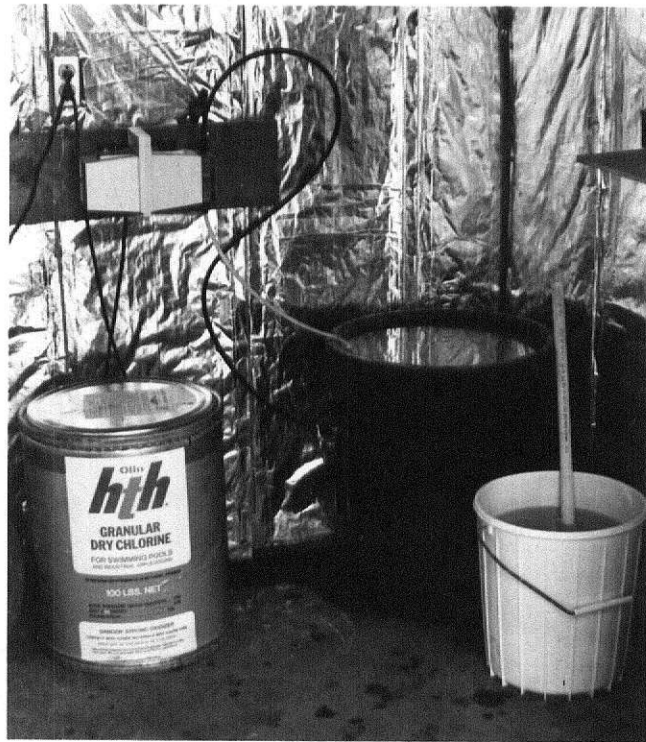


Figure 16. Chlorination Equipment

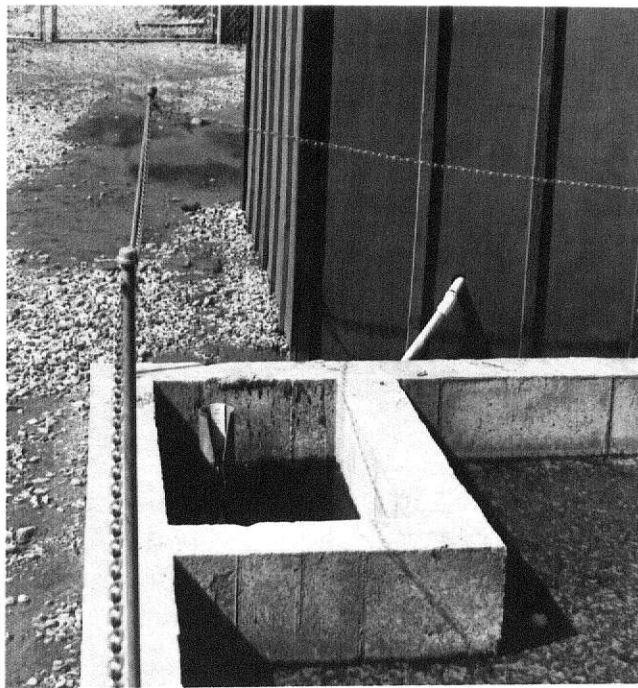


Figure 17. Chlorine Contact Chamber



chlorinator is adjustable so that it will provide a chlorine dose that gives a 1 mg/l total chlorine residual at peak flows.

The chlorine contact chamber, shown in Figure 17, is 2 ft x 4 ft x 7 ft and has a 15 minute retention time for peak flows. With the average design flow of 10 gpm the retention time is 43 minutes. The effluent flows into the contact chamber through a V-notch weir, which provides flow measurement through the treatment plant. Liquid level in the aeration basin may also be controlled by this weir.

#### POLISHING BASIN AND OUTLET

The polishing basin is designed to provide a four day retention at full development flow. It has a concrete bottom with vertical concrete sidewalls to eliminate any shallow areas that would require maintenance by mowing. The primary purpose of the basin is to settle out any biological solids that may pass through the system, although it also yields some additional degree of treatment. A longer retention time was not desirable because of the associated algal growths.

The outlet structure, Figure 18, consists of a 4 in. PVC pipe that has an inlet 15 inches below the water level with a cross-over to another 4 in. PVC pipe at water level. This last 4 in. PVC pipe drains to a storm drain, which has an 8 in. ABS pipe leading to Elbow Creek. Freeze-up is not a problem since the inlet is below the ice and the water is free-flowing through the entire outlet structure. Algal solids are also reduced in the final effluent, since most algae are found near the water surface.



Figure 18. Outlet Structure

## PROCEDURES

## Analytical Procedures and Equipment

## BIOCHEMICAL OXYGEN DEMAND

Five day biochemical oxygen demand ( $BOD_5$ ) determinations were run on (weekly) samples of both the aeration tank effluent and the polishing pond effluent. These samples were tested primarily according to the methods listed in Standard Methods (1). Both effluent samples were aerated for 30 to 45 minutes and an initial Dissolved Oxygen (DO) test was performed on each sample. The samples were aerated using laboratory compressed air and porous diffuser stones in beakers of up to 1,500 ml capacity.

Since only carbonaceous  $BOD_5$  values were desired, it was necessary to inhibit the nitrogenous  $BOD_5$  values. The elimination of nitrification in the  $BOD_5$  determination was accomplished by the method described by Siddiqi, et al., (44). A stock solution of 5 Molar (M) ammonium chloride ( $NH_4Cl$ ) was prepared by dissolving 267.5 grams in a liter of distilled water. Six ml of this stock solution were placed in a 300 ml bottle, yielding a 0.10 M  $NH_4Cl$  (5,350 mg/l  $NH_4Cl$ ) concentration when the BOD bottle was full. By placing the  $NH_4Cl$  directly in the BOD bottle instead of mixing it with the BOD dilution water, a concentration of 0.10 M ammonia nitrogen always was present in the incubated sample regardless of the sample size.

Since the research of Siddiqi, et al., (44) indicated that the sample pH was an important contributing factor in

inhibiting nitrogenous BOD<sub>5</sub>, one half ml of phosphate buffer was added to the bottles that did not contain dilution water. This was done in order to maintain the pH at approximately neutral (pH 7) or slightly below neutral. Bottles that contained dilution water were assumed to already have enough phosphate buffer to maintain an approximate pH of 7.

The dilution water was prepared according to Standard Methods (1) and aerated for several hours with laboratory compressed air and porous diffuser stones. Initial DO determinations were not run on the dilution water, the blank DO at 5 days was assumed to be the initial value. The dilution water was unseeded, and for each set of samples, three blank BOD<sub>5</sub> samples of dilution water were run.

Final DO determinations of the BOD<sub>5</sub> tests were run by the azide modification of the basic Winkler method as described in Standard Methods (1). BOD<sub>5</sub> calculations were arrived at by the direct pipetting method as described by Sawyer and McCarty (41). For direct pipetting the following formula was used:

$$\text{BOD}_5 \text{ (in mg/l)} = \left[ (\text{DO}_b - \text{DO}_i) \frac{\text{vol. of bottle}}{\text{ml sample}} \right] - (\text{DO}_b - \text{DO}_s)$$

In these calculations, DO<sub>b</sub> and DO<sub>i</sub> are the dissolved-oxygen values found in the blanks and the dilutions of the sample, respectively, at the end of the incubation period, and DO<sub>s</sub> is the dissolved oxygen originally present in the undiluted sample.

The equipment used consisted of 300 ml BOD bottles and a Precision Scientific Model 805 incubator.

## CHEMICAL OXYGEN DEMAND

Chemical Oxygen Demand (COD) determinations were run as described in Standard Methods (1, 5) for dilute samples, using 0.025 Normal (N) potassium dichromate and 0.01 N ferrous ammonium sulfate. A 10 ml sample was used for COD levels of 90 mg/l and less. For samples of 90 mg/l to 190 mg/l, 5 ml of sample was diluted with 5 ml of distilled water to retain the 10 ml sample volume. All results thus obtained were multiplied by a dilution factor of 2. Tests were run on all individual samples of both the aerated effluent and the final effluent, with soluble COD run on both periodically. Soluble COD effluent samples were obtained by passing an effluent sample through a Millipore filter and using the filtrate in the COD test.

The equipment consisted of either 200 ml or 250 ml Erlenmeyer flasks, 300 ml pyrex condensers, and a Lindberg Hevi-Duty type heater.

## DISSOLVED OXYGEN

Measurements of dissolved oxygen (DO) were taken periodically of both the aeration tank and the polishing basin. For one period of two weeks a continuous strip chart recording of the aeration tank was taken using a Delta Scientific Model 3410-01 Dissolved Oxygen Analyzer. In June and July of 1973 a YSI Model 51A Oxygen Meter was used to take spot DO readings of both aeration and polishing tanks.

The Millipore filter technique was used for total suspended solids determinations. The Millipore 0.45 micron ashless filter papers were placed in aluminum dishes and then placed in a



Thelco Model 17 oven at 103° C. The filters were placed in the oven for a period of 12 to 24 hours before the effluent samples were taken. After the filters had cooled to room temperature in a desiccator, they were individually weighed on a Mettler Type H6 analytical balance and then placed on the ground-glass filter holder with funnel. A sufficient amount of sample was added by volumetric pipet until the flow through the filter by vacuum became extremely slow. After filtration, the filters were returned to their dish and placed in the oven for one hour. The cooling and weighing procedure was repeated as above to obtain the suspended solids concentrations.

For total fixed solids determination of the aeration tank mixed liquor suspended solids (MLSS) samples, the previously mentioned procedure for total suspended solids was followed, utilizing porcelain crucibles instead of aluminum dishes and ashless filter paper. Following the suspended solids determinations, the crucibles were placed in a Thermolyne Model F-A1730 Muffle Furnace for 15 to 20 minutes. The crucibles were then cooled to room temperature in desiccators and reweighed on the Mettler balance. While the samples were being filtered, the initial weight of the crucibles was determined.

#### NITRATES AND AMMONIA

Nitrate and ammonia determinations were made of both the aerated effluent and the polished effluent. A standard Hach DR-EL Direct Reading Engineer's Laboratory Kit was utilized, following the testing procedure as described in its accompanying instruction manual.

## TURBIDITY

Turbidity determinations were made of both effluents, using a Hach Laboratory Turbidimeter Model 1860. The readings usually were made on the 0 to 100 JTU's scale with occasional use of the 100 to 1,000 scale. A standard of 68 JTU's was used to calibrate the Turbidimeter.

## CHLORINE

Total chlorine determinations were made using a Hach Field Kit and the Orthotolidine method as described in Standard Methods (1).

## COLIFORM ANALYSIS

The Millipore filter method of total coliform analysis was followed as described in Standard Methods (1). The media used for this analysis was M-Endo Broth-MF. Mf-Endo Broth suppresses the growth of most noncoliform colonies, thus aiding in the differentiation between these and the coliform types which exhibit the characteristic, greenish-metallic sheen.

## MICROSCOPIC OBSERVATIONS

Microbial examinations were made using a Bausch and Lomb DynaZoom research microscope at 430X or 100X. A record was kept of the time of appearance and relative abundance of various types of organisms in the mixed liquor. Also the types of solids were noted and an estimate was made of the percentage of organic material in relation to silt. During the algae blooms, determinations of the various algae types and their approximate percentage was attempted.

## FLOW RATE

The flow rate of the wastewater treatment plant was determined from an in-line water meter at the water treatment plant. Since this was a new, developing community with all new water mains and sewer systems, the flow through the waste treatment plant was considered to be approximately the same as the water used. This was considered an adequate means of flow measurement until the summer weather dictated the advent of lawn watering. After lawn watering started, the primary source of flow measurement was a 22.5 degree V-notch weir that measured the effluent from the aerated tank. Readings of flow were taken three times a week and were recorded in thousands of gallons per day.

## Experimental Procedures

### PLANT OPERATION

The daily operation of the wastewater treatment plant was part of the scope of this research project. Initial operation was started at the last of June 1972, with analytical monitoring beginning in November 1972. After the initial start-up problems, described in the discussion of results, operation of the plant required monitoring three times per week. The main operational duties included refilling the chlorine tank, skimming the floating solids off of the settling tank, determining the total chlorine level of the aerated effluent and finished effluent, recording the water temperature of the MLSS, and recording the flow by the V-notch weir. A chlorine solution was prepared by



dissolving two cups of commercial-grade granular chlorine (HTH) in a bucket of water. The solution was left to settle for two to three days until the 15-gallon chlorine tank needed to be refilled. This allowed time for the inert material and calcium carbonate to precipitate. The solution was carefully poured from the bucket, leaving the precipitate. Next the solution was diluted until the chlorine tank was filled. Making a new solution every time the tank was filled allowed the inert material time to settle before more chlorine solution was needed in the tank.

The floating sludge (solids) in the settling tank was skimmed with a hand net and returned to the aerated tank. At the end of May 1973, a self-skimmer was designed and built, and it was then no longer necessary to skim by hand. Except for the above-mentioned maintenance, the treatment plant was largely self-operating.

#### SAMPLING TECHNIQUES

For the first two or three weeks the collection of samples varied until a routine was established. Figure 5 shows the location of the various sample collection points. All samples were collected in either 500 ml or 1,000 ml Nalgene bottles. Usually the samples were collected in the morning and the tests conducted later in the same day. However, occasionally tests were not conducted until one or two days after the sample had been collected (4). After transportation to the laboratory, all samples were refrigerated at 4° until examinations were made.

Originally, the BOD samples of the aerated effluent were taken from the V-notch weir; however, within the first month of sampling the BOD samples were taken by immersing a grab sample bottle above the settling tubes. This technique was employed so that chlorination of the samples could be avoided. When there was an ice cover above the settling basin, the BOD sample was taken from the V-notch weir and treated as described in Standard Methods (1) for samples containing residual chlorine compounds. Samples of the mixed liquor were taken by grab sample at approximately the same location every time.

Single determinations of total suspended solids, nitrates, ammonia, and turbidity were made of both the aerated effluent and the final effluent. Three determinations were made of  $BOD_5$ , COD, and total coliform content of both effluents. Single determinations of the suspended and fixed solids, settling characteristics, and microbial activity of the mixed liquor were made.

The laboratory glassware and the sample bottles were cleaned in hot detergent water and rinsed with hot tap water. The glassware was then rinsed two or three times with distilled water and left inverted to dry. All pipets and burets were soaked in chromic acid for at least 24 hours and rinsed completely with cold tap water, then rinsed again with distilled water before being left inverted to drain and dry. Pipets and burets were also rinsed with distilled water just prior to use. Standard chemical solutions were prepared as specified in Standard Methods (1).

## RESULTS AND DISCUSSION

### GENERAL

Since this research involves the operation and monitoring of an extended aeration treatment plant, this work will present the results of data gathered, along with a discussion of results. Also included will be a summary of development of the plant, presenting problems which arose and solutions which were reached.

Biochemical oxygen demand (BOD) loadings of the treatment plant were calculated using the design assumption of 0.18 lbs per capita per day of BOD<sub>5</sub>. As mentioned in the section on experimental procedures, flow measurements through the plant were taken from the V-notch weir and were also estimated from the water meter at the water treatment plant. To arrive at an accurate estimate of sewage flow per person per day, the water consumption for the winter period of January 8, 1973, to April 30, 1973, was used as representative of the sewage flow. It was assumed that all water use during this period would be for domestic purposes. The calculated water use was 55 gal per capita per day. This value was used for all calculations of results, and was in fairly close agreement with the spot readings taken from the V-notch weir.

Basically, the discussion may be divided into four areas: start-up, winter operation, spring (thawing) operation, and warm weather operation. Discussion of start-up will include

the initial use and filling of the plant, covering the time period of June 1972, to the first cold weather during the last week of November 1972. Winter operation will include the cold weather operational time period from the last of November 1972, until the middle of March 1973. Spring operation involves the period of transition between cold weather operation and warm weather operation and spans the time period from middle March 1973, until the first of June 1973. The last time period of June 1973, until the present is included in the warm weather operation discussion. Therefore, the total time frame of discussion is from June 1, 1972, until early August 1973. Experimental procedures were not started until mid November 1972, so all discussion for the period prior to that time will be speculative. This researcher has had operational control of the treatment plant from early November 1972, until present, and conducted all experimental determinations until mid May 1973. From the first of June 1973 until present, another candidate for Master's Degree has conducted all experimental determinations. The latter's experimental determinations include evaluations of the aerated and final effluents only, with no determinations run on the mixed liquor.

#### START-UP OPERATIONS

The wastewater treatment system was first used in June of 1972; the applied load consisting of one home with four occupants (see Table 1). The treatment plant was filled with water and an initial operational check of the aeration equipment was made. Thereafter, the aeration equipment was operated

Table 1. BOD<sub>5</sub> Loadings and Retention Times

Date (1)	Population (2)	Flow (gpd) (3)	BOD <sub>5</sub> Loading (lbs/1,000 cu ft/day) (4)	Air Required (cfm) (5)	Detention Times			Settling Rates (gpm/so ft) (9)
					Aeration Basin (days) (6)	Polishing Pond (days) (7)	Chlorine Chamber (hrs) (8)	
June 72	4	220	0.3	0.75	91	273	45	0.01
Aug. 72	8	440	0.5	1.50	45 1/2	137	23	0.02
Sept. 72	14	770	0.9	2.63	26	78	13	0.03
Nov. 72	16	880	1.1	3.00	23	68	11	0.04
Dec. 72	20	1100	1.3	3.75	18	55	9	0.05
Jan. 73	26	1430	1.7	4.87	14	42	7	0.06
Mar. 73	32	1760	2.1	6.00	11 1/2	34	6	0.08
July 73	38	2090	2.6	7.12	9 1/2	29	5	0.09
Design	216	15,120	14.5	40.50	1 1/3	4	2/3	0.67

intermittently, approximately twice per week for two hours until September 1972, when it was used full-time. Since the starting load was about 0.3 lbs of  $BOD_5$ /1,000 cu ft/day and the aeration tank was not seeded, the plant operated as two large holding basins or sewage lagoons. For most of this period, until November 1972, there were no experimental determinations made on the effluents.

The initial detention times of the aeration basin and the polishing pond were 91 days and 273 days, respectively. The chlorine chamber had a contact time of 45 hours and the settling tubes were loaded at a rate of 0.01 gpm/sq ft of entrance area, (see Table 1). In August 1972, the number of users increased to eight; it increased to fourteen in late September 1972, and remained at that level until late November 1972. Therefore, the  $BOD_5$  loading with first full-time aeration was 0.9 lbs of  $BOD_5$ /1,000 cu ft/day, and the detention time in the aeration basin was 26 days.

When the treatment plant was constructed, earthen berms were built around it. These berms served two purposes: first, they lowered the elevation of the plant to allow for more grade relief for the sewer system; second, they helped provide protection from periodic flooding. The berms were seeded with Fescue grass for permanent cover, and rye grass for temporary cover. The fall of 1972, was extremely wet, and before the seed could take root, the area received a very heavy rainfall which washed much dirt and silt into the aeration basin. The amount of silt in the basin was great enough to restrict water movement. With

little volatile suspended solids present in the mixed liquor (MLVCS), there was minimal flocculation and very little settling of the suspended solids. Since a large amount of suspended solids was passing into the effluent, it was decided to let the aeration basin settle for one day and then pump out as much of the silt as possible. As the basin was emptied, it was flushed with water for six to eight hours and then refilled. This took place in mid October 1972.

Two weeks later on November 9, 1972, another large rain storm added more silt to the aeration basin. At this time it was concluded that the height of the side walls of the aeration basin should be raised. In mid November 1972, concrete bricks were laid on the walls in order to add approximately four inches of additional height. Improvements were made in the drainage around the aeration basin, and the pumping process of the previous month was repeated. After the silt was removed, the basin was again filled with water and ready for operation. In Figure 19, the mixed liquor suspended solids (MLSS) and the percent volatile are shown before and after the last flushing in mid November 1972. This was the last time the tank was drained and flushed, although in mid January 1973, the run-off from a heavy snowfall again washed some silt into the basin.

At the end of the start-up period, and the beginning of the recorded data,  $BOD_5$  and the chemical oxygen demand (COD) of both effluents were extremely low. This is shown in Figures 20 and 21. This excellent level of treatment was due primarily to dilution, rather than aerobic digestion. In the total

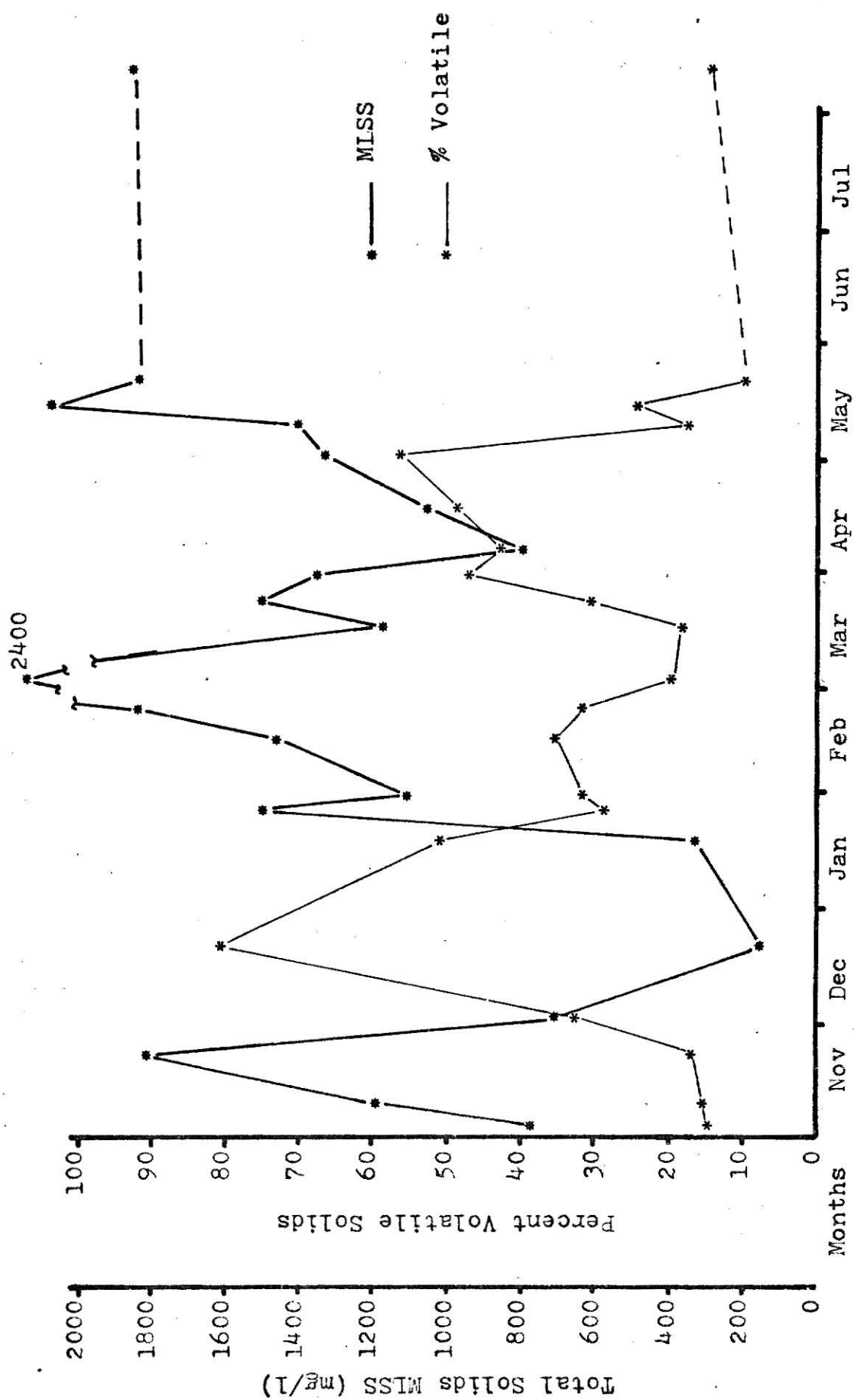


Figure 19. MLSS and Percent Volatile Solids



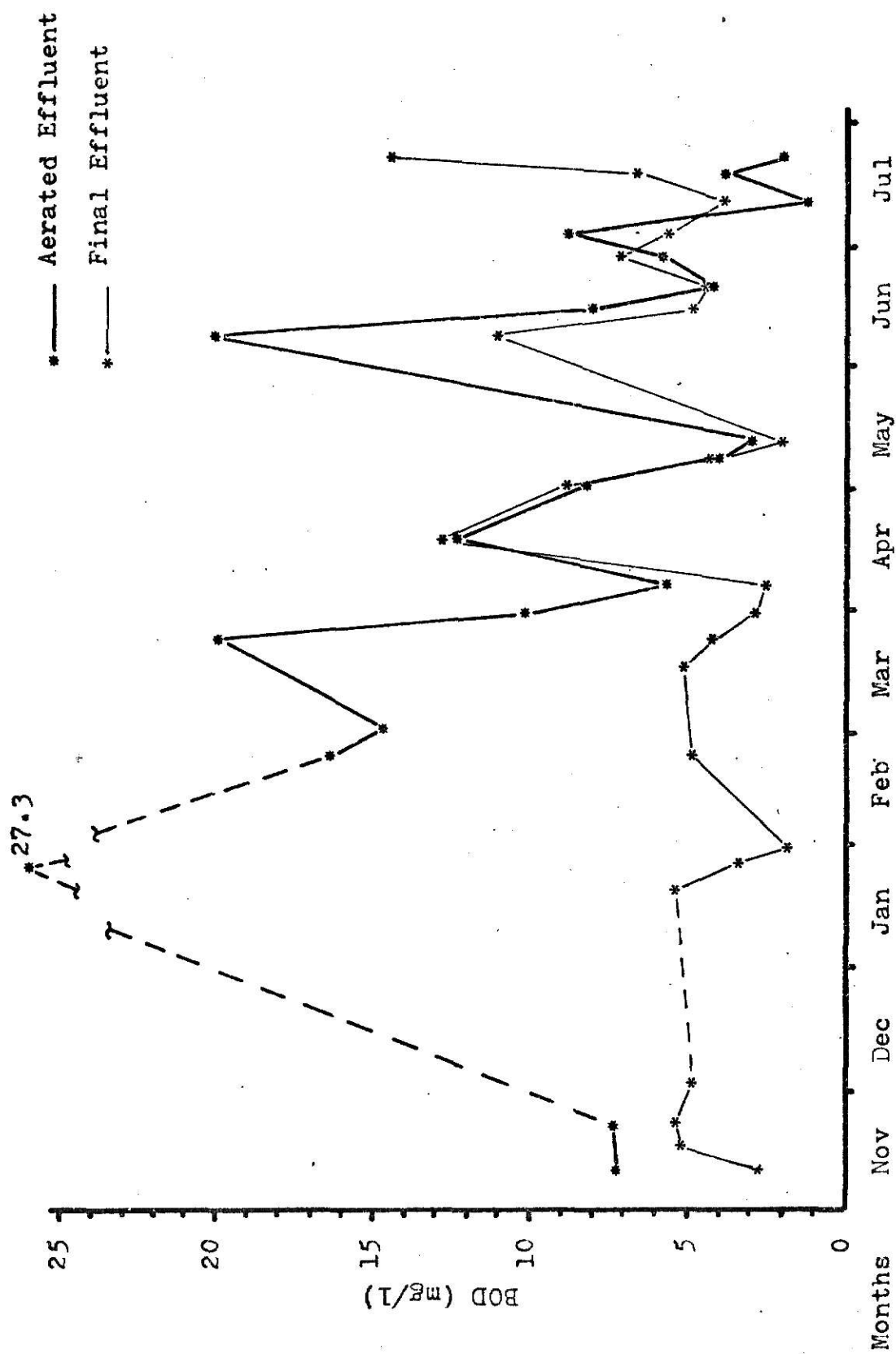


Figure 20. BOD Aerated and Final Effluents

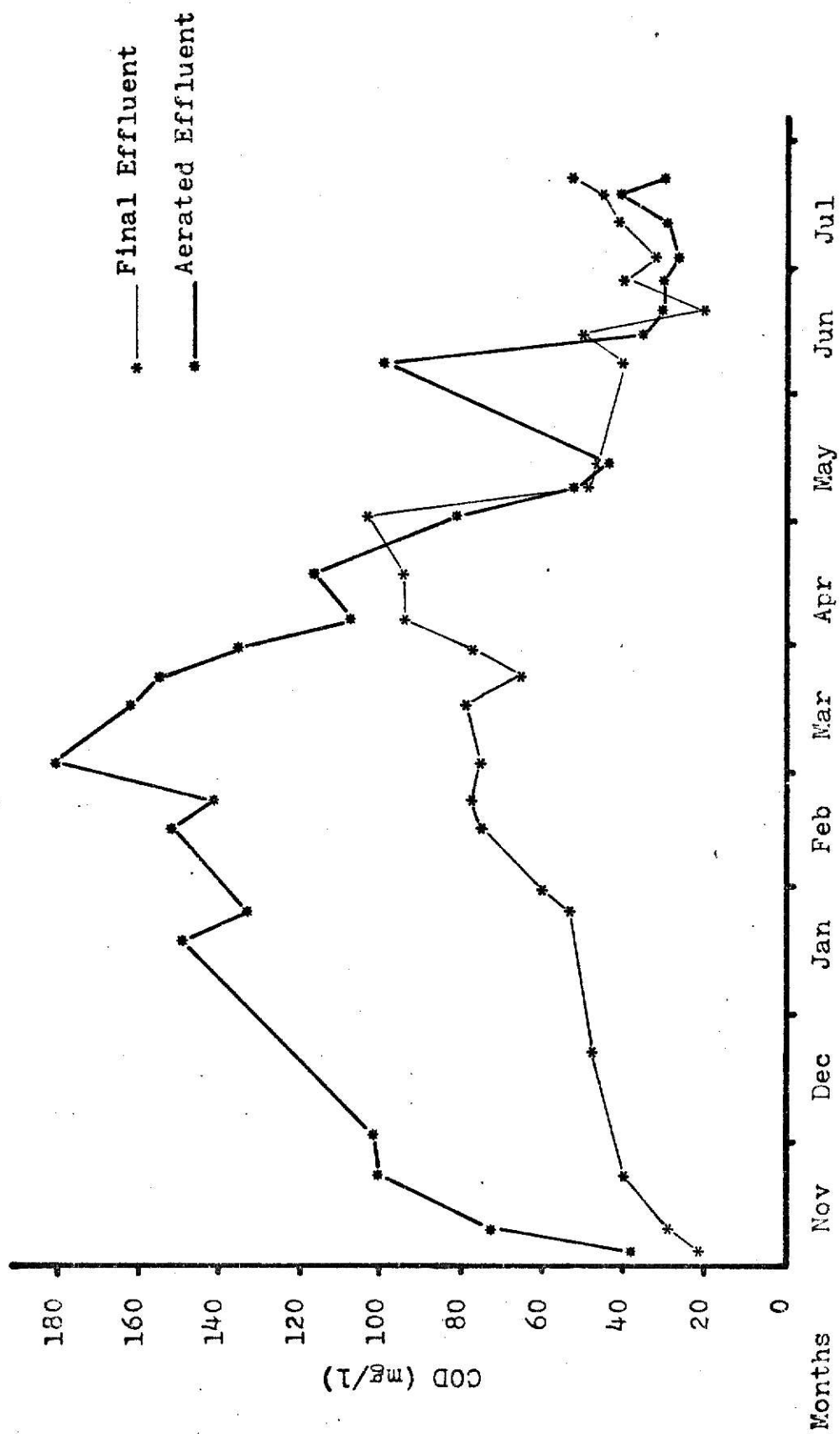


Figure 21. COD Aerated and Final Effluents

start-up period there was very little biological growth, and the biological population, if any, was very primitive.

#### WINTER OPERATION

The first heavy snow occurred on November 16, 1972, and air temperatures dropped about 15° F the following week. From this time until the middle of March 1973, the temperature stayed near freezing. This was an exceptionally cold winter with three very cold periods during which air temperatures were constantly in the range of 0° F to 10° F. The effect on the temperature of the aeration basin may be seen by the recorded water temperature in Figure 22. During most of this time both the polishing pond and the settling basin had an ice cover, with a thickness of up to four to five inches from the middle of December until mid February.

As shown in Table 1, the population of Timber Creek increased from 16 in November to 32 by March. Accordingly, the BOD<sub>5</sub> loading went from 1.1 lbs of BOD<sub>5</sub>/1,000 cu ft/day to 2.1 lbs of BOD<sub>5</sub>/1,000 cu ft/day by the end of the winter period. Also, the aerated basin detention time decreased from 23 days to 11 1/2 days. During the entire period the biological activity increased very slowly. It must be remembered that within two weeks after the last silt removal from the aeration basin, the first of the very cold weather began. Biological treatment was actually very poor until mid March when rotifers and stalked ciliate began to appear. Both had been present in the mixed liquor in the early fall, but were washed out with the silt and did not reappear until March. Sludge volume

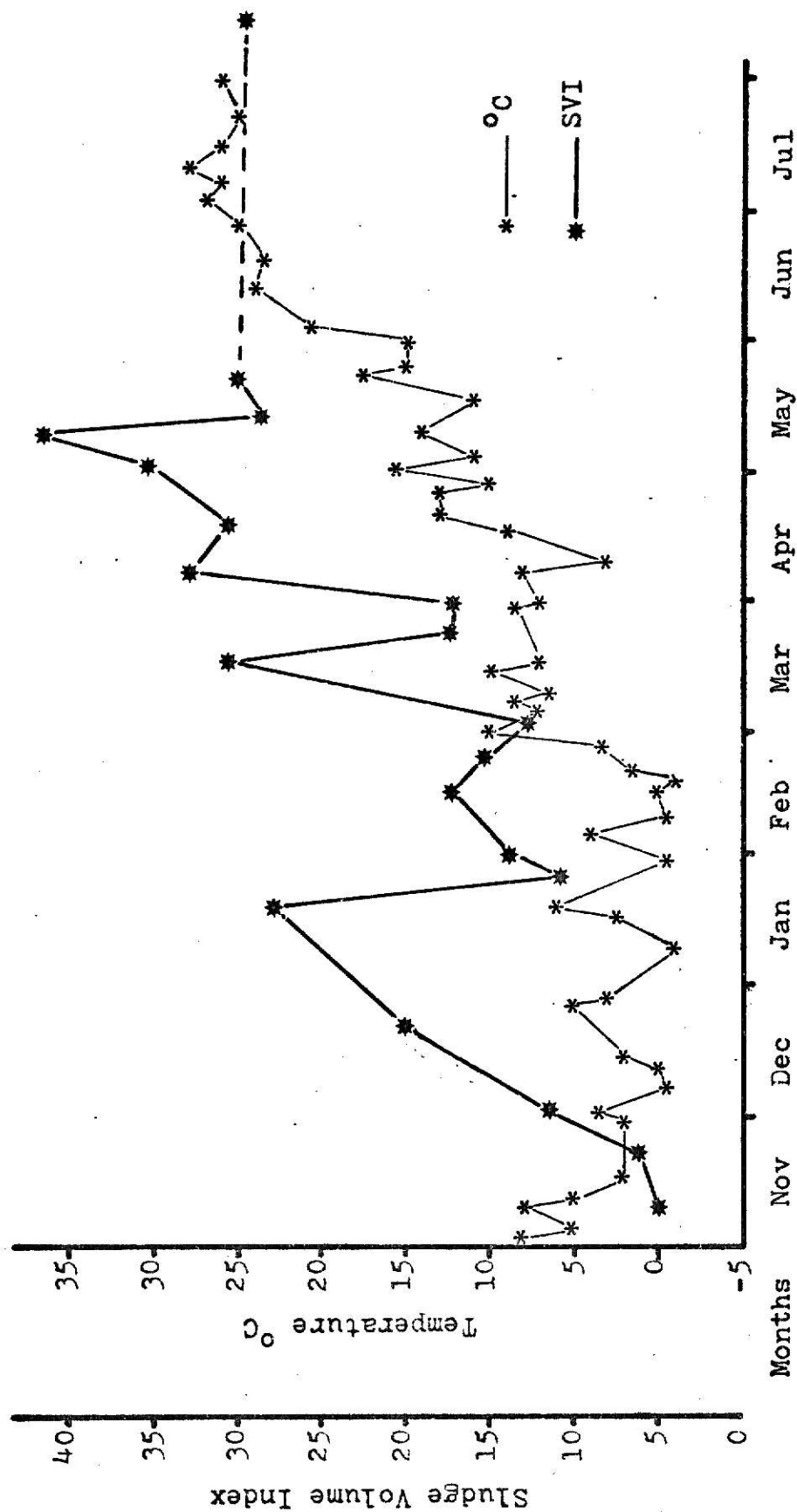


Figure 22. Sludge Volume Index and Temperature of MLSS

index (SVI), a good indication of the slowly building biological population, is shown in Figure 22. Through most of January the ammonia level in the aerated effluent rose steadily, reaching a peak of 14.3 mg/l, which indicated that there were no nitrifying bacteria available to oxidize the ammonia to nitrites and nitrates. After the end of January the nitrate level increased, and conversely the ammonia level decreased rapidly (see Figures 23 and 24). Microscopic examination verified the presence of a fast-growing biological population.

Even with very little biological activity, the effluent appeared cleanest during the period of January 18 through 30, 1973. It had a sparkling quality suggestive of a clear mountain stream. The  $BOD_5$  of the final effluent was below 5 mg/l and less than 2 mg/l for a short period. The COD remained at about 50 mg/l during the same period. There were essentially zero suspended solids (see Figures 25 and 26).

The major problems encountered during this period were directly related to the severe weather. Everything froze solid with a thick ice cover except the aeration basin. The greatest surprise came when the surface aerator froze solid during the first cold weather in December. This occurred while the ice shield was in place! In late November when the temperature of the mixed liquor had decreased to  $2^{\circ}\text{C}$ , the air diffusers were used rather than the surface aerator in an effort to raise the temperature. By mid December, during a period of  $0^{\circ}\text{F}$  to  $10^{\circ}\text{F}$  air temperature, the surface aerator was used again for better circulation in the basin since ice had started to form while

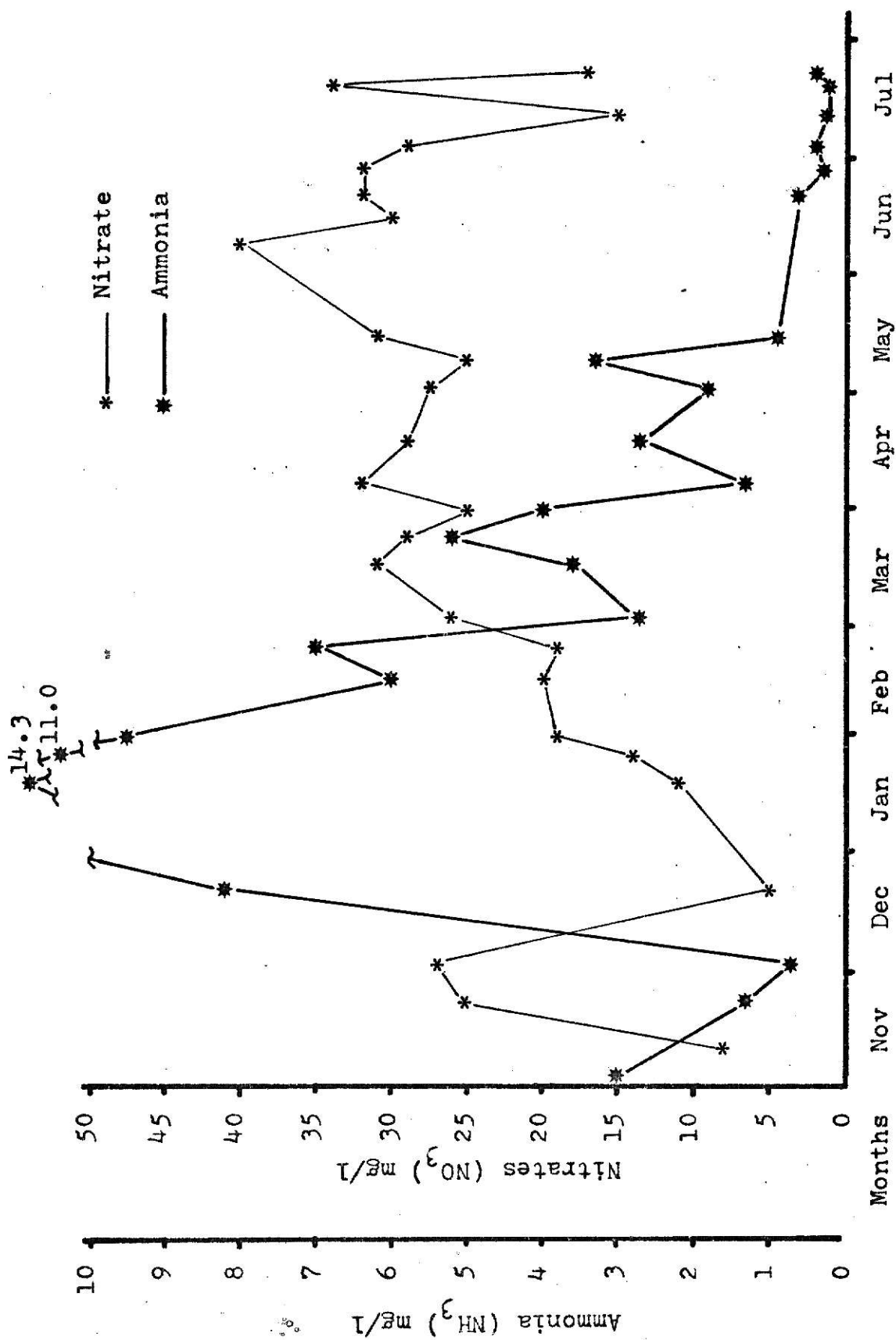


Figure 23. Ammonia and Nitrates Aerated Effluent

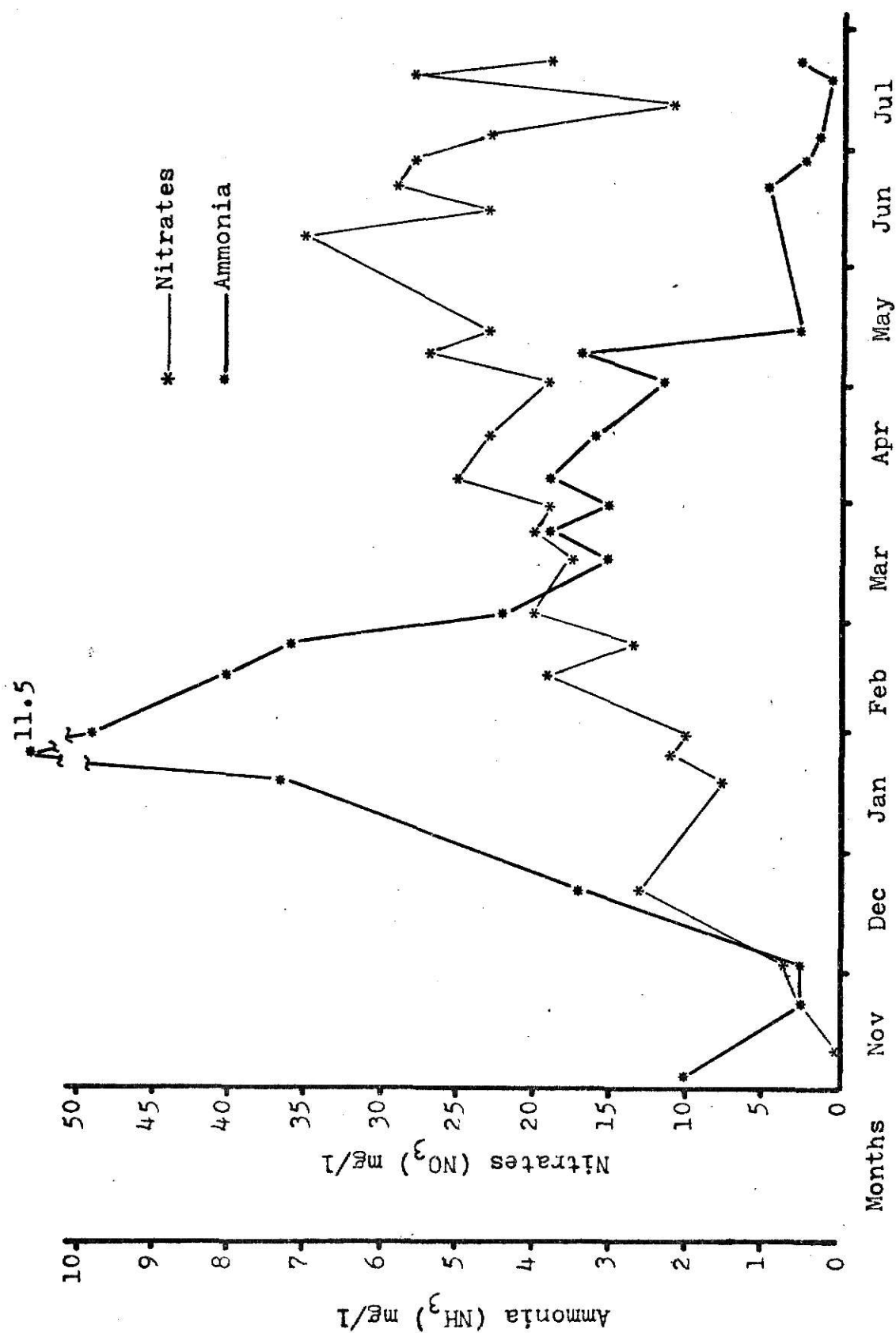


Figure 24. Ammonia and Nitrates Final Effluent

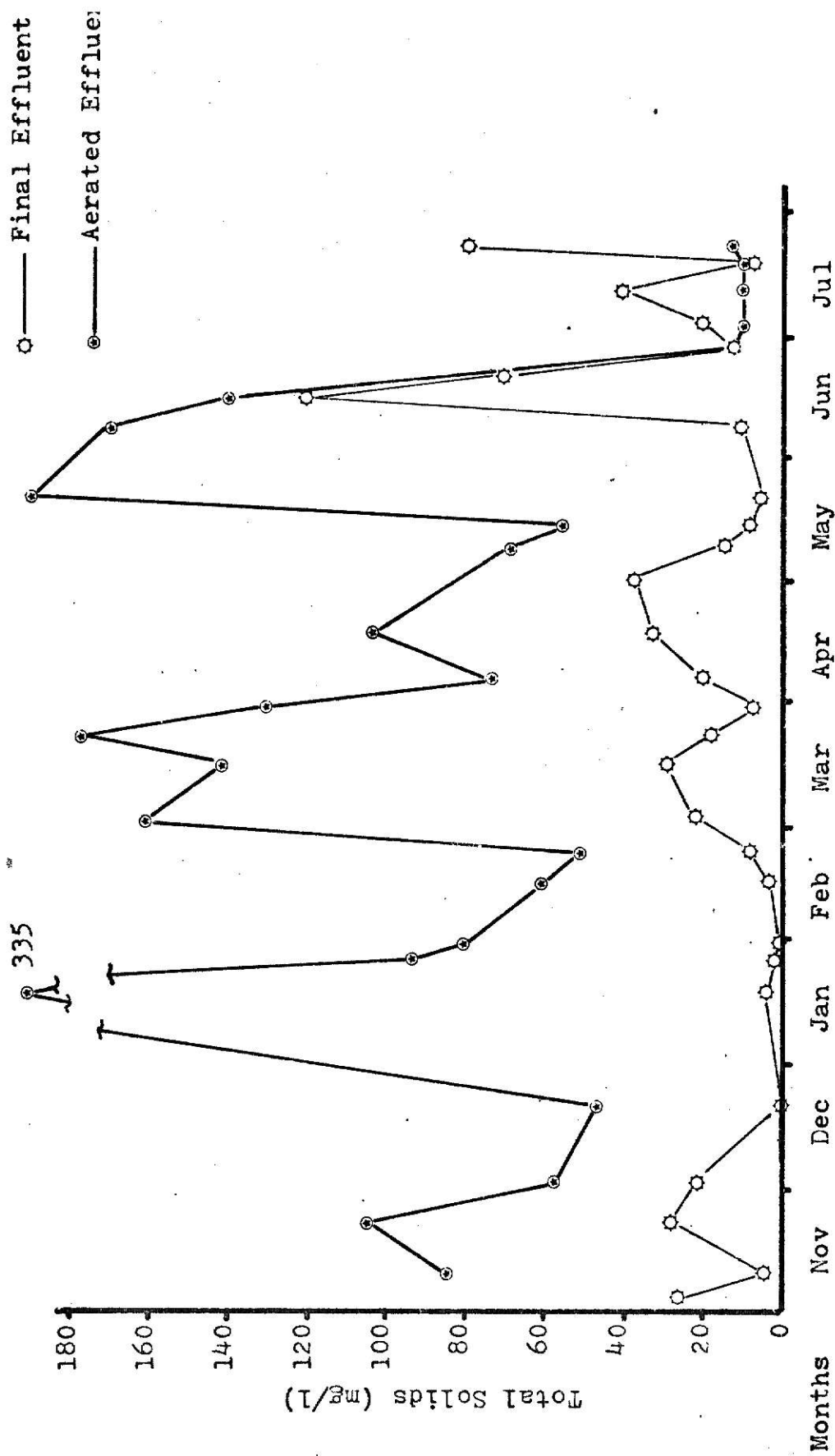


Figure 25. Total Solids Aerated and Final Effluent



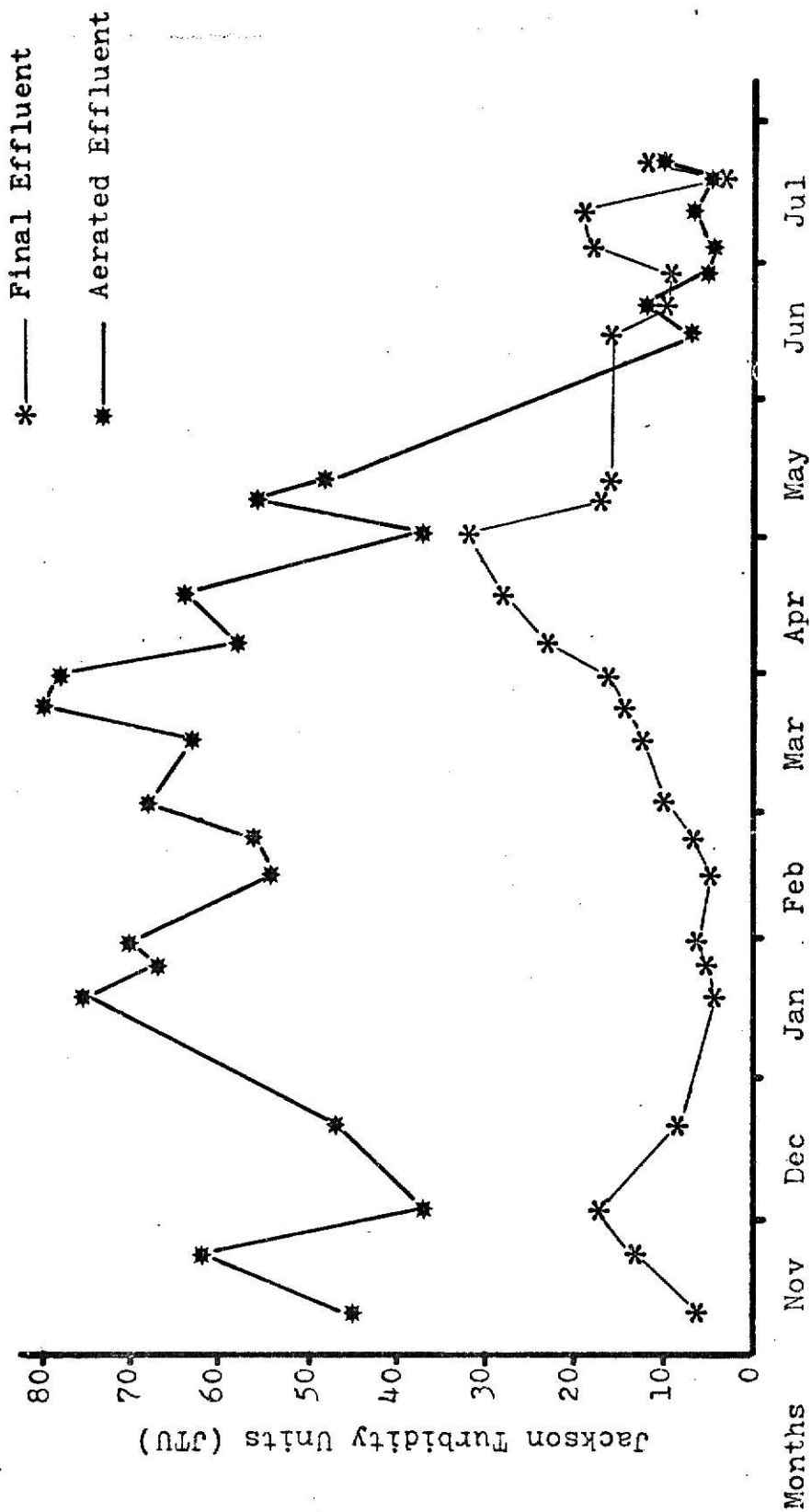


Figure 26. Turbidity Aerated and Final Effluents

using the diffusers. Overnight the aerator iced over, closing the throat completely and stalling the motor. The air diffusers were then utilized until warm weather returned.

As the situation was analyzed, major contributing factors were thought to be the very low biological population and the long retention time with the mixed liquor not receiving sufficient energy or heat from the sewage flow. Another contributing factor may have been that the aerator was grossly oversized for the basin and its  $BOD_5$  loading. If the aeration basin had been closer to its design load with the biological organisms providing energy to the mixed liquor, the surface aerator would probably have operated without difficulty. The freezing of the aerator is an important consideration for future designs.

Another difficulty that could have caused serious problems was the solid ice cover on the settling basin. Because of the low biological growth there was essentially no nitrification taking place during this time. However, in future winters with a large food supply and good biological activity, floating sludge trapped below the ice cover could cause serious problems in the settling basin. There is a reasonable question whether the water movement through a surface skimmer would be sufficient to prevent freezing. It would seem that an air diffuser system would be a necessity in locations which are subject to prolonged freezing temperatures.

#### SPRING OPERATION

The time period encompassed by spring operation started in mid March with the return of warmer weather and lasted until

the end of May. During this entire period the biological organisms were increasing in number and gaining in complexity. By May the mixed liquor would readily floc, and the sludge volume index had increased from 12 to 30 (see Figure 22). The organic loading remained constant at 2.1 lbs of  $BOD_5/1,000$  cu ft/day. The retention times of the aeration basin and polishing pond also remained constant at 11 1/2 days and 34 days, respectively. There was no odor from the waste treatment plant detectable at any time.

The record of total solids in the aerated effluent, shown in Figure 25, is a good representation of the problems associated with the sedimentation basin. They varied from 170 mg/l to 23 mg/l as different combinations of operational controls were tried. With the first warm weather the surface aerator had been utilized to increase the temperature of the mixed liquor and promote better biological growth. The use of the surface aerator destroyed the tranquility of the sedimentation basin. The basin was constantly disturbed by the flexing of the aluminum partition between it and the aeration basin. There was also a circulation problem with water shooting under the partition and up through the tubes. The surface aerator was moved as far from the partition as possible, and although this seemed to alleviate the situation somewhat, the partition was still too flexible. By mid May 1973, the decision was made to remove the partition and strengthen it with three horizontal aluminum channels.

Prior to May there had been an increasing layer of floating sludge forming daily above the tubes. With the advent of warmer weather, denitrification was producing sufficient amounts of nitrogen gas in the sedimentation basin to cause floating sludge. The circulation problem was also causing increasing amounts of grease to flow under the partition and become trapped in the sedimentation basin. Therefore, at the same time the partition was removed for strengthening, a surface skimming device was constructed and attached to it. This device is described in the section on treatment plant description (see Figures 13 and 14).

In addition to strengthening the partition, a hinged lower section was added so that the opening beneath the settling tubes could be restricted if necessary. After replacing the partition and restricting the opening below the tubes as much as possible, it was found that the surface aerator still created too much turbulence in the sedimentation basin. The curved sides of the aeration basin and the oversized aerator combined to create turbulent flow that did not allow proper settling in the tubes. Use of the air diffusers on only one side allowed a much slower circulation of mixed liquor with exceptionally good results with the tube settlers. This can be seen in the data on total solids and turbidity of the aerated effluent (see Figures 25 and 26). From the third week of May until present, air supply has been restricted to the air diffusers on the north side only. Checking with a dissolved oxygen (DO) probe has shown that the DO in the mixed liquor has remained at or near the saturation level. There has also been a lack of foaming in the aeration

basin. There was some foaming when the surface aerator was in use, although it was never considered a real problem.

The surface skimmer, with some initial adjustment, has worked exceptionally well. The water in the sedimentation basin above the settling tubes is very clear and does not have any floating sludge or grease build up. The suspended solids in the aerated effluent has dropped drastically.

Beginning at about March 12, 1973, there have been periodic algae blooms in the polishing pond. The final effluent total solids rose to 28 mg/l and 37 mg/l on March 16 and May 1, 1973, respectively (see Figure 25). Both of these peaks represent the passing of algae after an algal bloom. There was also a corresponding increase in the COD levels of the final effluent (see Figure 21). Overall the COD and  $BOD_5$  of both the aerated effluent and final effluent decreased as the air temperature increased and the biological activity of the mixed liquor increased.

#### WARM WEATHER OPERATION

June 1, 1973, until the present represents the best treatment level reached since the treatment plant received its first waste. The  $BOD_5$  and COD of the final effluent has consistently been below 10 mg/l and 50 mg/l, respectively. At the first of July 1973, the  $BOD_5$  loads increased to 2.6 lbs of  $BOD_5$ /1,000 cu ft/day, and there were 16 homes with a population of 38 connected to the sewer. This represents approximately 18 percent of the design population estimate. The detention times of the aeration basin and polishing pond have decreased to 9 1/2 and 29

days respectively. The settling rate applied to the tubes is 0.09 gpm/sq ft of tube entrance, and the chlorine chamber has a contact time of 4.8 hours.

The skimmer has continued to work well; many times the effluent above the settling tubes is clear enough to allow the tubes to be visible. The air diffusers have adequately met the air requirement of 7.12 cfm and have allowed good clarification by the settling tubes. The mixed liquor has contained a good biological population all summer with excellent  $BOD_5$  levels of about 5 mg/l in the aerated effluent. Ammonia levels have indicated that a healthy population of nitrifying bacteria is present. Coliform counts of the aerated effluent have ranged from 0/100 ml to 1,000/100 ml with most values below 200. In the final effluent the coliforms have fluctuated somewhat with the algae blooms; the coliform count has been as high as 10,000 and as low as no recorded coliform on two occasions (see Tables 2 and 3).

The only area requiring improvement is the control of algae blooms in the polishing pond. These blooms have caused periodic high levels of suspended solids in the final effluent. Comparing these high levels with the standard proposed by the Environmental Protection Agency, 25 mg/l suspended solids, it is apparent that an effective means of algae control is needed. The COD determinations increase from the aerated effluent to the final effluent. Soluble COD determination indicates some additional treatment takes place in the polishing pond; however, this is offset by the dead algae present. As can be seen from

TABLE 2. COLIFORM IN AERATED AND FINAL EFFLUENTS

Date	Coliforms in Effluent	
	Aerated	Final
May 1	--	200
May 12	--	200
June 7	200	60
June 14	1,150	1,600
June 20	120	10,000
June 27	1	25
July 3	1,000	4,000
July 11	0	0
July 22	0	0

TABLE 3. CHLORINE RESIDUAL IN AERATED AND FINAL EFFLUENT

Month	Average Chlorine Residual (mg/l)	
	Aerated Effluent	Final Effluent
Nov	3.2	0
Dec	2.1	0.2
Jan	5.2	0.4
Feb	4.0	0.2
Mar	4.9	0
Apr	4.4	0
May	2.5	0
Jun	4.1	0
Jul	2.8	0



Figures 20 and 21, the COD determination is a better guide to the organics in the final effluent than  $BOD_5$  determinations. This is an indication that COD should be the major determination for operational control of an extended aeration plant, and should be established as a pollution control standard.

## CONCLUSIONS

1. The extended aeration activated sludge treatment process will provide excellent treatment of domestic sewage from the initial wastes of a small, slowly developing community. The mixed liquor may be started without seeding and during adverse weather conditions. Excellent treatment is obtained by dilution and extreme detention times until the mixed liquor has developed a sufficient population of biological organisms. Extended aeration is a relatively stable treatment scheme at twenty percent of the design  $BOD_5$  loading and below. Minimal operational control may be performed by semi-skilled personnel.
2. Chlorination is very effective when applied to the aerated effluent prior to the polishing pond. Destruction of coliform organisms is complete with little regrowth in the polishing pond. Chlorine residual, which could endanger aquatic life, is not passed to the receiving stream.
3. A polishing pond has a leveling effect on fluctuations in the extended aeration treatment process. It also prevents solids loss to the final effluent during times of upset and poor settling in the sedimentation basin. With proper algae control, year round suspended solids in the final effluent can be kept to a minimum. The polishing pond also provides additional reduction of  $BOD_5$  and COD of the effluent.

4. Settling tubes allow constant return of the settled sludge to the aeration basin without costly sludge return equipment. The aerated effluent is very clear if the dividing wall between the aeration basin and sedimentation basin is sufficiently rigid. A surface skimmer will provide return of floating sludge to the mixed liquor and help prevent solids from being lost to the polishing pond.
5. Gross oversizing of surface aerators for aeration basins should be avoided. The turbulence an oversized aerator generates in the mixed liquor will inhibit the biological treatment by breaking up the flocculation of organisms. Turbulence will also decrease the settling efficiency in the sedimentation basin. During cold weather, an oversized aerator will adversely cool the mixed liquor.
6. More thought must be given to winter operation of very lightly loaded extended aeration plants. Until the icing problem of the surface aerator is solved, an air diffuser system should be provided as a standby. Also, the ice cover on the sedimentation basin could create problems with removal of floating sludge, and might possibly need to be covered to prevent freeze-up.
7. Biochemical oxygen demand ( $BOD_5$ ) determinations are not representative of the reactions taking place in an extended aeration process with accompanying polishing pond. Chemical oxygen demand (COD) determinations give a better indication

of the treatment achieved and provide more useful information in the operational control of the treatment process. COD should therefore be used in establishing effluent standards for these types of treatment plants.

## RECOMMENDATIONS FOR FURTHER RESEARCH

1. This study should be continued through the coming winter to evaluate continuing freeze-up problems. The subsequent performance of both the surface aerator and the sedimentation basin would be extremely valuable in future designs.
2. Continued monitoring of the treatment plant until it reaches its fully-loaded condition would provide a more complete evaluation of the extended aeration treatment process. This would also allow for evaluation of any upsets created by hydraulic shock loadings after near-capacity BOD<sub>5</sub> loading levels had been reached.
3. Research is also needed in developing this treatment scheme for package plant design. Varying uses of the settling tubes in package plants could be evaluated with the modeling of flow patterns in aeration and sedimentation basins.
4. There is a need for an effective means of algae control in polishing ponds until the ponds obtain their design retention times. Chemical costs in relation to overall treatment cost need to be evaluated as a part of the algae control.

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## APPENDIX

TABLE 4. MIXED LIQUOR SUSPENDED SOLIDS DATA

Date	Solids			% Volatile	Settling Characteristics (ml/1000ml)	Sludge Volume Index (SVI)
	Total (mg/l)	Total Fixed (mg/l)	Total Volatile (mg/l)			
Nov 3	825	730	95	11.5	--	--
	720	595	125	17.4	--	--
Nov 9	1190	1009	181	15.2	6 Imhof Cone	5.04
Nov 22	1817	1517	300	16.7	11 "	6.05
Dec 2	706	476	230	32.6	8 "	11.33
Dec 21	152	29	123	80.9	3 "	19.74
Jan 18	325	160	165	50.8	9 "	27.69
Jan 25	1495	1070	425	28.4	16 "	10.70
Jan 30	1100	753	347	31.5	15 "	13.64
Feb 14	1458	945	513	35.2	25 "	17.15
Feb 22	1838	1245	583	31.7	28 "	15.23
Mar 2	2408	1938	470	19.5	30 "	12.46
Mar 16	1175	962	213	18.1	36 "	30.64
Mar 23	1493	1042	451	30.2	26 "	17.41
Mar 30	1347	717	630	46.8	23 "	17.07
Apr 6	793	457	336	42.4	26 "	32.79
Apr 17	1050	543	507	48.3	32 "	30.48
May 1	1333	583	750	56.3	50 "	35.26
May 8	1400	1160	240	17.1	58 Cylinder	41.43
May 12	2077	1577	500	24.1	59 "	28.41
May 21	1833	1660	173	9.4	55 "	30.01
Aug 12	1853	1590	263	14.2	55 "	29.68

TABLE 5. EFFLUENT SUSPENDED SOLIDS AND TURBIDITY DATA

Date	Suspended Solids		Turbidity	
	Aerated Effluent	Final Effluent	Aerated Effluent	Final Effluent
Nov 3	2	26	--	--
Nov 9	84	5	45.0	6.0
Nov 22	104	28	62.0	13.0
Dec 2	57	21	37.0	17.0
Dec 21	46	0	47.0	8.0
Jan 18	335	4	75.0	4.0
Jan 25	93	2	67.0	4.8
Jan 30	80	1	70.0	6.0
Feb 14	60	3	54.0	4.5
Feb 22	50	8	56.0	6.5
Mar 2	160	21	68.0	10.0
Mar 16	140	29	63.0	12.0
Mar 23	177	18	80.0	14.0
Mar 30	130	7	78.0	16.0
Apr 6	73	20	58.0	23.0
Apr 17	103	32	64.0	28.0
May 1	23	37	37.0	32.0
May 8	67	14	56.0	17.0
May 12	55	8	48.0	16.0
Jun 7	170	10	--	--
Jun 14	140	120	6.5	16.0
Jun 20	--	70	12.0	9.5
Jun 27	12	12	5.0	9.3
Jul 3	10	20	4.4	18.0
Jul 11	10	40	6.5	19.0
Jul 18	10	7	4.5	3.0
Jul 22	13	80	10.0	12.0

TABLE 6. EFFLUENT BOD AND COD DATA

Date	BOD Data		COD Data	
	Aerated Effluent	Final Effluent	Aerated Effluent	Final Effluent
Nov 3	--	--	37.8	20.7
Nov 9	7.2	2.7	72.5	28.5
Nov 16	--	5.2	--	--
Nov 22	7.0	5.3	100.0	39.6
Dec 2	--	4.8	101.1	94.7
Dec 21	--	--	--	47.4
Jan 18	--	5.4	148.9	--
Jan 25	27.3	3.3	132.8	52.8
Jan 30	--	1.8	144.5	59.6
Feb 14	--	--	151.7	74.6
Feb 21	16.3	4.8	140.8	77.1
Mar 2	--	--	180.1	75.2
Mar 16	14.7	5.1	161.7	78.7
Mar 23	19.9	4.2	154.7	65.6
Mar 30	10.2	2.8	135.2	77.4
Apr 6	5.6	2.5	107.3	94.0
Apr 17	12.3	12.8	116.5	94.6
May 1	8.2	8.8	81.0	103.2
May 8	4.0	4.0	52.0	48.7
May 13	3.0	2.0	43.7	46.3
June 7	--	--	--	40.0
June 14	8.0	4.9	35.0	50.0
June 20	4.2	4.4	30.0	20.0
June 27	5.8	7.1	30.0	40.0
July 3	8.8	5.6	26.1	32.0
July 11	1.2	3.8	29.0	41.0
July 18	3.8	6.7	41.0	45.0
July 22	2.0	14.6	30.0	53.0

TABLE 7. EFFLUENT AMMONIA AND NITRATE DATA

Date	Ammonia (NH <sub>3</sub> )		Nitrate (NO <sub>3</sub> )	
	Aerated Effluent	Final Effluent	Aerated Effluent	Final Effluent
Nov 3	3.0	2.0	--	--
Nov 10	--	--	8.0	0.0
Nov 22	1.3	0.5	25.0	2.5
Dec 2	0.7	0.5	27.0	3.5
Dec 21	8.2	3.4	5.0	13.0
Jan 18	14.3	7.3	11.0	7.5
Jan 25	11.0	11.5	14.0	11.0
Jan 30	9.5	9.8	19.0	10.0
Feb 14	6.0	8.0	20.0	19.0
Feb 22	7.0	7.2	19.0	13.5
Mar 2	2.7	4.4	26.0	20.0
Mar 16	3.6	3.0	31.0	17.5
Mar 23	5.2	3.8	29.0	20.0
Mar 30	4.0	3.0	25.0	19.0
Apr 6	1.3	3.8	32.0	25.0
Apr 17	2.7	3.2	29.0	23.0
May 1	1.8	2.3	27.5	19.0
May 8	3.3	3.4	25.0	27.0
May 14	0.9	0.5	31.0	23.0
Jun 7	--	--	40.0	35.0
Jun 14	--	--	30.0	23.0
Jun 20	0.62	0.98	32.0	29.0
Jun 27	0.3	0.5	32.0	28.0
Jul 3	0.4	0.3	29.0	23.0
Jul 11	0.25	--	15.0	11.0
Jul 18	0.2	0.15	34.0	28.0
July 22	0.4	0.55	17.0	19.0

## SUMMARY OF FIELD OBSERVATIONS

November, 1972

Silt washed into the aerated basin with snow fall during the first two weeks. The surface aerator was utilized for the first part of the month. Air diffusers were used after November 29, to raise the temperature of the MLSS. Ice formed on the polishing pond. Mixed liquor was very silty with little biological activity or fibrous material.

December, 1972

Very cold temperatures continued through most of the month. The polishing pond and sedimentation basin became ice covered after December 5th. The ice cover was four inches thick for the latter half of the month. The mixed liquor temperatures remained around freezing most of the month, and the surface aerator froze. Microscopic exams showed less silt and more organic material along with an increase in small, single celled organisms.

January, 1973

Severe cold weather during the first two weeks of the month caused the mixed liquor temperature to remain at just below freezing. The aeration basin developed 25 percent ice cover with the air diffusers in use. During January 18 to 23, the surface aerator was used to increase the temperature of the mixed liquor since air temperatures rose to the low 50's. The polishing pond remained ice covered during the entire month.

The organic matter in the mixed liquor was still increasing, with a corresponding increase in biological activity. Rotifers first appeared toward the end of the month. The silt content increased during thawing of snow at mid month. Cold weather returned for the last of the month. The clearest final effluent for the entire research period occurred from mid December to mid January.

#### February, 1973

The first half of the month was very cold with continued ice cover on the polishing pond and sedimentation basin. Warmer temperatures during the last half of the month decreased the ice cover; the polishing pond was less than half covered with ice at the end of the month. The aeration basin developed foam during the warm weather. Surface aeration was used after mid month. The mixed liquor was still very silty with a slight increase in the number of rotifers present.

#### March, 1973

The mixed liquor had a steady increase in biological activity and temperature, and some stalked cilliate appeared. Foam was present on the aeration basin for the first part of the month. The first algae bloom in the polishing pond occurred at mid month. The aerated effluent was very turbid during the entire month. During the last week the surface aerator was moved as far from the sedimentation basin partition as possible.



April, 1973

The mixed liquor continued to increase in biological activity and temperature. The aerated effluent was very turbid. Problems with the performance of the settling tubes continued. There was intermittent floating sludge on the sedimentation basin. Algae blooms appeared in the polishing pond.

May, 1973

The mixed liquor developed a diverse population of biological organisms. There were many rotifers, stalked ciliate, and large single celled organisms. Heavy rain during the first week washed more silt into the aeration basin. There was an increasing amount of floating sludge in the sedimentation basin, which formed a two to four inch cover within 48 hours by the end of the month. Modifications were made in the sedimentation basin at the end of the month. Algae blooms continued in the polishing pond.

June, 1973

After June 2, the air diffusers were used, and there was no foaming in the aeration basin. No floating sludge was present in the sedimentation basin. After the second week the effluent above the settling tubes was clear enough to allow visibility of the tubes. Periodic algae blooms continued in the polishing pond. The mixed liquor temperature reached and remained at 26° C.

July, 1973

The plant operated very well with very clear effluents. Algae blooms continued. No difficulties were encountered.

EXTENDED AERATION WASTE TREATMENT  
WITH LOW LOADING CONDITIONS

by

RICHARD A. FORNELLI

B.S., Kansas State University, 1972

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AN ABSTRACT OF A MASTER'S THESIS

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## ABSTRACT

The extended aeration activated sludge waste treatment process was investigated to determine its effectiveness for small communities during initial operation. New concepts incorporated into the plant design were evaluated.

The treatment plant provides excellent treatment through the dilution of wastes and extreme detention times associated with the low flow conditions. Settling tubes allow constant return of the settled sludge to the aeration basin without costly sludge return equipment. A polishing pond has a leveling effect on fluctuations in the extended aeration treatment process; preventing solids loss to the final effluent, and providing additional reduction of effluent  $BOD_5$  and COD. There is little regrowth of coliform organisms. Chlorination is very effective prior to the polishing pond.

Winter operation of a lightly loaded extended aeration plant creates many problems that require special design considerations. Oversizing of surface aerators upsets the treatment process and contributes to additional winter problems. COD determinations give a better indication of the treatment achieved and provide more useful information in the operational control of the treatment process than BOD.